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Innovative beer dispenser based on collaborative robotics

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INTRODUCTION

1.1 Meaning of collaborativity

Collaborativity measures the possibility and the ability of interaction between robot and human operator, also called HRC (Human-Robot Collaboration). Historically all the old robots, like today's classic industrial robots, do not allow this kind of contact and for safety they physically divide by barriers (for instance, with a Plexiglas barrier) the area in which the robot operates and the area in which the worker can attend the end of operations. In fact, due to the contact between the robot and the operator, the type of impact resulting from the weights and inertias, the metallic material of which the robotic arm is made and the speed involved, would cause serious damage to the operator, whose safety he would be constantly in danger. Even in the case of the presence of collaboration, some collisions in the common area where cobot and human have access can still be happen. These collisions are impossible to predict because of the infinite possibilities of movement, even wrong, of the operator. Therefore the law deals with considering the effects of the various contacts possible from the biomechanical point of view, and how to operate to bring these contacts back to an acceptable situation, through a Control Analysis & Risk Assessment procedure. With this procedure, which refers to a different legislation depending on the field in which it is applied, we are going to consider all the causes of risk due to the malfunction of one or more components or the occurrence of certain conditions, evaluating the severity of the damages that they could have. Depending on the probability of this situation and on the severity of the resulting injury, it is the legislation itself that gives an indication of how radical the intervention on the system must be to ensure that the cause of the potential accident is eliminated or the consequences deriving are reduced in an acceptable way. Considering the shocks that could occur between the man and the robotic arm, the typologies could occur according to the regulations in robotics, they are essentially the two reproduced in the 1.1:

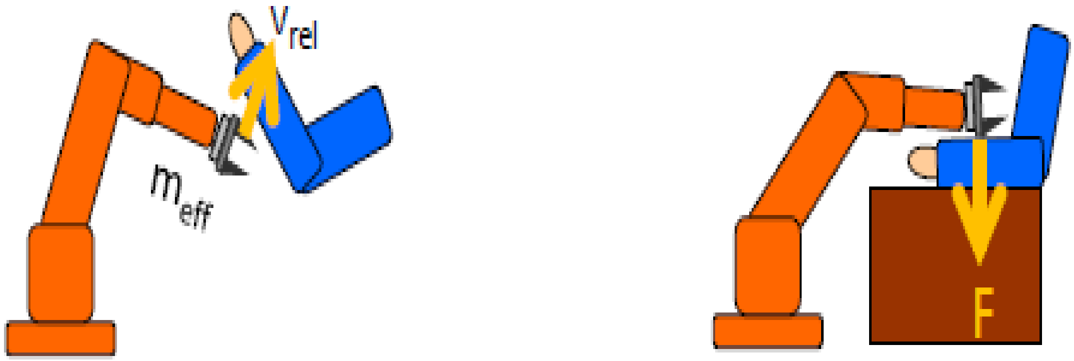


Figure 1.1: **Different types of shocks**

The collision shown on the left is also called transitory, while the one on the right is almost static. In the first case, the duration of the impact is usually short (the maximum duration value is 50 ms) and the human can recall the arm to move it from the area in which the impact occurred. The collision occurs at a relative speed between the two parts, which causes a stress on the affected limb also as a function of the mass of the robotic arm, of the area on which the developed force is distributed and of contact duration. The duration in the first case is limited in time; if instead, as shown on the right, the limb is tight between the robotic arm and another object produces a prolonged contact, without a certain maximum time, bringing the force to be approximately constant if we continue to supply power to the engines. A shock with the same peak of force and pressure, if prolonged in time, could cause more serious effects on the operator and must therefore be treated with greater attention [Mat]. In order for a robot to be collaborative, it must obviously comply with the regulations whatever is the point of the robotic arm that impacts with the operator: in order to work without mutual restraints and without creating problems for safety, it will be necessary that both the end-effector, as shown in 1.2 that arm and hand are properly configured. In the following image is instead represented the scale through which divide the shocks according to their intensity, indicating at the top in which area a robot must remain in order to be considered collaborative:

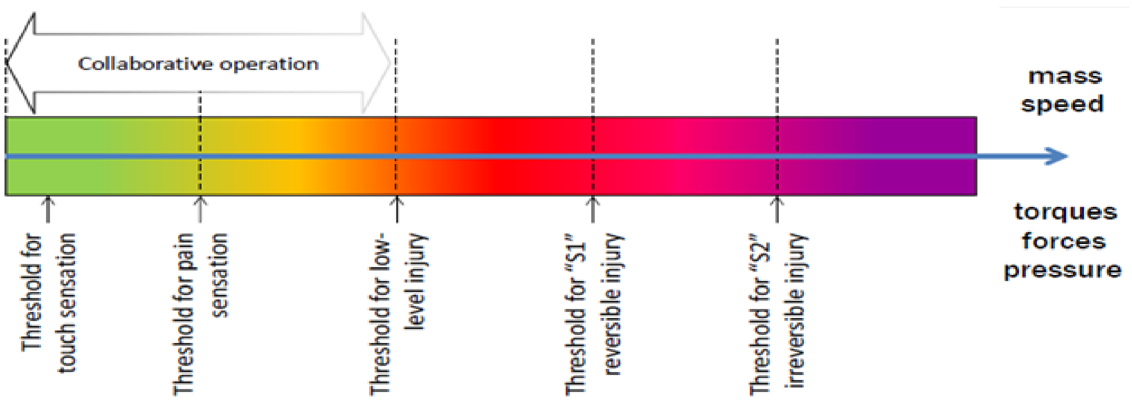


Figure 1.2: **Injury and collaborative area**

The solutions to avoid the accident or limit the threshold value below the maximum value are many and vary according to the severity of the impact and especially its type. In the case of a transient contact we can decrease the speed with which the robot is moving by controller, rather than the mass (equivalent or effective) of the robot through precise design choices in the distribution of weights and powers to the various motors and to the link elements as you approach the end of the kinematics. The equivalent mass is calculated by both the robot and the operator part, such as the mass that is actually involved in the collision. When a real, partially elastic collision occurs between the operator and the robot, is not considered the whole body mass of the man or the robot: only the part of the body directly involved and, with a smaller coefficient, the adjacent parts must be considered. The same procedure is applicable to the various links of the robot.

From the mechanical point of view we can instead act on the shape of the components, to make the robot smooth or without small prominent elements that would not be able to distribute the impact on a large surface. Another strategy is to provide deformable inserts that partially absorb the energy of the impact, making it even slightly longer over time with the same total energy exchanged between the parts and thus breaking down the peak distributing it over time. In the second case mentioned in the figure above instead we treat an almost static force: the concern will be vice-versa to reduce the contact time between the robotic arm and the human limb to reduce the damage; it will also be important to reduce the torque given to the joints in cases of this type of collision. These choices must be made in compliance with various standards, which refer both to the performance of the robot (Safety Performance Level, PL, and Safety Integrity Level, SIL), and to the robot architecture, defined by the ISO 13849-1 and IEC standards 62061.
Especially with regard to quasi-static contacts, in order for a robot to be collaborative, it is necessary to operate on the robot controller so that the robot can sense to a possible impact affecting the robotic arm, and react accordingly to it. In order for the operator to free himself from the squeeze between the robot and another object, the power must be cut to the motor, or the movement must be interrupted and then the cobot TCP slightly back from the stop point. This movement is necessary to allow the operator to leave the danger zone but also to recover that residual advancement of the robot we have between start of contact and suspension of movement and the effective stop of the robot. This additional advance is lightly due to the processing of the shock signal that causes the robot to send the stop command, but above all from the various inertia involved, although they are carefully limited already in the design phase.

In order to respect the safety rules in the effective working environment it will then be necessary to consider some complementary factors, such as ensuring that the robot does not work in close contact with humans if an incident with unacceptable consequences could occur due to contact between operator and the object moved.

1.2 The tapping beer robot idea

The idea of using the robot as a barman to tap the beer comes from some considerations on the market, on the technical difficulties present in the development and on the current possibilities we have of overcoming them.

First of all, as we will see immediately in the next chapter 2, this solution from the commercial point of view is not yet present, but was only implemented in the prototype stage in various fairs by directly taking the beer from the tap with a robot that could then serve the public. These examples of collaborative robots that serve beer use bottles: each bottle translates into additional space and consequently there must be an operator who reinsert the bottles every few cycles to allow the robot to continue serving customers, without having therefore a true automation of the station. These stations, in fact, or provided a dedicated employee or at most could be inserted in an integrated way next to a counter with staff due to the frequency of required interventions.

A point of considerable importance is the growing interest that beer is buying in our country, historically much more linked to wine as alcoholic beverage, with consumption much lower than those of the Nordic countries, the United States and Canada [Ann16], [Bee16]. In the last twenty years there has been a non-substantial increase in consumption of the product as in the early 2000s which, however, after a contraction in the years of the crisis has returned to the values of 2006 (from 28 l per capita of the first millennium, we passed 31.1 l, while in the "traditional" countries the consumption is slightly down), with a deeper penetration of the beer. At the same time, the volume of business grew more sharply thanks to the birth of a multitude of craft breweries, small brewers who have contributed greatly to create attention to this beverage and all its various nuances. Moreover, the particularity of working with small and medium volumes, enormously smaller to those of the big multinationals in the sector (a beer is considered craft for production below 200,000 hectoliters per year [Bira]), creates the problem of producing a less stable and standards beer, emphasizing the instability characteristics of this beverage. As we will see later, in fact, beer is not a simple drink to treat from this point of view, and their characteristics can easily change from one type to another and depending on the physical characteristics of the place in which they are inserted.

2015 Ranking	Country	Per-capita Beer Consumption		
		Consumption Volume (L)	633ml Bottle Equivalent	Comparison with Previous Year (bottles)
1	Czech Republic	142.4	225.0	-0.3
2	Seychelles	114.6	181.0	0.0
3	Germany	104.7	165.4	0.1
4	Austria	104.7	165.4	-0.2
5	Namibia	102.7	162.2	-2.1

Figure 1.3: **Per capita beer consumptions in 2014 and 2015 for the beer major consumer**

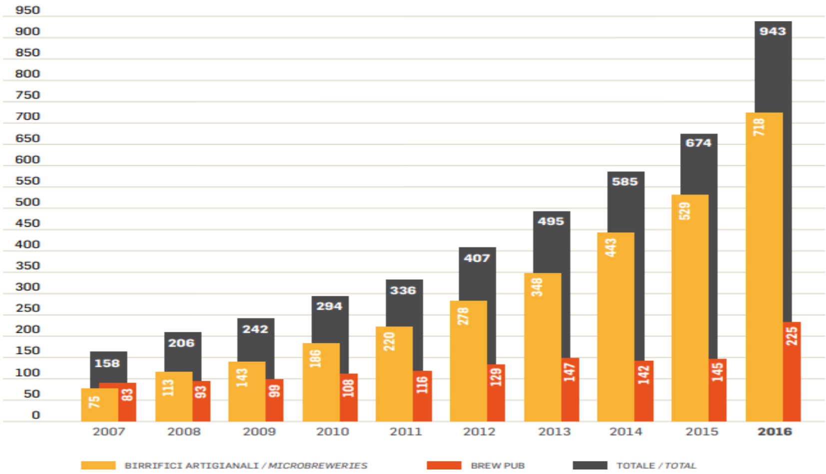


Figure 1.4: **The brewery growth in years in the last decade**

Another important point, the main one, is that of the current state of technology, which is reflected on two aspects in particular: the robot and the plant. In both cases, the significant steps done forward taken place in recent years have created developments capable of overcoming obstacles and problems that would not have been resolvable and which would undermine the usefulness of our system. Regarding the field of robotics and automation, it is evident the constant evolution that is entering more and more in daily life, the greater capacities of the systems, accompanied by more limited weights and smaller and smaller volumes. Fundamental for our purposes then the introduction of the collaborativity explained previously on compact systems (or at least comparable with human dimensions), with skills and whose cost (which will have a significant impact on the total cost of the system that you want to develop) becomes more and more accessible each passing year. Also from the point of view of the plant, technological progress has changed the cards at stake: here too, the growing interest in the product and the push given by the craft brewers mentioned above were very important. Because

of the need to avoid some problems due to the greater variability of the product, in fact, much attention has been paid to its valorization on the market and to its special characteristic properties, not only relegating it as good at low cost and large consumption. This can translate into an increase in quality, also pushing towards experimentation with new solutions, sometimes technical and not only commercial, in order to reduce waste and problems to make production sustainable and profitable even without large volumes. The fact that near of the company in which I developed the thesis project, L'EPF srl, is based one of the most important national craft breweries, is then a great added value both to become aware of these technical solutions to configure a system that is as lean as possible and capable of responding to our needs, both as support for the subsequent steps aimed to carry the station on the market or on possible upgrades.
From a technological point of view, in the same period of time, the capillary development of the network, all the social media, etc. they have evolved from a little more than an embryo to a presence that affects our lives every day. Also these technologies will surely be an instrument on which to aim for the evolution, even if not physical, of the station. The development of this idea of an autonomous station in which a robot directly pins the beer to the customer will certainly produce conflicting reactions between those who will be very surprised and at the same time enthusiastic about the idea and who will reject it as useless or even dangerous, as any other automatic system that can potentially replace human work. This is certainly not the goal of our project that has as its destination, after a phase of development, large spaces open to the public "passing through", for example areas dedicated to airports, where they can provide a quality product different from a simple vending machine to customers, in addition to making it more appealing. Of course in any way the station will be structured it will exist people belonging to one rather than the other category, but consider from the beginning how to reduce as much as possible the distance between the customer and the robot, the "protagonist" of the station, can only make the system is more expendable. To succeed, it will be important but not enough to consider how to make the robot pleasant from an aesthetic point of view to grab the favors of the public establishing almost a kind of empathy, thus making a "human-friendly" mechanical system. It will also be very important to use these new means to be able to involve this public, to ensure that being served by the robot can be part of a different experience that provides something more to the customer than usual, as well as a good beer tapped in the right way.

The intent to study this system at a time when the technology available has evolved enormously but it is not yet fully developed for our purpose, it will put us in front of residual problems, the overcoming of which will also be largely the aim of this thesis. It is very likely that developing the system in ten or twenty years with a new generation of collaborative robots and better techniques on the tapping plant would have resulted in a simpler and more linear development, capable of responding more precisely to the requests or do it with a lower or faster system cost to be amortized. Precisely for this reason, however, it is important to address the problem now that the technology has just allowed us to address all issues in a complete way and in-depth: you will have an overview of the advantages and disadvantages between the various solutions, creating a solid background. In this way, as soon as possible any developments that will be able to influence an evolution of the system, the scope of the changes on the system can be assessed more consciously and the experience gained will allow to respond to these changes more quickly.

Chapter 2

OVERVIEW OF THE ACTUAL APPLICATIONS

In each new project, the first step to begin to realize the basic idea is to analyze any solutions on the market. A careful analysis to try to understand the operation, the common points and the differences with the destination of the product you want to develop are useful to begin to realize this idea and possibly take a hint from some particular solutions used in these applications that could be revealed useful for our purpose.

There are still no solutions in which the robot is used to tap draft beer. The similar solutions already present are divided into two main categories: the robot with the task of preparing cocktails and industrial robots that provide, either alone or with the help of external mechanical structures, to serve the beer by pouring out the contents of a bottle. We will start by analyzing the first category that, although it may seem less similar because it treat a different beverage, has more similarity and features that may be useful because are not improvised stations but real stations, intended to interface with an external customer.

In the first solution of robot-shaker, present on the cruise ships Anthem of Seas and Quantum of the Seas, the characteristic we see first of all is the large overall dimensions of the system, not designed to be movable [Qua], [Har]. In the first phase in which it was exhibited at trade fairs, before being implemented on a cruise ship the station, although closed, kept the dimensions of a container and had to be moved through a heavy means of transport. The current location inside the station bar allows first of all to have personnel often near to the system for maintenance, load of ingredients and object, but without having a person dedicated only to it, as it would also be useful for the first commercial phase of the tapping robot. There are two Kuka industrial robots, each with a single arm, which

Figure 2.1: **The stations on Anthem of the Seas**

work in parallel and independently of each other. The station consists of two identical, mirror-like systems that work in parallel to satisfy the various requests. The bottles are hung with the neck down to the ceiling: to prepare cocktails there are about 130 bottles of alcohol in which the level is automatically monitored for a ready and programmed replacement, and since you must avoid contact between robots, this means having about 260 bottles. Part of the system is hidden behind the wall and has the function of feeding the taps behind the two robots: from these taps are taken soft drinks, sugar, lime and various ornaments, while next to it is the dispenser of glasses and a sweeper. In part, the dimensions of the system are also due to the system of delivery of the glasses to the customer consisting of the conveyor belts visible in the figure above, activated once the preparation of the cocktail is over. In this way, potential contacts between the non-cooperative robot and the customer are avoided, making the product withdrawable once it is ready. The robot approaches the customer only if he has to take a liqueur placed towards him, but at such a height that there will be no possibility of collisions. The volume just above the worktop in the working area of the robot instead goes to the most inaccessible area for the customer. At the end of the robotic arm a special end-effector appears, specially designed for the application. A shaker is placed on the end-effector, where the cocktail is actually prepared: it is equipped with a container to which the opening or closing is controlled in a pneumatic manner, so as not to disperse the liquid during the shaking of the cocktail ingredients. At the base of this shaker there are two suckers, converging towards a single point, which have the task of withdrawing the glass and releasing it in position. The transport phase of the glass takes place always with the latter empty and the minimum weight allows you not need large forces to move it, while being

completely cantilevered and at the same time the suction cups avoid the risk that I would have with the pliers to damage in take the disposable cup. Once the order has been received, the robot is first positioned under a tap and rinses the shaker, after which it rotates on itself to let the water and any residues present flow out. At this point it takes the glass from the dispenser and places it in a final position among the free ones. The arm then goes to the ice loader, which discharge its dose falling by gravity into the shaker and then heads for the bottles hanging from the ceiling. Every bottle ends with a three-arm element mounted on a valve: the shaker is pressed against this element which, by compressing a spring, opens the valve, delivering the exact dose required. This is possible because the liquid has already filled an overlying doser, which will then be slowly refilled once it has been emptied from its contents, thanks to a very light passage of air. As for solid-state ingredients and non-alcoholic beverages such as soda, they don't use this system because these elements are added when the shaker, after having inserted and shaken all alcohol, simply stop under the mouth of the corresponding tap and the presence is detected by a special sensor. At this point, the cocktail is shaken and ready to be poured into the plastic cup, which will then go directly to the customer. It is interesting to underline some peculiarities of the system, after having described its operation.
For example, the interactive part related to the app seems well taken care of [Mak] on a station screen are displayed the order in preparation, the various steps to prepare it and the indication of the current one, making the customer more involved and, in our case in which we will use a collaborative robot, inviting it even less to interact in the wrong way while the order is still in preparation. In the same way, the graphics of the app are precise and simple, with cocktails or liqueurs divided into categories and the possibility of creating a personalized cocktail at the moment, a not replicable aspect with beer. The same app is used to receive payment, excluding for convenience and simplicity items such as the coin mechanism that would complicate the system.

As already explained above substantial differences compared to our idea are the point at which the preparation of the product, far from the customer, is finished, the single arm physiognomically different from the human appearance and that this latter does not require interactions or synchronizations with the other arm. Even the end-effector is not designed to be similar to a hand or at least to a clamp, but essentially to be functional to the context, which provides more to surprise the viewer through the robotics that try to be more human friendly, with all the positive or negative reactions that may derive from it. If this were also our objective (certainly simpler and cheaper), even in our case it would be used a single arm, with the drafted controlled by an actuator activated by a separate sensor or by a signal switched when the robot reaches the correct position. Another difference is that

relating to the control of beer temperatures, which must remain within a well-defined range, while here it is not necessary to implement any additional control.
An interesting characteristics is the double delivery position for each robot, to avoid having orders that cannot be executed because the final position is already full. In fact, this system is designed to move the plastic cup towards the customer when the latter "unlocks the order" passing its recognition code which is detected by an optical reading sensor. Another interesting spectacle of the station is given by the fact that the Kuka can "dance" if not used.

Now we moved on to the observation of the stations where the industrial robot served the beer contained in a bottle. Many of these solutions are, as mentioned earlier, much more improvised. Then not real stations with the study including the part of design are treated, but they present only the mechanical and programming part. Such cases will not be treated here; even the subsequent solutions are however lacking from the smart and interactivity point of view.

Figure 2.2: **A detail of the single arm Kuka bartender in Hannover trade fair**

The first solution [Kuka] analyzed uses a Kuka robot that uses a single robotic arm here, even if there are solutions in which the system consists of two identical robots, which in any case use bottles. The Kuka robot succeeds without apparent problems to lift the loads that have been delivered to him, which however remain slightly below the kilogram (500 ml of beer plus the weight of the glass of the glass or of the bottle). The shape of the gripper is made in such a way as to adapt to the conical surfaces of the plastic cup and the bottle being able to reach the optimal inclination rotating around a central hinge, while in proportion the robot gripper is very massive. This structure lies on a extension of the bar counter: this is reflected in the choice of glasses, which can be washed by the bartender while the robot only takes care to press then these latter on the plastic cup dispenser before placing it in the station and continue the cycle. Not visible in the image is the structure on which you have the bottle opener, with the cap that once removed falls into a hole inside the table. From other holes on the table top the bottles are taken, inserted by the bartender and which comes out only halfway, leaving the floor very uniform, bright and pleasant to see.

The loader can contain 12 bottles at a time, requiring here also to be reloaded frequently; the external operator must also take care to take away the box (with the same capacity) where the robot deposits empty returns. As the glasses are positioned by hand, the robot first moves towards the glass and performs preset movements to push the glass into the correct initial position if it is slightly misplaced. If we succeeded in giving a precise position and not with the uncertainty associated with the plastic cup to be taken, this phase would not become necessary. Like all single-arm robots, an external structure is needed to hold the cup in place, as well as to open the cap. The alternation of tasks delegated to the single arm, however, produces a considerable lengthening of the total time necessary for the preparation of the product, compared to what happens in the solution with two arms. A good quality of this example is the low noise in the whole cycle, and the background buzz is well disguised by the low music present in the room. In the two-armed version [KUKb] the differences are essentially two: on the arm that takes the bottle is present in addition to a classic end-effector with pincers, also the open-bottles. This arm in fact takes the bottle from the hole in the table, laying it on the floor, opens the bottle and after having dropped the cap goes to the plastic cup, already taken from the other arm. With this solution it is possible to fill the cup by straightening it gradually (and not in two different positions with the first tilted and then vertical glass), while the bottom of the bottle is agitated and then poured into a straight glass. Among the disadvantages of the solution we can observe that even here the beer, despite being poured practically all together, requires a process lasting 2-3 minutes, in spite of the presence of two robot which make the total cost sharply grows. In addition, the foam produced in the plastic cup is too low compared to that which would allow the product to be adequately protected.

Another interesting solution is that in which the beer is tapped by the robot, present in the 2.3, which represents the most similar solution [Robb] from a concept point of view compared to that which is our idea:
The first difference that can be immediately noticed in the system called Robokiosk® RS Tech, is that related to the base of the robot, very long and fixed on the ground, but that does not even contain

Figure 2.3: **Robokiosk® RS Tech bartender**

the control unit. The whole station seems to be quite limited in space, easily movable once it has passed from a test phase to a real system; behind you can see a refrigerator, which contains the beers that the robot goes to pick up. Differently from the solutions seen until now, in this case it is also possible to tap the beer through the plug with a small integrated refrigeration system in front of the robot. This robot, which is a Yaskawa Motoman SDA10, has not found wide use in practice due to the high cost (about € 75,000), which observing the system does not include neither the cost of the clamps, complex and one different from the other and so designed only for this aim. Approximately only with regard to the robot, without considering the system around, we will easily reach the order of magnitude of € 100,000, with a disproportionate investment and difficult to amortize it. Part of this cost is due to the large payload of 10 kg that can be moved, even oversized for our application, in which the mechanical capabilities of Robotkiosk are small used.

Going to analyze the information related to the robot, however, we see a discriminant characteristic: in addition to being very noisy, the robot is not collaborative. To ensure safety requires barriers and therefore can never be a system able to work alongside human presence. That said, the operation of the laboratory station will be analyzed here only to observe useful and problematic solutions that could also occur for our system, knowing the system we are going to analyze will never pass from a laboratory test phase to a real station, independent, in contact with potential customers. It can be observed how differently from all the other systems the plastic cup is taken from the left end-effector from the base, where it is more resistant with respect to a disposable plastic cup; this solution, however, requires that at the end of the cycle it must always exchange the cup from one hand to the other, complicating and increasing the total time of the cycle. The two grippers are very articulated and reproduce the gripping movement well, but they are also very massive and disproportionate compared to a human hand and the robot. The robot is very fast moving with a full cup, and the speed resulting should be reduced to avoid breaking the foam that has just formed on the beer or even pour the beer. In case you go to take the beer from the fridge, it is necessary immediately the intervention of both arms, with the left arm that opens the door while the right takes the bottle. While the right arm removes the cap and moves into position, the left arm closes the refrigerator door and grabs the glass; in case the tap is instead used, the right arm waits for the glass to be grabbed and then goes towards the tap. After that in both cases the filling takes place with final straightening of the plastic cup. If the filling is done by pouring the beer from the bottle, before the exchange of the glass takes place in the robot hands, you will have to wait until it is thrown into the appropriate basket.

Chapter 3

TRASVERSAL KNOWLEDGE

3.1 Beer: characteristics and tapping styles

Starting from the idea of the tapping system and transforming it into something physical and real, the first thing to do is to know the various components necessary for the operation of the system, the technical variants we can choose at the state of the art in order to obtain at the end the features that best meet the basic application requirements. All this is strictly linked to the characteristics of the final product to be distributed, whose characteristics define many aspects of the components found on the market and among which we will choose the ones suitable for our purpose: the beer. Although the development of beer as a product is completely foreign to the functions of our system, it is therefore useful to make a brief description of this drink and how it is obtained, to better understand its properties and any problems that must be resolved in the development of our system.

Beer is an ancient drink, whose origins date back to at least 5000 years ago [Stoa], obtained from the fermentation of a must based on barley malt and bitter from hops. Its use dates back to the Mesopotamian peoples and the Egyptians (production and sale were already regulated by the famous Babylonian king Hammurabi), also passing through the Romans: the governor of the Britannia Agricola returning to Rome is also behind the master brewers for not lose his passion. Development in Europe is mainly due to the Germanic peoples and the monasteries in the Middle Ages [Birb]; it was thanks to the monks that the hops began to be used as an ingredient for this drink. Barley malt, often called malt, is nothing more than germinated barley also subjected to drying [Ric04]. The germination takes place in large tanks in which a mixture of water is supplied at a controlled temperature (at about 10-12°) and in continuous recirculation and oxygen. After reaching the right degree of humidity, the barley germinates in an aerated place: in this phase the enzymes begin to divide the long molecular chains of the starches into shorter chains. The grains of barley malt, together with the other cereals used (mainly wheat, corn, rice, oats, spelled, rye) are now ground, to make the starches (organic compound of the carbohydrate category) even more ready to react in the phases later. At this point the malt is immersed in hot water (65-68 °C) for the mashing, where some enzymes (which are catalysts of biological processes) convert the starches into fermentable sugars. The temperature of the water, together with the introduction of the correct amount of oxygen, has only the ability to make this process easier and faster, which also occurs naturally for each carbohydrate. It must is now cooked for a time which generally varies between one and two and a half hours in copper tanks with water at high temperature and pressure, which in addition to boiling also carries out the sterilization process. At this point, thanks to the yeast, the fermentation takes place: during this phase, in addition to different waste products, carbon dioxide is produced (mostly already expelled during the process) and alcohol, which are the two products of the yeast reacting with sugars; yeast is nothing else that a particular variety of mushrooms. The fermentation is composed in turn by two phases, a main one lasting a few days and a second at a temperature close to zero that allows to precipitate the residues of yeast and saturate the carbon dioxide, usually lasting 3-4 weeks. The first phase can take place at a more or less high temperature, giving rise to high fermentation beers and low fermentation beers, respectively. Apart from the category of "raw beers" then, an additional 60° pasteurization phase is added for a better preservation of the product.

Depending on the variant of the process used and the various ingredients, we define the different types of beer, each with different intrinsic characteristics. All these characteristics are referred to as the organoleptic properties of beer, that are the set of physical and chemical characteristics perceived by sense organs such as sight, smell and taste, provoking emotional reactions in response [Org] the main ones in our case are smell, taste, color, consistency. In a beer different types of malt are used which together with the other cereals constitute the so-called mixture, which are divided into three main categories according to their cooking:

- Basic malts: clear, slightly cooked. They retain a great enzymatic power.
- Additives malt: dark or amber, very cooked and of low enzymatic power, used in small quantities to change color or taste of beer.
- Mixed malts.

To vary taste and properties of beer also small quantities raw cereals can be used. The malt is natu-

rally very sweet, and hops are used to counterbalance this characteristic. Only the female flowers of the plant are used, which contain a substance called cryo hops which gives the beer its usual bitter taste; the hops resins are instead responsible for the aroma. The hops are subdivided mainly into bitter hops, used at the beginning of boiling and in aroma hops, more valuable and generally less able to make bitter, generally used at the end of boiling. Also the yeasts are different and are normally classified in high and low fermentation yeasts according to the temperature at which they operate. Proteins are complex and branched substances (even hundreds of thousands of amino acids) that constitute the "structure" of the foam and give it persistence. The resins of hops are the part responsible for the bitterness of the beer: to check their presence and to simply moisten the lips in the foam.
The amount of residual carbon dioxide inside the finished product is not a negative characteristic and its quantity is not random, but it is that decided a priori by the brew master. Once the beer is poured or tapped, carbon dioxide plays a fundamental role for the correct tasting of a good beer: it transports the proteins and the resins of the hops to the surface, forming the characteristic layer of foam. The foam is very important because in addition to bringing to the nose of the taster a series of more volatile particles that determine the smell of beer, plays a protective function that allows you to maintain the organoleptic properties of beer as stable as possible for the entire duration of the tasting. In fact, the contact of the air with the beer produces the oxidation of the beer itself, which quickly leads to the alteration of the product both in the odor and in the taste; at the same time the combination of sugars and amino acids leads to an alteration of color, browning. A compact and persistent foam strongly delays this degradation, and should therefore not be treated as a "drawback" that has the sole result of reducing the quantity of beer inside the glass. The foam is also influenced by the temperature with which the beer is served: the lower the temperature, the lower the amount of foam that will be formed. Each type of beer has a characteristic temperature to which it must be tapped, to optimize the amount of foam. As a rule the more a beer has a high alcohol content and is rich in spicy and floral or fruity flavors, more the ideal serving temperature will be high.

There are different types of beer and each of them has a different compactness and persistence of the foam, strongly dependent on the raw materials used, as well as of course by a correct technique both in the various fermentation processes and in preservation and tapping. It is not something good disperse too much carbon dioxide before consuming the product in order not to fall in a situation where the foam is too scarce or not very persistent, because the enzymes have broken too much the protein fraction of the beer.

Beer is mainly divided into three large families:

- **Ale**: high fermentation beer (obtained at a higher temperature which allows fermentation in less time). It includes the British and Flemish beers, which are generally more spicy and floral. The well-known beers of this family are the IPAs, the Bitters and the Trappist and Abbey abbots.
- **Stout**: highly fermented beers, characterized by a very amber color, with low gradation and high bitterness, sometimes included in the macro category of the wings (the best known example is Guiness).
- **Lager**: low fermentation, produced with a more easily industrialized process (and therefore repeatable, standardized), represent the most common type of beers on the market (about 80% of the entire market) and are characterized by a taste malted and hop. Although there are also dark lagers, most of them are light beers. The best known example is pilsner.
- **With spontaneous fermentation**: characteristic of some Belgian beers.

Another type of classification for beers takes place according to their degree of bitterness, through the IBU (International Bitterness Unit) scale.

3.1.1 Types of tapped

In order to properly taste a beer, the technique with which it is tapped or poured is also very important; seen the use that we should make of the system, in our case it is useful to analyze the tapping techniques, and the correct methods we have to use in order to serve a beer from the bottle. There are different techniques of tapping and each of these has been designed and developed to maximize the class of beer in question. The different tapping techniques are divided into four main categories, each one with its characteristics, typical of beer historically more widespread in the region in which it was born. For each of these categories, however, there are some main steps to follow before starting the tapping.

In any case, in fact, the glass must be taken and, if it is made of glass, it must first be degreased. This operation consists of pressing the glass against the rinse-glasses, where a mixture of water and a vegetable degreaser is sprayed against the glasses and eliminates the composition of patina which otherwise will prevent the foam from forming properly adhering to the wall of the glass. The foam, unable to adhere to the wall, modifies the normal properties of stability and persistence and cannot adequately protect the beer from oxidation. Another essential step for a good tapping is also to eliminate the first beer that comes out of the tap. This beer, standing immediately before the internal valve of the tap, in the horizontal part of the same, cannot be adequately cooled and comes into contact with the atmosphere in a minimal way, with the result of seeing their organoleptic properties degraded. Using the refrigerated taps, with recirculation of coolant also inside the spine column, this problem is solved for the beer that is stationed in the column.

The Belgian tapping [Aca], [HEIa](typical of Belgian beers) is characterized by a filling of the glass in a single stroke with foam cut operation. The glass is placed under the tap at an angle of 45° and gradually straightened during filling, then the tap is closed when the foam starts to come out of the glass and is then removed from the area below of the plug. The foam is made up of proteins and resins of hops and carbon dioxide. At this point, using a special gobelet (spatula), the layer of foam over the glass is removed. Given the lightness of the gas, the first foam that comes to the surface is normally formed by the larger bubbles, which contain a greater quantity of carbon dioxide. With the cutting of the foam it is therefore necessary to eliminate mainly the larger bubbles, leaving then to the remaining part of the foam, containing smaller, more compact and cohesive bubbles, the protection of the beer. It is therefore important to move away the glass from the mouth of the tap, to prevent residual drops from falling and breaking the bonds formed in the foam. At this point the glass is immersed in a sink full of water to clean the outer walls from the foam and subsequently served. This type of tapping is done in one shot to allow the aroma of beer, very rich and floral, to emerge already from a first olfactory impact towards the consumer. In the case of "weissbier" the initial inclination of the glass can be increased yet where the beer is pasty and a slightly higher residual carbonate slightly covers this characteristic.

The Gaelic-Irish or "legal" tapping [HEIc] is typical of stout beers, beers that have a particular very persistent and creamy foam. This foam and the tapping technique are closely linked to the uses and traditions of the places where it has developed. With the tolling of the 11 p.m. in ancient times every pub or other commercial activity had to close and a beer with particularly persistent foam allowed to prolong the evening even outside the locals: the tapping has evolved so to allow the foam characteristic of stout beers to keep the most long as possible. The tap is divided into two strokes: in the first shot the glass, initially inclined at 45°, is gradually straightened and removed from underneath the plug when it is full for approximately $\frac{3}{4}$. After letting rest and compact the foam you end with a second cascade (so it's called the cascade with a vertical glass resting on the floor). This type of beer typically uses a different type of plug, not the classic one that uses carbon dioxide but different version with a disc to break the main big bubbles in the beer flow before the glass filling. It use a mixture of carbonitrogen used for non-sparkling beers, in which carbon dioxide is used to maintain the sparkling characteristics of beer. nitrogen is used to provide the pressure needed to push carbon dioxide out of the drum. Nitrogen is used because it is an inert gas, which does not alter the product and is odorless and tasteless. The most common mixture is 70% CO_2 and 30% nitrogen: the nitrogen must be used only for the thrust, while the CO_2 is delegated the task of maintaining the sparkling beer.

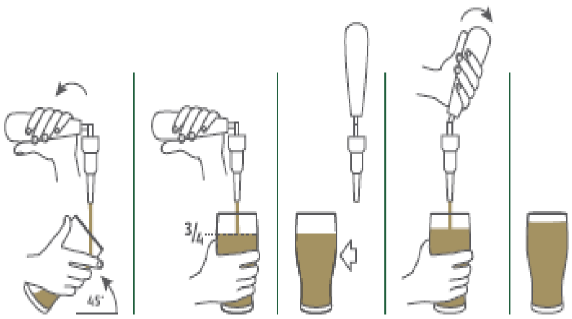


Figure 3.1: **The sequence of the legal tapped style**

In the German tapping [Aca], [HEIb] instead, three strokes are used, alternating with a rest phase in which the foam produced by the previous stroke is lowered. The first shot always occurs with an initial inclination of 45°, and a subsequent straightening, roughly when the beer reaches half of the glass. The second and third taps are instead to be made in cascaded and usually the last is more powerful to be able to provide the beer with a thick and compact foam hat, according to the tradition capable of supporting a ”pfenning”, the one-penny German Mark. With a correct technique, such a hat will swell over the edge of the glass, without overflow and pouring outwards.

The last great category is the Anglo-Scottish tapping. In this type of tapping the glass, inclined at 45°, is filled more slowly than with other techniques and gradually straightened, paying close attention to forming the minimum amount of foam possible, even if these beers are usually characterized by a low quantity of carbon dioxide. The glass is filled with this single shot, then it is still left to stand for a minute before being served to expel a further portion of carbon dioxide.

There are some operations that should be avoided in any case during tapping, to serve the beer properly [HEId]. For example, direct contact between the tap and the glass or beer contained therein is incorrect, but at most, tapping can be immersed in the foam to achieve the drawing desired by the customer. It is also inappropriate to open and close the tap during a single stroke of the tap to avoid lowering the quality of the tapping itself or to use a rinse aid on the glass beakers, which would prevent proper adhesion between the wall and the foam.

3.2 Tapping beer system and components

The draft beer is so called because in ancient times a real thorn was planted inside the barrel as a tap, to make the beer comes out [Birb]. Since keeping the beer at room temperature became less and less accepted in centuries, systems were gradually developed to store the barrels in cellars, bringing the beer where necessary through pipelines, with distances and differences in height to be overcome. Currently on the stem is hooked, through various types of standard attachments (the most used types are bayonet, U-shaped, jolly type) shown in the 3.2, an attack that opens two valves of the stem: one inlet for the pressure of gas (CO_2) under pressure to give the necessary thrust to the beer surface, which is then conveyed through the second valve connected to a float on the bottom of the keg and sent to the tap.

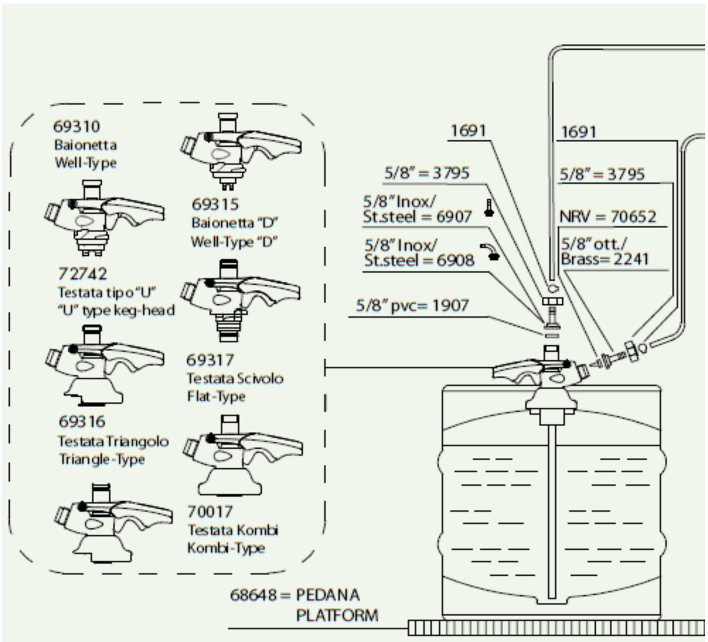


Figure 3.2: **A keg with the most common attachment types**

As already mentioned, a certain quantity of carbon dioxide, also called degree of saturation, is already present in the beer. This parameter, variable according to the type of beer, is controlled by the master brewers at each stage of the process, disposing of the excess CO_2. This value is then also to be found when exiting the tap, supplying the stem with the overpressure suitable to compensate for the falls we have in the pipes. To obtain a glass with the right amount of CO_2, it is necessary to take into account the various factors that influence its quantity: temperature, distance and difference in the height of the stem from the tap. A beer too low pressure result a "flat" beer, and as I go to the bottom of the stem it has difficulty in being tapped, because the bubbles dissolved in it tend to aggregate and get rid before reaching the mouth of the tap removing thrust to liquid. Applying too much pressure, instead, we will have too much foam in the glass, obtaining a quantity of beer not sufficient to serve or, in the case in which a system is automated and choose not to use vision sensors but rather rely on opening time of the faucet, an excessive amount of foam that can tip over the work plan. The temperature is a factor to which we must therefore pay much attention because it strongly affects the pressure with which we need to feed the stem to tap the beer. This pressure is also influenced by the relative position between thorns and kegs: it is good practice to increase the pressure obtained before 0.1 atm for each meter of difference in height to be overcome and of other 0.05 atm for each meter of tube between stem and plug [?]. More precise value are indicated in the **Table 1** attached [Aum]. For a dozen years Carlsberg has introduced a new stem with different characteristics. The various drums are in fact inserted into a structure with a suitable attack from where the beer is drawn by compression of the plastic stem in which it is obtained: in this way I do not have the insufflation of carbon dioxide into the stem to cause the beer exit, with the advantage of having a beer coming out with the exact amount of dissolved CO_2. Another advantage is given by the volumes and the ability to dispose of the stem once empty, without return service, which have a cost that is spread when buying the drums. Regarding our application, however, a keg that "crushes" as it is used would go against our goal of having the stems or at least some of them in plain sight, because they would not be more beautiful to see each other.

	0	4	8	12	16	20	24	28	32	36
4.3	0.35	0.60	0.85	1.05	1.35	1.36	1.95	2.25	2.55	2.85
4.5	0.45	0.65	0.90	1.15	1.45	1.80	2.10	2.40	2.70	3.00
4.7	0.50	0.75	1.00	1.25	1.60	1.90	2.25	2.55	2.85	3.15
4.9	0.60	0.85	1.10	1.35	1.70	2.05	2.40	2.80	3.20	3.60
5.1	0.65	0.90	1.20	1.50	1.80	2.10	2.55	2.90	3.30	3.70
5.3	0.70	0.95	1.25	1.55	1.90	2.30	2.75	3.25	3.75	4.25
5.5	0.75	1.05	1.35	1.65	2.05	2.40	2.90	3.40	3.90	4.40
5.7	0.84	1.10	1.45	1.85	2.15	2.55	2.95	3.50	4.00	4.50
5.79	0.90	1.15	1.50	1.95	2.25	2.65	3.05	3.55	4.05	4.55
6.1	0.95	1.20	1.55	2.00	2.35	2.70	3.10	3.60	4.10	4.60

Tab.1 Overpressure to guarantee for a good tapped

Normally in a plant, in the presence of different barrels, I don't have an environment in which the beer is chilled already at the temperature that will be the service one. In some cases they are already located in a controlled temperature environment (usually between 15 and 25°[Coo13]), to avoid that the external temperature changes cannot be completely deleted in tapped. This solution has a cost but it also has the clear advantage of keeping the beer contained in the kegs longer: the beer coming out towards the tap will still pass inside a cooling system. In any case, the kegs for a correct preservation of the beer must be placed on a raised level, isolated from the ground. The beer taken from the stem is directed, through the pipes, to the refrigeration system, to obtain a fresh beer at a controlled temperature.

The refrigeration system consists of a fridge, an insulated tank (a tank with walls covered with insulating material, such as polyurethane foam) in which there is a coil generally made of copper, an excellent heat exchanger, resting on the walls of the fridge; externally, a few centimeters, is instead a stainless steel coil for each product to be tapped. At the center of the tank there is also a water recirculation pump, which ensures that local areas do not develop at different temperatures in the tank and above all draws part of this water by pumping it into two recirculation pipes that pass through a tube bundle covered with insulating material called python; in it pass all the tubes in the beer coming from the stem and directed to the spine. As a refrigerant, the most used gas is the freon R134a compressed, used since the 90s to replace CFCs that dispersed in the air were among the main factors responsible for the ozone layer depletion [Coo13] .However, even this gas has its problems from the point of view of pollution, due to its high GWP (Global Warming Potential): it is therefore trying to replace it with other refrigerants with the lowest impact on the environment such as R290 (propane gas) or R744. The use of pressurized refrigerant gas also requires the use of a compressor; in addition there is also a drain tank connected to the insulated tank. The refrigeration system cools the beer that flows inside, but naturally has the effect of heating the surrounding environment. This data must be taken into account for the preservation of the stored beers: towards this direction the chiller must be adequately thermally insulated or, preferably, it must be in a different room from the one in which the beers are stored. The refrigeration system is present under the counter in a position very close to the plug or even incorporated in it for small plants intended for domestic use (the so-called kegerator). These systems, however, are voluminous and if placed on a sort of counter facing the draft the beer and not towards the customer, they greatly limit the view between the two parts.

From the plant the chilled beer goes to the plug, where it continues to be cooled thanks to the recirculation of a coolant also in the column, in order to tap a good beer without having to pour a large amount each time in case of intermittent operation. The beer is then kept at a low and predetermined temperature and in the more expensive plants it is also possible to create special columns with an ice effect on the outside, creating a scenographic effect exploiting the fact that the freezing point of the beer, that varies slightly depending on the ingredients that compose it and the alcohol content, is around -3°C. The increase in cost is due not only to the refrigerant (the glycol) but to the system for its recirculation and the thermostat that must be very precise to keep the temperature constantly between -3° and 0°. Part of the plant too is what is downstream of the tap spout, that is the drip tray: they exist in various shapes and sizes, can be divided into several sections or into one. A very important element present in some of them is the rinse glasses to remove residues from the walls of the glass before tapping, used with glass beakers and often incorporated into the drip tray. The glass will be pressed downwards by activating the jet composed of water and vegetable degreaser which must be contained in a separate tank. This solution allows you to rinse glasses without having a real sink with brushes available, with a saving of both cost and space that in some cases can be decisive. In addition, cold water also has the function of cooling the inside wall of the glass, in order to keep the temperature of the beer then stuck constantly for as long as possible. In order to have an effective system I cannot allow any residual beer to be poured out on the floor, which will degrade inside the drip tray with consequent odor issues. It is therefore advisable to have a discharge of these liquids towards an ad hoc tank inserted under the worktop, to be cycled. Likewise, the liquids of the glasses still wet but already washed after use, through the drain glasses.

Chapter 4

MAIN CHARACTERISTICS OF THE SYSTEM

4.1 Repeatability and reliability of the system

Having defined the general idea about the system we want to achieve, it is clear that the first characteristics to be reached effectively are those of reliability and repetitiveness. The various operations must be performed, cycle by cycle, always equal to themselves, less than minimal and not appreciable differences. This is necessary both for what concerns the robot and its movements, both for the movements related to the opening and closing of the knobs of the tap, which for the initial positions in which the glasses must be in order to be picked up. This concept of repetitiveness is essential for us, because it is also based on that of the reliability of the system: the robot must be able to provide every single time the beer requested by the customer, tapped correctly and on schedule. You will not have to recreate conditions for which you can fail, since the order of cycle start given to the robot will start thanks to the payment that will be made by the customer and because it will be a "stand-alone" system, able to reach the objective without the help of external operators who can intervene to correct misbehavior.

In the various movements that must be performed, the games between the robot's claws and the glass or the knobs of the tapper will always be a few millimeters, both in the approach and in the junction phases. Considering the characteristics of the collaborative robots currently on the market, this aspect should not be a problem, at least as long as we use the robot in a manner compliant with the manufacturer's requirements. Since the repetition value indicated by the manufacturer is unique and represents a sort of maximum limit among all those that can occur, once satisfied, it will not even be necessary to adjust the speed, lowering it. Repetitiveness is in fact one of the main characteristics of a robot, in our case not used to perform operations of extreme precision as can occur in other fields (such as in watch making). Since the start and end points of the movements will be achieved even with a precision of an order of magnitude higher than what is strictly necessary, the attention will have to focus mainly on the accessory elements such as knobs, glasses, etc. Here, more changes may occur with the passing of cycles, for example due to mechanisms that are not well lubricated, or too large uncertainties in the initial positioning of the glasses can happen: the choice of the components, which must have the necessary quality to not be an obstacle, will be important to the development of the cycle. Repeatability of movements is a necessary condition to have a reliable system, but to achieve our purpose we must avoid malfunctions that may occur over time. Good maintenance will be essential to reduce these inconveniences to a minimum, but it is not realistic to think about being able to eliminate them completely, despite the need for the station. We must therefore evaluate each of these risks by associating it with the consequences that could derive from it: if these consequences will not be considered acceptable, we need to take action to reduce the risks or at least ensure that the system is able to detect the danger independently, requiring assistance and stopping until the problem causing the stop is resolved.

Also here it will be necessary to operate in the next phases of the choices on the techniques to be adopted, the type of elements that will constitute the plant. As the ultimate goal is the reliability of the system, as in any industrial machine, it will therefore be preferring technical solutions and components that are constructively simple and linear, aiming at practicality even at the expense of aesthetic or technical spectacular but accessory embellishments. The latter can then be reviewed and possibly included in a second phase, but only after having guaranteed a consistent reliability of the basic cycles.

4.2 Pallets compatible dimensions

The station that we want to develop at first could be inserted in places where it can be assisted by an operator in a fairly rapid way in case of need. In the initial phase, the functioning of the system has yet to be verified and considering that in the prototypes we have built in the planning phase the system is not yet complete in all its parts or that the accumulated working hours have been much less than those for which it will be operational, new problems and problems could arise. The most suitable places where it is possible to place an operator next to the robot without dedicating it completely to the system could be locations around the bars (open-space) or fairs. Our intent is also to avoid having to depend on large and expensive means of transport to move and place the system in various places, such as a large truck whose sole purpose was to host inside the prototype of the Bionic bartender station analyzed in previous chapters [Roba]. To make the system easily movable the best solution would be to make it palletizable: our intent will therefore become that of being able to realize our station in a functional, aesthetically pleasing but also compact, able to be contained in the spaces that the pallet (also said pallet of load) imposes us. The dimensions of the pallets are regulated by the EC directive n. 29/2000 [Pat00], which foresees two standard dimensions: the first one of 800x1200 mm, also called EUR, and the second one, of 1000x1200 mm, called EPAL or Philips. In order to be able to exploit vehicles of various sizes, with regard to European transport, which take place mainly on road, the use of the first type is definitely more suitable.

Considering all the various elements that make up a tapping system, in both cases there will be different factors to be considered during the development of the system to comply with these parameters. Even in height, the volumes will be severely limited because the work plan must be in a position such that it is easy for customers to interact. At the same time, as indicated in the description of the system, we will must have an internal floor level raised a few centimeters not only to fix the hidden elements for the refrigeration of beer but also to isolate the system from the ground. The total volumes will also depend on the number and on the size of the drums that you will want to insert: the set of all the elements of the plant and the need to have at least one stem for each type of beer the robot tap to the consumer, there requires abandoning the idea of building the whole system on a single euro pallet. The alternative, in order not to lose the possibility of transporting the station comfortably, is to create a modular system, in which there are two distinct parts, each of which is housed on a standard-sized pallet. The best way to distribute the components on the two pallets is to insert the station with the robot and the plug, the cooler and the relative motor, the CO_2 bottle, the pipes, the drinking glasses or jugs and sensors needed on the first pallet. The second will have the function of housing the stems at controlled temperature, the sensors and the motor to maintain this temperature within the preset limits, and the various stem connections and any systems to select the stem to be tapped.

This solution also has the advantage of being able to take part of the drums above the worktop. Otherwise this would not have been possible because the necessary space would have been subtracted from the robot, which naturally must be completely outside the window. In the dimensions indicated above, in fact, the collaborative robot would have been inserted with its control unit (unless the control unit is moved under the floor, in a space already fully exploited), the plug with the drip tray, the space all the various movements of the robot need and all the other elements necessary for the tapped. Now the upper part of this kind of refrigerator can be exposed to show the aesthetics of the barrels or the kegs, showing through the glass with a certain degree of transparency appropriately inserted the "good and fresh" product. At least initially we will begin to consider the idea of developing the system on two pallets, each one of medium size (those from 800x1200 mm). This, in addition to the greater ease of transport, to put ourselves in more restrictive conditions and to avoid that for a minimum variation that can be carried out subsequently, then this characteristic is lost by the system, as we would already be in the easiest case. Secondly, because given the range of the class of robot we want to use (about half a meter) we should consider positions actually reachable from the cobot to insert the glasses, the plug, the knobs, the place of delivery of the beer to the customer. These positions must not only be reached by the robot, but in these points you will also have to perform precise movements, which will then be developed later. Finding distant points that belong to the task-space but then not reachable in the correct way, would involve revisiting the system completely. If then the passage to the greater size of the pallets becomes necessary, it will be subsequently carried out.

4.3 Maintenance and safety

One of the main objectives of our system will be to have a station that requires less maintenance as possible, because such interventions in a mature phase of the project will require the intervention of external personnel every time. The risk, if these interventions should become very frequent, would be to obtain an automated system but not autonomous if not for very short time intervals and therefore useless when not flanked by staff. Maintenance interventions can be divided into two main categories: ordinary maintenance and extraordinary maintenance [Tog]. In choosing the components, the cycles to be adopted, in specific implementation solutions it will be necessary to take into account both these types, trying to reduce them to the minimum. Ordinary maintenance may be reduced but not eliminated in many cases and it becomes extremely important to try to foresee targeted interventions over time and making the various planned interventions coincide as much as possible within them, to make the number to the minimum. In the case of extraordinary maintenance interventions, they cannot be foreseen over time: the only viable solution is to put ourselves in the conditions whereby their probability is reduced to a minimum and to equip the station with sensors that detect any problems and give a request signal for an operator's intervention, which is probably not located on site but remote. If the malfunction will not be detected, in fact, the failure to promptly intervene could compromise the operation of the entire station. In this phase some necessary or probable maintenance

interventions to be carried out cyclically will be analyzed: in the development of the thesis, on the other hand indications will be provided on how the choices made in our specific case will influence and limit the necessary maintenance.
For routine maintenance, it will be useful to define now what the operations to be carried out each time are, in correspondence with the change of the drums and the refill of the glasses. The maintenance operator must have all the necessary equipment available at the moment in which it intervenes to carry out those routine checks, which make it possible to avoid serious damage in the long run on important components, for which the intervention of the dedicated assistance. In these routine operations the operator will also be provided with spare parts or tools to intervene on small problems, to avoid stopping the entire station for long periods. Banal but very important are the cleaning of the floor and components from dust and residual liquid and the periodic lubrication of the elements that require it, which cannot be carried out by the robot itself.

With regard to the system pipes, an important maintenance to be done from a hygienic point of view is the sanitizing of the lines. This transaction is regulated by HACCP legislation, implemented in Italy by Legislative Decree 155/1997 [Lel]. It consists of the internal cleaning of the pipes and is to be carried out with a frequency of about 30-40 days between the interventions, a period of time also influenced by external factors as the first of all the productivity of the system. Sanitization, in fact, is useful for sterilizing the ducts, eliminating those turbid residues inside the tubes that degrading produce bad smells, tastes and which over time can cause bacterial infections. Naturally, even if the contact with the air is minimal inside the piping, the less a system is used the more these residues have the possibility to form and create problems: as a good rule, in fact, it is not recommended to use a system of tapping if less than two stems per week are on average drafted. Very important is also the correct storage of the same stems, as already indicated: they must be stored on a raised board and isolated from the ground, at a temperature between 15° and 25°C (the ideal one is about 18°) for avoid early alterations. Even the type of beer can influence the frequency of this intervention, which increases for example in the case of stout or double malt beers, in which the yeasts work at temperatures close to the environment. It is also advisable to check the tightness and operation of the various parts of the system to avoid leakage or contact with air that produce a more rapid degradation of the product. In particular, the critical components are:

- the tank, whose water must be clean and at a level that completely immerses the coil and the evaporator. The ice inside the cooling system must be uniform, and never cover the coils

- the stem attack, to be kept clean to avoid bacterial infiltration, must not lose CO_2
- the plug, which must be clean (even more frequently than sanitizing)
- the seal of the gas cylinder and the quantity of residual gas inside it
- operation of the refrigerator condenser (the radiator) and the recirculation pump
- cleaning the condenser fins, to be carried out with a soft brush or compressed air
- the tap with hot water, to be cleaned and if necessary, lubricate with Vaseline
- the tap O-rings, to be replaced if broken

For what concerns the robot it is instead necessary to provide for the replacement of any damaged parts, if possible to do it on site, without having to call the dedicated service and will be required to lubricate the various joints with the appropriate frequency. To carry out the sanitization it is necessary a solution of water and detergent suitable (and depending on the detergent used also glasses and gloves for their own protection during the procedure), for about 10 **l**, while another 10 **l** of clean water are necessary for rinsing. After that we must proceed as follows:

- the plant is emptied from the residual beer in the tubes and the solution is replaced with the drums
- the first half liter of detergent solution is tapped and the plant pipes are left to full for about 15 minutes
- another half a liter of detergent solution is tapped and the pH of the solution at the output is measured, which must be between 5.0 and 8.0; otherwise, the procedure is repeated
- re-insert the beer until it starts to come out again: at this point you check the amount of foam, tasting the product to feel the conformity to taste

The pH meter is the appropriate tool for the study of the pH of a liquid, which is detected by immersing the probe that sends a signal to the electronic device, which analyzes it and provides the result. The glass electrode is composed of a bulb where on one side there is a reference electrode (practically neutral, of ph 7.01) and the other from a measuring one: the potential of the output signal will be dependent on the difference of ph between the two electrodes, amplified properly. Often a thermometer is also present, because depending on the measured temperature, a corrective coefficient must be applied to the detected potential. In both glass electrodes there is a silver wire immersed in a solution of silver chloride and an electrolyte: one of the two, however, is placed in contact with the solution by means of a porous diaphragm, present in the wall, thus changing the solution inside one of the two chambers and creating the potential difference.

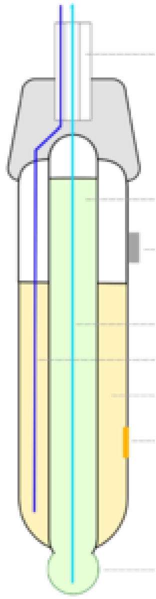


Figure 4.1: **ph-meter section**

The problem with these tools, especially for the cheaper ones, is that they tend to be fast [PHM] and their calibration must be carried out frequently. The glass electrode is generally stored immersed in a very low pH solution to prevent the glass membrane from drying out; the use of distilled water should be avoided because it could extract the hydrogen ions present inside the electrode by osmosis.
In addition to the procedures listed above, there are also a whole series of other operations that may need to be performed on the plant in maintenance daily or at least more frequently than the others, to delay the need for sanitizing the system:

- Rinse the system with pure water at each drum change (or in our case of remote station, every time the stems are recharged)
- Wash the spout and the tap with warm water
- Check the fridge condenser cleaning
- Since the robot and the floor are also part of the system and unlikely, they are not cleaned regularly as in a bar, they must also be cleaned.

Very important from the point of view of hygiene is also the preservation of glasses: the latter must be stored upside down, but not in a rack, because in both cases impurities, dust and fumes could end up inside. In the same way it is not healthy to even lay them on a cloth, eliminating the ventilation necessary to dispose of the residual moisture, with consequent molds and bad smells.

There are also a series of precautions that must be observed during the maintenance phase, such as keeping the CO_2 cylinder and the beer at temperatures above zero and far from heat sources, even if stored in a real refrigerator and, above all, remember to always switch off the system and the robot before working on the station. Also for a matter of conservation, moreover, it is necessary to avoid switching off the refrigeration system outside of the maintenance phases explained above.
In order to avoid that faults in some components are very bad for the station operations, it is necessary to provide some sensors that react to such malfunctions by contacting the assistance for extraordinary maintenance, which must in any case be reduced to a minimum upon loss of the station autonomy feature. Some problems related to the refrigeration unit, with the probable underlying causes could be for example [Lel]

- The machine does not work: the unit or the thermostat could be switched off or the power plug disconnected
- The machine blows the current: this may occur if some components such as the motor, the fan or the compressor short-circuits. In any case, it is a good idea to reduce the humidity to the minimum so as not to favor this situation; in case of occurring, contact the remote assistance to request the spare part.
- The stirrer motor is stopped: check that the plug is correctly inserted and the electrical connections. If you do not find the solution to the problem, you should contact support for a possible replacement.
- The machine works, but does not cool the beer: here the problem can be twofold, in the sense that it can be attributed to the fan that remains stationary (with a compressor and stirrer working) or to an external cause. In the first case, as before, it is advisable to check the electrical connections and if it is a problem with the motor-driven fan, contact the assistance. Otherwise it could be a problem of the refrigeration unit: this may happen due to a lack of cleaning of the condenser or the depletion of the refrigerant gas, to be replaced.
- In the event that both the fan and the compressor are stopped, this can be attributed to the low water level in the tank (easy to solve); the system may also not work due to a failure of the thermostat, no longer able to supply a reference temperature. The faulty thermostat can also

lead to many other problems: it may not cool at all, cool down until the product freezes. This last situation, if not correctly prevented, can lead to serious consequences such as the breaking of some components of the system as well as the stop of the plant itself to thaw the liquid once contacted the assistance. In this case the frozen liquid must be threw away.

- Finally, if the stirrer is very noisy, the bearings should be checked and replaced if necessary.

4.4 IP grade

The IP code (International Protection code) is a code whose function is to measure the degree of protection from the intrusion of solid and liquid external bodies of a product, as specified by the standard EN 60529. It is defined by two figures, without any sign to divide them, each of them of increasing value as protection from the external intrusion grows: the first digit defines the degree of protection from solids, the second from liquids. If there is no information on the degree of protection the digit is replaced by the letter X, while other letters may be used to indicate additional protection. The protection scale from solids typically ranges from 0 to 6, that of liquids from 0 to 9; the value 0 is indicated to express the complete absence of protection. It is possible in some cases to find a third digit, variable between 0 and 9, which indicates the protection against mechanical impact. Below there are the various tables, with the degree of protection associated of case in case:

Level sized	Effective against	Description
0	-	No protection against contactand ingress of objects
1	> 50 mm	Any large surface on the body, such as the back of a hand, but no protection against the deliberate contact with a body part
2	> 12.5 mm	Fingers or similar objects
3	> 2.5 mm	Tools, thick wires, etc.
4	> 1 mm	Most wires, slender screws, large ants, etc.
5	Dust protected	Ingress of dust is not entirely prevented, but it must not enter in sufficient quantity to interfere with the satisfactory operation of the equipment.
6	Dust tight	No ingress of dust; complete protection against contact (dust tight). A vacuum must be applied. Test duration of up to 8 hours based on air flow.

Tab.2 Solid coefficient classification

	Protection against	Effective against	Details
0	None	–	–
1	Dripping water	Vertically falling drops shall have no harmful effect on the specimen when mounted in an upright position onto a turntable and rotated at 1 RPM.	Test duration: 10 minutes Water equivalent to 1 mm rainfall per minute
2	Dripping water when tilted at 15°	Vertically dripping water shall have no harmful effect when the enclosure is tilted at an angle of 15° from its normal position. A total of four positions are tested within two axes.	Test duration: 2.5 minutes for every direction of tilt (10 minutes total) Water equivalent to 3 mm rainfall per minute
3	Spraying water	Water falling as a spray at any angle up to 60° from the vertical shall have no harmful effect, utilizing either: a) an oscillating fixture, or b) A spray nozzle with a counterbalanced shield. Test a) is conducted for 5 minutes, then repeated with the specimen rotated horizontally by 90° for the second 5-minute test. Test b) is conducted (with shield in place) for 5 minutes minimum.	For a Spray Nozzle: Test duration: 1 minute per square meter for at least 5 minutes, water volume: 10 litres per minute Pressure: 50–150 kPa For an oscillating tube: Test duration: 10 minutes, water Volume: 0.07 l/min per hole
4	Splashing of water	Water splashing against the enclosure from any direction shall have no harmful effect, utilizing either: a) an oscillating fixture, or b) A spray nozzle with no shield. Test a) is conducted for 10 minutes. Test b) is conducted (without shield) for 5 minutes minimum.	Oscillating tube: Test duration: 10 minutes, or spray nozzle (same as IPX3 spray nozzle with the shield removed)
5	Water jets	Water projected by a nozzle (6.3 mm) against enclosure from any direction shall have no harmful effects.	Test duration: 1 minute per square meter for at least 3 minutes Water volume: 12.5 litres per minute Pressure: 30 kPa at distance of 3 m
6	Powerful water jets	Water projected in powerful jets (12.5 mm nozzle) against the enclosure from any direction shall have no harmful effects.	Test duration: 1 minute per square meter for at least 3 minutes Water volume: 100 litres per minute Pressure: 100 kPa at distance of 3 m
6K	Powerful water jets with increased pressure	Water projected in powerful jets (6.3 mm nozzle) against the enclosure from any direction, under elevated pressure, shall have no harmful effects. Found in DIN 40050, and not IEC 60529.	Test duration: at least 3 minutes Water volume: 75 litres per minute Pressure: 1000 kPa at distance of 3 m
7	Immersion, up to 1 m depth	Ingress of water in harmful quantity shall not be possible when the enclosure is immersed in water under defined conditions of pressure and time (up to 1 m of submersion).	Test duration: 30 minutes - ref IEC 60529, table 8. Tested with the lowest point of the enclosure 1000 mm below the surface of the water, or the highest point 150 mm below the surface, whichever is deeper.
8	Immersion, 1 m or more depth	The equipment is suitable for continuous immersion in water under conditions specified by the manufacturer. However, with certain equipment, it can mean that water can enter but without produce harmful effects. The test depth and/or duration is greater than the requirements for IPx7, and other environmental effects may be added, such as temperature cycling before immersion.	Test duration: Agreement with Manufacturer Depth specified by manufacturer, generally up to 3 m
9K	Powerful high temperature water jets	Protected against close-range high pressure, high temperature spray downs. Smaller specimens rotate slowly on a turntable, from 4 specific angles. Larger specimens are mounted upright, no turntable required, and are tested freehand for at least 3 minutes at distance of 0.15–0.2 m. There are specific requirements for the nozzle used for the testing. This test is identified as IPx9 in IEC 60529.	Test duration: 30 seconds in each of 4 angles (2 minutes total) Water volume: 14–16 litres per minute Pressure: 8–10 MPa (80–100 bar) at distance of 0.10–0.15 m Water temperature: 80 °C

Tab.3 Liquid coefficient classification

Letter	Meaning
f	Oil resistant
H	High voltage device
M	Device moving during water test
S	Device standing still during water test
W	Weather conditions

Tab.4 Additional protection letters

After listing the various codes, it is important to contextualize them in this case: when dealing with beer, protection against liquids is very important. This protection is necessary for parts that contain electrical components, while we can state that protecting part of the plant under the floor from any beer leaks will still be very simple and many of these components will still be properly shielded to avoid compromising the operation of the system, due to possible leaks from the pipes or the cooler tank. The main object to be shielded is therefore the robot and the relative clamps, without compromising the functionality on the other side. Being a station left "at the mercy of customers", it must still be protected from any type of inclusion with objects that for some strange reason a person decides to thread, for example between joints, during operation: therefore it is essential to ensure a IP level of at least 4 against solid, even if an IP 5 would be better. In fact doing so is also protected the entry of dust in such a quantity to create in the future need for more maintenance. Furthermore, having a high degree of protection for solids is also a basic condition for raising the one against liquids, our real goal. The overpressure guaranteed to the beer is used only for tapping, to ensure that the thrust is maintained to keep the desired flow on tap: the outgoing beer will therefore not be overpressed, as well as naturally that contained in the glasses. The only beer under pressure is contained in the pipelines but any leaks would still occur under the work surface and would not affect the robot. It is therefore not necessary to get to grade 5 but any splashes could come from any direction must be shielded to not create damage to the system: the degree of protection desired for the robot and clamp, therefore, must have as a minimum indicator the IP 54. In the case the level is not assured by the different components chosen, it will be necessary to intervene so as to bring it to what was foreseen: if not, the station is something useless.

Now consider the robot, which will be the most important element to shield inside the station. Virtually no collaborative robot presents the IP values required for our application, because they are mainly intended for pick-and-place operation or where they are treated only solids. To respond to this need to increase protection, fortunately, companies have developed whose task is to create special fabric covers, or with bellows, etc., based on specific customer requests [ABc]. The robot we have chosen will be to be isolated everywhere, from the base to the caliper, in case it does not meet the necessary values, with a suitable fabric. These coatings must have different characteristics depending on the case, but for us it is very important to be able to wrap the robot parts without limiting their movements or speeds. Secondly, it is not necessary to create too high temperatures inside, as these fabrics will however constitute an obstacle to the disposal of the heat produced by the motors of the robot as conceived by the manufacturer. If this situation should occur, the solution would be to create a forced recirculation of the internal air between the robot and the waterproof fabric to avoid overheating.

Chapter 5

ROBOT CHOICE

5.1 The YuMi ABB robot

The YuMi ABB robot is a collaborative industrial robot with integrated controller equipped with two mechanical arms, each with 7 d.o.f. and 7 axes, also called with the initials IRB 14000. The fact that the robotic arm has 7 axes around which to perform its movements can be a good advantage from the "human-friendly" point of view, because the same thing happens for the human arm. Six dof would be enough to reach every point of the robot's task-space with the desired orientation, if the excursion given to each joint is sufficient: having this extra axis allows us to make the movements in a much closer way to the YuMi to that of a human being, of the barman in this case, reducing the emotional distance of the client. In the image below you can see the cobot and the axes on each of the two arms with the numbers associated with each axis. The YuMi can communicate with different devices external to the system and the human collaboration in safety, for each part of the robot, according to the UNI EN ISO 13850 [Arr] "Safety of machinery - Emergency stop function - Principles of design, 2015". This peculiarity allows the YuMi to work without any physical barrier against an external operator. It was the first collaborative robot to be analyzed because it is the only one with these characteristics in its weight (38 kg) and wingspan similar to human, while competitors have all dimensions and weights more relevant or are equipped of a single arm. Due to the characteristics described so far, this robot has immediately become the main "suspect" to play the role of barman inside our station. The footprint of the base, inside which the controller is also included, is only 399x497 mm and most of this can be mounted cantilevered to the worktop.

Given the weights and the effort contained, the YuMi was designed to be fixed, screwed to the floor only through the two front ends, which protrude from the base, as can be seen in the image below (where only the right one is visible , while the left one, symmetrical, is almost completely covered by the shoulder of the corresponding arm). This aspect will be important for our application, which has been designed to be contained in confined spaces and easily movable, but will be feasible only if the module of the beer stem at controlled temperature in contact with the one on which the robot will be fixed, facing the spectator will not be inserted; however, the small plant could be mounted on the floor leaving space for the various movements. In the case in which instead space is left between the two modular elements, this can be easily hidden from the public for aesthetic reasons thanks to movable wings. The price is about € 40.000, a value to consider also in relation to the fact that this robot has two arms unlike other small cobot and that from here to the final definition of the system this price may still decrease because in the meantime technology obsolescence will occur. The robot is very versatile, but was designed primarily to assemble small parts quickly and accurately, even in collaborative mode, going to perform different operations and complementary to those of the operator, in the same workstation. It is also suitable for testing components, or for pick and place activities.

It should however be emphasized that although it is collaborative, IRB 14000 has nevertheless been conceived and designed for operations in which contact with the operator is harmless, that is not causing serious damage or injury in the future operations. In case of stop with the robot at maximum speed in fact, a bit for the minimum computation times and a little for the associated inertias, there will still be a minimum stop time, in any case not more than 4 tenths of a second, but usually in the order of a few cents. To avoid this, in case of arrest the YuMi, after stopping, slightly withdraws from its stop position. The gripper supplied by ABB and the movement provided by the grippers [YuM] also fall within the collaborative norm. This gripper also has a mobile, patented plastic casing, able to absorb any impact. The only element not included in this sense is given by the actual nippers, which are supplied by ABB but which in almost every application will have to be replaced with a model designed specifically for the specific purpose of the user.
To perform these operations with good productivity, the YuMi is equipped with a high enough high speed (1500 mm/s), which, however, even if set, may or may not be reached by the TCP according to the particular combination of movements of the various axes for the required one at the joints and is valid only for automatic mode; the maximum speed for manual handling is smaller. In addition to this maximum speed value of the TCP, the speed of each of the seven axes is also limited: the limit values are 180°/s for the axes 1, 2, 7, 3 and 400°/s for the axes 4 , 5 and 6 [YuM]. These speeds, relatively high for the category, are achievable in collaborative mode thanks to the voluminous and padded additive protections on the robot arms. The robot is equipped with a controller and a con-

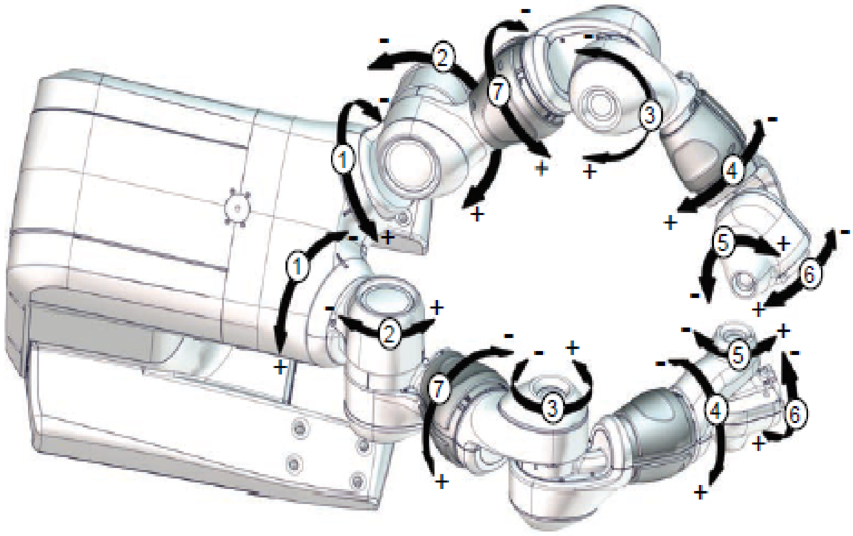


Figure 5.1: **Sketch of the YuMi with the numbers associated to each joint**

trol software called RobotWare: this software deals with all aspects of the robotic system, from the control of movement, to communication with external devices, to the development and execution of application programs based on the RAPID, a flexible and high-level communication language [Ris15] The controller also has an electrical input that can be accessed in external device mode to stop the robot, for example, from a safety PLC. The safety stop function interrupts the power supply until the control that triggers the stop is switched off manually. In addition to emergency stop protections and collaboration, it is also important to comply with safety and fire regulations, which satisfy the UL (Underwriters Laboratories, an independent organization of safety certifications)[YuM] standards.

Very important for the definition of the applications to which the robot can be destined is the payload limit parameter, of 0.5 kg for each arm. In this quote it is to insert all that is downstream of the wrist of the IRB 14000 and must therefore also be considered the weight of the pliers, the nippers, suction cups, filters, feeding systems, etc. The payload is determined by the motor of the joint 5, which is the most delicate and least powerful among the engines: it in fact determines a mechanical limit, if the required torque is greater than that which the electric motor is able to supply, the robot will not be able to continue the operation he was performing, interrupting the program. This limit would not be the same for the other engines in the various joints, more powerful and slightly oversized compared to the one present in the joint 5. As can be seen from the YuMi manual in fact, the torque to axis 6 (determined by the engine immediately upstream, that of the joint 5), is 0.23 Nm, against 0.64 Nm available on the axes 4 and 5. For safety reasons, the calculation of the maximum nominal load is carried out with maximum offset from the wrist, maximum speed and all 6 moving axes; the useful capacity of this maximum load is 0.559 m [YuM]. If the system is overloaded, depending on the overload and its duration, without a control by the IRB 14000 motors, reducers or mechanical structure could be damaged. The LoadIdentify service routine is available in the robotic system, which allows the user to prepare an automatic tool and load definition in order to determine the correct load parameters. The maximum load that can be moved by the robot is not only a function of the payload and of the weight of the gripper, but also depends on the distance between the center of gravity of the load and the robot's wrist. At the same load, in fact, the more this distance increases the higher the torque required to the robot to balance the load and to move it. The distance of the center of gravity from the wrist should be calculated along each of the axes, and not just on the plane. Another constraint on the part of YuMi is the IP rating of 30. This despite the connections and the power supply of the robot are completely internal, which also benefits from maintenance because it minimizes the risk of accidentally damaging the cables. The most exposed parts are in correspondence with the robot flange and the gripper housing.

An in-depth study that needs to be carried out is that related to how the collaboration was taken into account during the design and design phase of the YuMi, which is greater than that provided by other collaborative robots. In the first place the YuMi has been built for applications that allow good productivity and modest payload. The high speed compared to other cobots is a direct consequence of the low payload, which means that for relatively high speeds the operator goes to a collision with a reduced mass, partly due to the payload itself, partly due to the low weight of the materials with which the arms are built. Consequently, once the maximum speed (1500 mm/s) has been determined, the low payload, due to the low maximum torque of some coupling motors, produces non-high limit forces beyond which the robot is stopped to avoid damage. The low inertias then reduce the stopping times of the robot once the command has been given by the controller if a force greater than the threshold is detected; in addition to the stop, said type 1 stop, there is a slight retreat of the robot TCP. From this arrest, if the cause that created it is lost, the robot starts again in the performance of its task. In addition there is a second emergency threshold, upon reaching which the robot still changes its behavior, removing power from the motors to allow objects or a part of the operator possibly blocked between the arm or the caliper and another object to be freed without any kind of resistance: this is called a type 0 arrest [Arr]. To mitigate any impact, soft inserts are provided at various points on the arm, slightly prominent with respect to the arm structure to increase the probability of impacting on them and not on the other harder parts. From the controller's point of view, moreover, a modality has been foreseen that allows the manual movement of the arms, removing the brake from the engines of the first joints. Also included are commands to prevent an arm from programming in some volumes defined by the user or in any case to do so only under certain conditions or external signals.

As far as the calculation of the impact with YuMi ABB is concerned, it is considered an inelastic collision, which will be a conservative condition with respect to the actual impact [Ris15]. The mass of the robot is calculated by concentrating its mass at the midpoint for each link between the various joints and considering the velocity at that point, for each link between the shoulder and the point where contact can occur. The total mass will be given by:

$$m_r = \frac{\vec{p_r}\vec{v_r}}{{v_r}^2}, \text{ with } \vec{p_r} = \sum_i m_i \vec{v_i}$$

40 year old American male		95th percentile [kg]	[%]
0	whole body	98.5	100%
1	head	4.55	4.6%
2	neck	1.27	1.3%
3	thorax	31.76	32.2%
4	abdomen	2.96	3.0%
5	pelvis	15.15	15.4%
6	upper arm	2.5	2.5%
7	forearm	1.72	1.7%
8	hand	0.61	0.6%
9	hip flap	4.38	4.4%
10	thigh minus flap	7.92	8.0%
11	calf	4.76	4.8%
12	foot	1.18	1.2%
	sum	97.45	99%
5+4+3	torso	49.87	50.6%
9+10	thigh	12.3	12.5%
7+8	forearm + hand	2.33	2.4%

Figure 5.2: **Mass considered for the shock computation**

where the compliance of the kinematic chain is not considered, which could reduce the value of the mass considered. For the mass of the body's part with which the impact occurs, on the other hand, the table above regarding the average weight of an adult man is considered, considering the 95th percentile of weight for reliable data. Considering the moment of maximum compression, the reference contact areas with spherical or cylindrical surface were then calculated, to understand how the force that develops is distributed on the part of the body in contact and to calculate the consequent stress (in both cases the contact areas that will result will be slightly lower than the real one and therefore more conservative). Energy and power are calculated instead by the calculation of the reduced mass and the resolution of the usual equation:

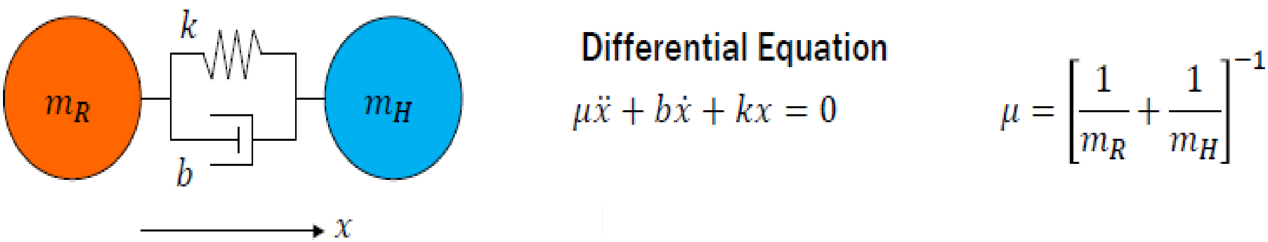


Figure 5.3: **Shock model used by the costumer**

In the development of the differential equation, elasticity as a constant was then considered for simplicity. In reality, deforming the material progressively increases its resistance to a further deformation and therefore the interpenetration between the bodies will be slightly lower, and so will the contact areas. This must be taken into account in the definition of the constant k, as every constant is also subject to uncertainty, but in any case it should be treated with an approximation more than compensated by the previous restrictive choices in the development of the model.
Each arm ends with a tool flange, for the assembly of the calipers supplied as standard or for others, specifically designed and constructed in such a way as to be compatible with the connection provided for the various feeds. Very important is also the characteristic of the robot to request a very low level of maintenance, without the need for intervention on the engines or change of lubricant (which is synthetic grease for all engines).

Movimento del robot

Asse	Tipo di movimento	Grado di movimento
Asse 1	Bracci - Movimento di rotazione	-168.5° to +168.5°
Asse 2	Braccio - Movimento di piegatura	-143.5° to +43.5°
Asse 7	Bracci - Movimento di rotazione	-168.5° to +168.5°
Asse 3	Braccio - Movimento di piegatura	-123.5° to +80°
Asse 4	Polso - Movimento di rotazione	-290° to +290°
Asse 5	Polso - Movimento di piegatura	-88° to +138°
Asse 6	Flangia - Movimento di rotazione	-229° to +229°

Figure 5.4: **Working limits of YuMi's joints**

The 5.4 shows the movement limits of each joint, very large, in some cases much higher than the excursions that a human is capable of. This is necessary in order to carry out the various movements, as unlike what happens for an operator performing the same operations as the robot, the shoulder (the position of the origin of the first joint on the base) is fixed in space, I do not have a trunk mobile but rigid and you cannot make complementary or corrective movements in the execution of operations by the arm. As you can see from the left column of the table the joints are not listed in numerical order; the order represented is that of the arrangement in space, moving from the shoulder to the wrist. The first two movements are proper to the shoulder (rotation along the 2 axes) while along the axis 7 is the movement, very large compared to the human, which allows the rotation between the shoulder and the elbow, and then everything that is downstream. Movement 3 is that related to the bending of the elbow, while the 4 represents the rotation of the forearm, an example of exaggerated excursion with respect to the human one. The movements along the axes 5 and 6 are instead those proper to the wrist, which will often be the object of discussion of the exposure later. The axis 7 does not follow the progressive numbering of the other axes, because it is the additional joint that gives the dof plus the YuMi compared to a six-axis robot. Each arm of the YuMi has a field in which is able to work, called task-space, determined by the length of the various links and the combined freedom of movement of the various joints. With respect to the position of the origin of the axis 1 of each arm, the task space is roughly spherical, even if it tends to be slightly more limited along the X axis, above all the quadrant behind the origin of the arm and downward; other limitations are present near the robot's shoulder and the volume occupied by the structure of the YuMi or the other arm. To avoid contact with the structure, the controller can also intervene: if the TCP is already near the robot and is destined to collide in order to reach the final point of the controlled movement, the controller calculates the trajectory and notices the movement releasing a special message on the terminal. The IRB 14000, then, is also able to provide a good accuracy in the movements, more than suitable for the application for which we would like to use, as indicated in the 5.5

Descrizione	Valori
	IRB 14000
Ripetibilità della posizione, RP (mm)	0.02
Precisione della posizione, AP (mm)	0.02
Ripetibilità del percorso lineare, RT (mm)	0,10
Precisione del percorso lineare, AT (mm)	1.36
Tempo di posizionamento minimo. PSt (s), entro 0,1 mm dalla posizione	0.37

Figure 5.5: **Fig.15 Repeatability and precision of the robot in question**

The resolution of the angular position of each axis is instead equal to 0.01°. The IRB14000 is powered by alternating current at 100-240 VAC (ie via a common socket), at 50 or 60 Hz (United States frequency), which is supplied to the robot by connecting it with the connector on the right side panel at the base of the robot together with the connector for the FlexPendant (a touch terminal) and the *0/1* switch. The tool applicable to the clamp, on the other hand, will be internally supplied with a 24 V current through the poles E and H of the tool-holder flange with 8 poles at the end of the arm, shown in 5.6. The other poles supply the reference voltage and the various ethernet inputs, with which the controller gives the movement commands. On the left side panel of the base there are the various ports for communication with the outside, for example to connect via LAN cable with the PC . From there interact with the programs developed with RobotStudio, or to connect external security signals (for example from a PLC), input/output signals, external air supply for the left or right arm. There is also a service port to which it is possible to connect externally to communicate with the controller, which is identified by an IP address (Internet Protocol address), univocal and not modifiable by the user. As regards the *I/O* port, it can be used for the tool flange as an alternative to communication via Ethernet; otherwise, it can function as a normal port for external *I/O* signals.

The basic clamp supplied by ABB is available in different versions, depending on the service modules present [YuM]. The basic component of the clamp consists of the servo-assisted module. It is the module through which objects can be taken and the movement and strength of the fingers is controlled and monitored by the gripper itself. Then there are 1 or 2 suction modules through which it is possible to take small objects up to a maximum of 150 grams. These modules are inserted laterally with respect to the gripper and contain the vacuum generator that can supply the module with the grip capacity: the release of the removed object takes place instead by blowing. The vision module contains a Cognex AE3 In-Sight camera that supports all ABB Integrated Vision features. In any case, the ABB clamp is fixed to the flange of the corresponding YuMi arm through 3xM 2.5 mm screws and alignment is also facilitated by the presence of guide pins. The air transmission is guaranteed by the joint between the hole in the pincer and the element protruding from the flange, shown in the figure, while the 8-pin connector is pushed towards the counterpart of the arm by a spring with a stroke equal to 1 mm.
In case you want to customize the whole pincer, or adopt one for which it is not automatically provided for adaptability to the YuMi ABB (not recommended) you will have to follow the configuration of the holes provided and faithfully reproduce the guides for the standard ABB clamp to be able to correctly couple the parts, with all the problems that derive from it if a certain degree of IP protection is needed and subtracting even more capacity from the payload of the YuMi. The suction and vision modules are costly and also a further weight for the clamp, which would limit even more an already minimal payload; therefore the only ever present module is the servo-assisted one, the others are available on

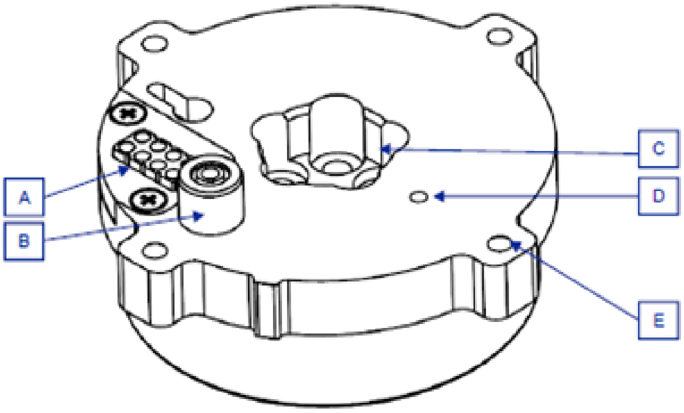


Figure 5.6: **Gripper connector on the arm side**

request. In the 5.7 there is a pincer with a servo assisted module, a suction module and a Cognex AE3 vision system. If a second suction module is inserted instead of the latter, this will be in opposite position to the first one on the clamp.

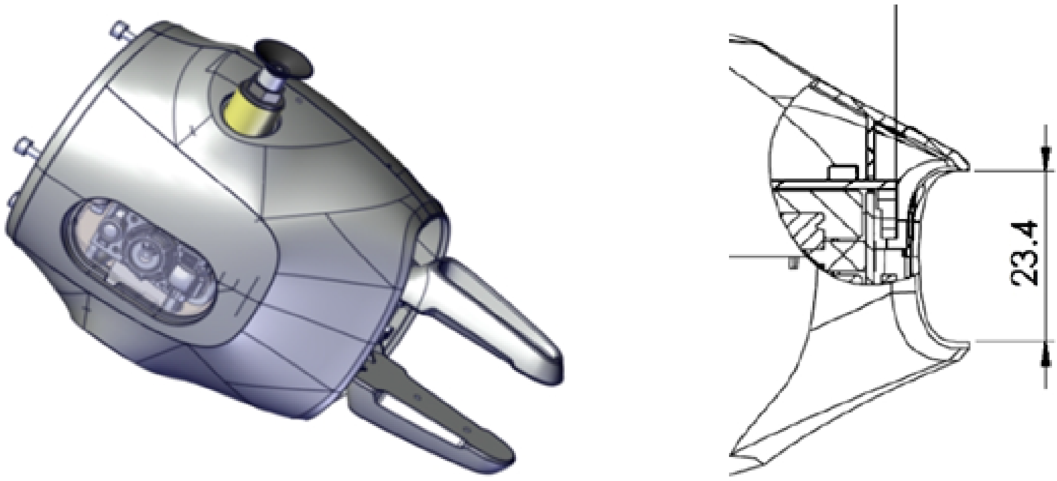


Figure 5.7: **A gripper with vision and servo-assisted module and a Gripper connector on the arm side**

Even if the suction and vision modules are not inserted, the weight of the clamp including the claws is 230 grams, almost half of the payload supplied. If you decide not to use the basic claws, this weight will drop to 215 g, which will be added to the weight of the fingers customized for the case in question. Each of the two claws of the servo-assisted module has an excursion of 25 mm (50 total), with a maximum movement speed of 25 mm/s. The maximum gripping force, which can be actuated for loads taken within 40 mm along the Z axis with respect to the point where I have the housing of the nippers, is equal to 40 N with a force control, not so precise, equal to $\pm$ 3 N. Over 40 mm the gripping force that the YuMi is able to develop decrease. Customized fingers are encouraged, but their design is necessary done in a careful way, to avoid collisions with the external shell of the clamp on the bottom-stroke and to optimize the choice of material, according to the desired stiffness and weight requirements. As can be seen from the figure at the top right, the flange on which the fingers are housed is located further back than the side edge of the outer shell, although it is already set back from the prominence we have upwards and downwards. Considering that the games of the base claw are practically nil, a minimum angle or initial projection towards the outside of the customized claws is enough to cause bumps every time the claws are completely opened. It is very important then that the installation direction and the position of the custom fingers follow that of the original fingers and that the thickness of the flange for fixing is of a thickness suitable for the supplied standard screws.

The YuMi clamp has a minimum working temperature of 5°, which is also compatible with the serving and storage temperature of the beer; the only limitation could occur if it is precisely the external environment in which the system is inserted. Below this temperature at any outdoor trade fairs, you should therefore consider this limit when deciding whether and how to install the system. Leaving the system outdoors it would be possible to overcome, even if rarely here, the maximum temperature expected of 40° C.

5.2 Payload constraints

The payload of the YuMi of 500 grams depends on the static limit that is had on the joint 5 (which gives the rotation of the wrist) and is therefore not circumvented by acting on the software, as the value is limited by the maximum torque that the robot is able to provide. If the load is completely cantilevered with respect to the joint in a vertical position, all its load is cantilevered and tends to rotate the joint itself. A slightly higher load is not completely balanced by the engine even at the maximum of its possibilities and the joint begins an uncontrolled rotation. The control unit would become aware of this situation in which it would no longer be able to carry out its task safely and provide a category 0 stop, in compliance with the UNI EN ISO 13850. This maximum payload value also includes the weight of the clamps, of about 215 grams as indicated above, which added to the weight of the glass (in the case of a Baladin glass is very low, about 8.8 grams) plus the weight of pincers and screws for the stirrup and weight of the beer that can be contained in the moment in which the glass would be full, they would overcome this value altogether. As for the glass, the capacity of 300 ml, considering the average specific weight of a beer of 1030-1040 kg/m^3 [Pes] would correspond to about 310-312 g of content, according to the different ingredients can be used, their concentration and the alcohol content. As you can easily see already the sum of the weights, full glass and of the nippers, even without optional modules and standard or self-made claws, filters, already overruns the limit value set by the manufacturer. In addition, the claws given are already made of plastic with very low weights and have a maximum opening of only 50 mm and a very limited length, as can be seen from the image below and therefore whatever the nippers we use cannot be still subtract weight on this component.

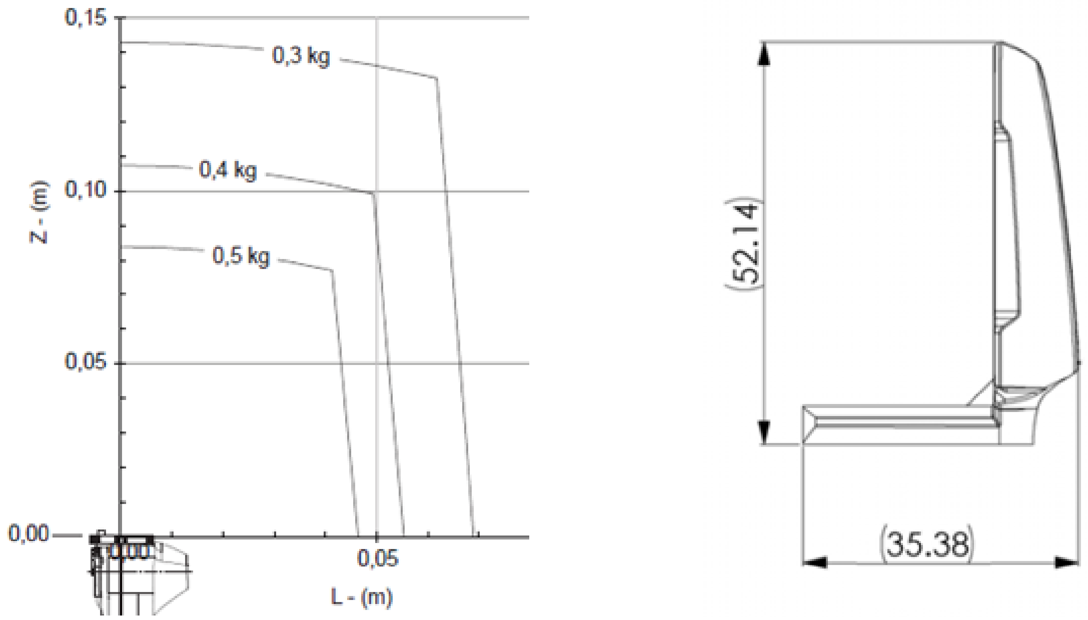


Figure 5.8: **Payload limits on the base of center of gravity distance from the arm end; Standard claws dimensions**

The 5.8 also shows how the payload available drops from the maximum value provided, moving away from the clamp origin. This graph refers to the ABB series gripper housing: considering that it has a length of 84 mm [YuM], it can be seen how the total gripper + load center of gravity must remain inside the gripper so as not to reduce the payload. Even with some imprecision on the pick-up point depending on the various games, as the weight of the plastic cup and the nippers will be higher than that of the pincer, it will lower even more if the payload is available. Some other millimeters of deviation from the situation in the graph will be due to the full plastic cup, which will lower the total load center of gravity with respect to the plane for which the graph above is derived. The total weight of the clamp plus the nippers that we should provide will certainly exceed 230 g, for a weight that will exceed the threshold of 550 g. The only way to use the YuMi in accordance with what was foreseen by ABB, if the problem of running the cycle slightly above the maximum load will be completely unsolvable, would be to decrease the capacity of the glass (which does not already need a medium beer but 300 ml) at only 200 or 250 ml, lowering the weight of the load accordingly. This solution seemed immediately useless and led us to return to other solutions that may be present on the market, to try to find other cobots that better meet our requirements.

Through the customer service, we were told that the load, however much lower than the kilogram, would not have led in any case to the impossibility of movement by the robot. The problem, however, was of a structural nature, linked to the maximum power that can be supplied by the motor of the joint 5, with a much lower power than the other engines. The effect would therefore not only be a reduction in parameters such as precision or repeatability, but the actual inability of the robot to support the glass. Handling a load greater than the maximum weight by weighing the weight completely overhang would have led him to stop the movements. This limit of payable torque that defines the payload, very low and insufficient for our purposes, it was not in fact inserted on joint 5 for a simple case, but for a question related to safety. The other engines have more power on one side because they have naturally to support downstream the weight of the robotic arm that is placed downstream from them, but also because for the first 4 joints the maximum rotation speed is much lower than that of the last 3 (180 °/s against 400) and can still increase summing vectorially the component of the upstream joints; this results in a lower speed in the event of an impact with the operator. In spite of a higher mass it will thus be possible to keep the energy exchanged in the collision within the expected values. The maximum torque, however, is a function (although not in a linear or calculable way) of the homonymous acceleration: by cutting the acceleration it is possible to reduce the torque required and, for small overloads, keep us in safe conditions. It was therefore decided to use this option, remaining outside the payload but considering the weight to be handled in each step of the subsequent development, to avoid that the share of overload greater than necessary. Another way of not having an excessive load on the joint 5 would be to obtain configurations such that the load is distributed on other joints, for all the movements in which the overload is present. In the development of movements we will try to achieve this goal, but given the uncertainties on the real weight and the many variables of the entire kinematic chain, it is not reasonable to analytically consider the thing.

5.3 UR3

After finding the impossibility of the YuMi ABB to be able to carry out our application within its payload and without yet having yet the certainty on how to bypass the problem and if it is possible to do so, we had an extra motivation to carefully observe the possible alternatives available on the market. Among these, already at a brief analysis the main alternative has been identified in the UR3, the smallest robot of the Universal Robotics family of collaborative robots. Here too, the evaluation of collaborativity is subordinated to the fact that a simple collision must not immediately create serious

Figure 5.9: **The UR3 robot**

damage or injuries. Like all other cobots of comparable size to the human one, unlike the YuMi, the UR3 has a single arm, to be mounted on a plane. This means that to get a solution similar to that of the YuMi ABB and in the same way "human-friendly", you should have two robots mounted on a torso, in which trying to accommodate both controllers for a correct space exploitation, which is not simple or less to recreate a very massive torso. Otherwise it will be necessary to move the connections from there and provide a volume below the workplan, which will however subtract space to the rest of the system. This solution has been historically adopted by ABB as the first step in the study of YuMi, as seen in the 5.10.

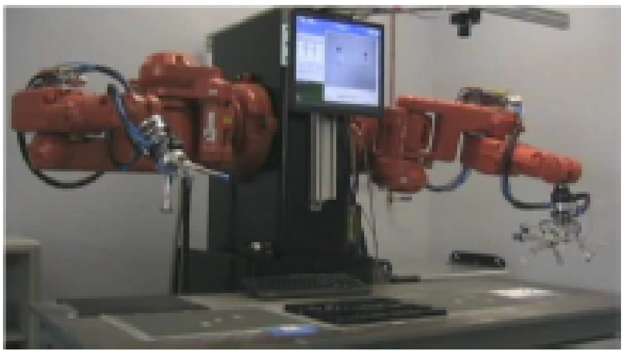


Figure 5.10: **First prototype step in the YuMi development**

Even the torso would have been the object of a structural and design study, with the overall times and costs that would have risen significantly. Obtained afterwards the division of the tasks, then, this would have meant buying a robot just to move the two knobs, which at the appearance could be solved much more economically by sensors. If, however, inserting two robotic arms could still be a choice in the study and prototype phase, by hiring them, it would have been to carefully reconsider during the marketing phase, how to make such a costly and cost-effective system: the amortization time of the initial investment would increase excessively, and we should also optimize the position of the bases to be able to get the desired task-space. This is because the UR3 has been designed to work for coordinates mainly with respect to the plane on which it is fixed, without distinction of direction, while the spaces used in our application will not be symmetrical. Moreover, despite the double controller, the coordination between the two arms will be lower than what was seen for the YuMi: it is not possible, for example, to stop the preventive to avoid contact with the robot structure or the other arm, because the controller of a UR3 does not have information about the space occupied by the other UR3 momentarily, nor does it know the volume occupied by the torso that will have to be built specifically. In case the practical problems in the practice proved too great with the YuMi, this was the only viable way to the state of the art. The critical parameter of the payload is here increased to 3kg [UR3], much greater than the weight expected for our load, which is about 400 g plus the weight of the clamp. Each arm of the UR3 has, at the flange on which the nipper would then be mounted, a task space of 0.5 m, very similar to the one seen previously. As in the case of the YuMi, working near the shoulder is more complicated and here it is also necessary to avoid the cylindrical volume above the base, as it is much more likely to run into a singularity point with consequent increase in speed or stop of the cobot. Other advantages are the possibility of infinite rotation of the last joint, the low weight that would allow a simple movement (9.4 kg per arm, thanks to the wide use of aluminum), the tensions and feed frequencies equal to those of the YuMi and therefore it can be supplied by connecting to a simple electrical outlet. Furthermore, an IP rating of 54, therefore with a high level of protection also against liquids, which probably would not have required an additional expense to cover it with suitable materials to increase this index. Slightly worse but still good for our purposes was also the repeatability value of the movements, of 0.1 mm. The very low weight is mainly due to the fact that unlike the YuMi, the control unit is external to the arm and contains on it and not as a peripheral terminal, also the teach pendant, called PolyScope, through which to program the robot. This control unit can be fixed or supported but must have a free space of at least 50 mm around it for correct ventilation, and must be protected by contacts that do not comply with the IP class 20. From here it is also possible to connect external devices, with a very large number of ports. The main power supply of the control unit, as for the YuMi ABB, is via an IEC port:

If the robot detects an anomaly in the safety system, it starts a category 0 stop. The safety limit can be reached by maximum arm extension (exactly 500 mm), maximum speed limit, but also for exceeding the payload. In the worst case, the reaction time from occurring to detection of an error

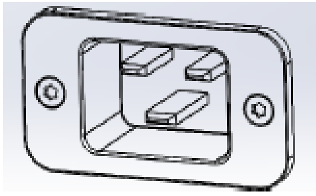


Figure 5.11: **IEC port**

until the robot is shut down and shut down is 1250 ms [UR3], about three times the YuMi ABB limit, partly due to the greater inertia involved that could occur given by the increase in payload. In the event that a safety limit is violated, the program cannot be continued, but the special reset mode is activated, with parameters at reduced speed, to bring the cycle back to its starting point. This parameter would be detrimental to us, even if it occurred only for type 0 stops, while for normal shocks the crash would be of type 1 and then the robot once immobile, if it is no longer present the cause of the arrest would start again along the planned route. In practice this would mean, in case of contact that determines a detection of a payload greater than the allowed, interrupt the cycle and possibly discard the already tapped product. Also the maximum speed at TCP is lower than the previous one, reaching 1 m/s. It should be considered that the combination of expected speeds and masses moved would then allow more violent shocks than for the YuMi, making it less suitable for close collaboration with customers, who are not trained operators. These shocks would also be less amortized as no soft external protections are envisaged, unless the protections are included and also provided since design and development phases. The price of the UR3 is about € 30,000, compared to the 40,000 of the YuMi ABB, but wanting to use two arms the price would naturally double. In addition to this quote then the costs of the trunk on which to support the two arms should be considered (which should also have reasonable capacity to withstand mechanical stresses as the forces of the two UR3s would be discharged on it) and the costs of any houses suitable to better protect the control units leaving room for their ventilation. Furthermore, the robotic arms of the UR3 are not provided with pliers. The same is true in the case of the YuMi if you do not want to use the series nippers: if you want to build the nippers by yourself you need to take into account a lot of factors, from the adaptability to the arm, the weight and the distance of the center of gravity of the load from the point of attachment of the clamp. Another parameter to consider in this case, would be the IP degree: having a low IP rating for the caliper, which is also the most exposed part of the robot, would be a bottleneck for the whole system, with the result of having to protect with appropriate fabrics or other this component to achieve the expected safety. The pliers recommended by Universal Robotics are the 2Finger and 3Finger calipers of Robotiq: considering the use for which they would be destined and the price, which is relatively € 4075-4225 and of € 15,325 [Rob16b], only the caliper is treated here 2Finger as a possible choice. This clamp is available in two versions, 85 and 140 [Rob16a], in which the number represents the maximum opening between the two claws in millimeters; for our use it would probably be enough the most compact version, shown in 5.12.

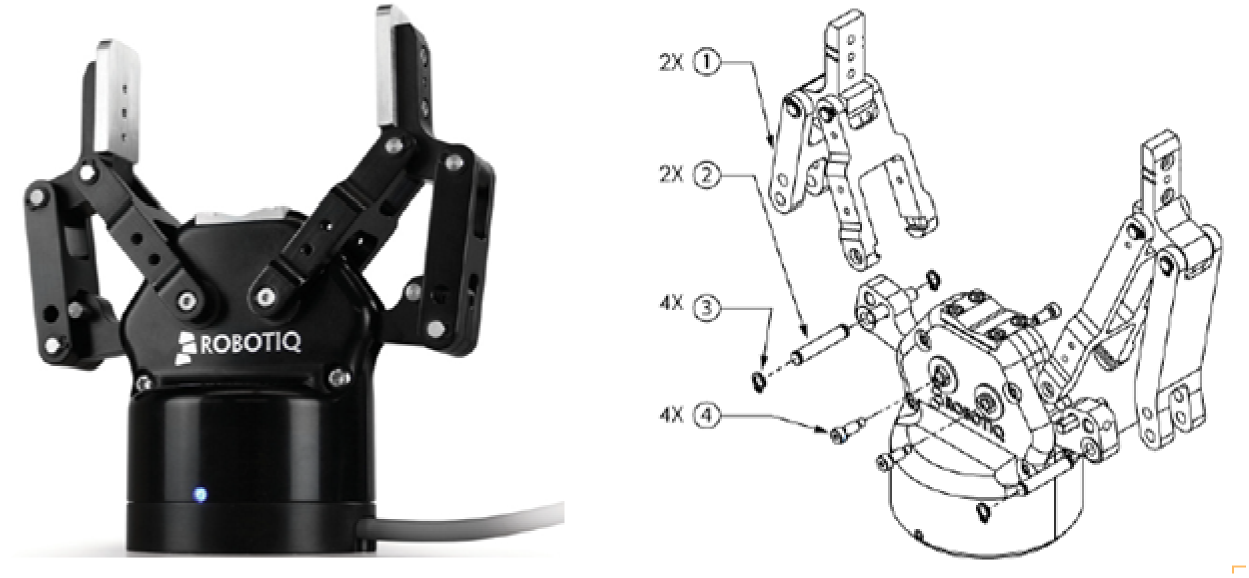


Figure 5.12: **Robotiq 2-Fingers 85, for real and a 3D exploded**

This clamp would be functional to our use, going to reduce the payload of the UR3 of only 850 g [Rob16a], having the ability to grasp objects with a diameter or a grip size between 43 and 85 mm, a maximum high payload so much as to be actually limited by that of the UR3 and a holding force of 50 N, ie two and a half times that of the YuMi. The opening size is controlled directly by the robot's teach pendant and there is also a wide temperature range in which to operate. Compared to the ABB basic clamp, the gripping speed (from 20 to 150 mm/s) rises again, while positioning accuracy drops to 0.4 mm. The clamp has an IP rating rated at 54, although not supplied directly by the manufacturer [IPR] which would be great for our purposes: in any case some form of coating of the robot, even if much cheaper, would have to be made to respond in aesthetic terms, also because of the feeding tube, which would flow out of the arm of the UR3 and would be more subject to tampering or shocks in "critical" directions that could shorten the life of the component.

Following all these considerations, we can state that if it will be possible to solve problems related to payload and protection from external agents, for the current generation of cobot the best solution, in many ways and overall, is that represented by YuMi ABB. The UR3 will be considered momentarily as an alternative, but to be adopted only if it is really possible to develop a system with the chosen robot, at least for the development of the thesis and the prototype: more difficult that this solution can reach even a marketing phase.

Chapter 6

TECHNICAL COMPONENTS AND SOLUTIONS BY BALADIN

After having seen how a normal tapping system is usually constituted, we tried to understand how the components could be chosen and what measures could be implemented to obtain a system that was as standardized and reliable as possible, minimizing unexpected consequences and useless variables. A typical characteristic of beer with respect to the tapping of any liquid is its variability depending on temperature, pressure and other factors. Not having the necessary sector knowledge, we relied on Baladin, the brewery in the area of Carrucese, one of the most important in Italy in the field of craft beer production. Reliability of the system and repeatability of the process are two essential characteristics for our project, with the idea of providing a beer that is of quality, with a good tapping: moreover an industrial beer having huge quantities has characteristics that are more defined and less subject to external agents, which is more difficult to obtain for beers produced in smaller quantities. The first planned change compared to a classic system analyzed above, already starts directly from the place where the beer is stored: the keg.

The Baladin keg [Fus], developed especially for the company, has a capacity of 24 l and has a black outer stem (to protect the product from sunlight) and an internal bag. The pressurized gas is insufflated between the rigid outer casing of the drum and the deformable inner bag: acting on this bag it creates the thrust that is able to push the beer inside towards the plug, emptying the stem gradually. The probability that the inner bag will break is low (it has been reported that in the text experiments of Baladin there were 2 cases out of 1400): in case of breakage, the length of the stem after breaking is a couple of days, after which the product inside is oxidized and lose quality, in contact with the amount of air that is cyclically introduced, even if minimal, to maintain constant pressure. The volumes of liquid and air under pressure being closed, however, will always remain separate from

Figure 6.1: **The Baladin keg, for real and a 3D exploded**

each other, without creating other damages. Without this inconvenience the beer is guaranteed for 30 days from the opening of the stem, optimal duration for our use that can be intermittent. Once exhausted, the barrel can then be disposed of without being returned and is completely recyclable because it is completely made of plastic, including the attachment spring; the keg is in fact made entirely of polyethylene and nylon.

The other great advantage of the stem is from the aesthetic point of view, as unlike the Carlsberg stem I have a stem that can be put on display because always nice to see and also has the attack of a normal bayonet barrel, which the overall dimensions also decrease. Also the price of the stem is not so high (cost about 11 €/u) and amortizable in relation to the number of beers that can be tapped by everyone. Since the gas must not come into contact with the liquid it is not obligatory that it is inert gas, such as carbon dioxide or nitrogen. It is therefore possible to eliminate another characteristic element of the tapping system: the CO_2 cylinder. The alternative is to use a small compressor, which must be carefully soundproofed, to collect air from the atmosphere and inject it directly into the bag from which the beer is to be taken. The great advantage of inserting the compressor instead of CO_2 cylinders is, besides containing the volumes, that of not having another component to be replaced cyclically with the relative maintenance and which can be a source of instability in the product. In fact, if the cylinder starts to run out, before being replaced, it will be able to exert less pressure on the beer and the tap should be opened gradually to regulate the flow, which is not expected for the robot, even more so than the flow regulation tap in the plug will be blocked to prevent external tampering. In the event that the CO_2 is blown directly into the beer then, the ratio between stapled beer and

quantity of foam produced should also be changed, which would then grow, eventually obtaining a glass of quality not acceptable to the customer, due to too much foam and a little beer. In this way, however, I have no change in carbon dioxide contained in beer, the amount of which remains that desired by the brew master. This system allows to maintain the tapped pressure between 2 and 2.5 bar: as in our system the beer will be stored below or at the level of the tapper, with a reduced piping development compared to what normally happens in pubs, I have no problem calculating an overpressure to counter the pressure drop with respect to the spine [Tog]. A higher pressure in the absence of other problems leads to a more compact beer inside the pipes, which therefore produces less foam when it comes out, in addition to that obviously necessary to protect the product. The replacement of the CO_2 cylinder with the compressor will then be a further advantage also from the point of view of the cost cushioning: as the average cost of a CO_2 cylinder is around € 60, the initial cost of the compressor would affect a minimum on the total price of the system then being amortized within a few cylinders with a subsequent savings.
Currently there are six different types of Baladin beer stored in these barrels: this also gives us the possibility to include different types of beer in the system, in order to give the customer the possibility of choice. Depending on the selected beer changes the amount of CO_2 dissolved inside. In a timed system this could mean, unlike what has been foreseen up to now, having to tie the tapping time to the chosen type of beer, to always obtain the same quantity of beer with two potentially different flows. This would not be a big problem, since if by design choice every type of beer will be tied to a different tap, and then from the positions foreseen for the treated cycle one could immediately go back to the beer characteristic of the current cycle.

Always with the goal of limiting maintenance, a big limitation of the classic systems is that of needing an operator that every time, when the stem ends, unscrew the stem from the stem currently in use to insert it on a new one, with interventions that would become very frequent in case of continuous orders (every 80 beers around the stem would be exhausted). The solution is to connect the various beers of the same type to a single conduit, separated from it by a solenoid valve. The various solenoid valves will then be controlled by an exchanger, which switches the solenoid valve by activating a new drum after a certain number of beers or, if possible, linking the change of the stem to the slight pressure drop that will occur on the valve when the beer contained in the stem is about to run out. However, this pressure should decrease in order to be sure that you can pass a predefined threshold value for switching the valve univocally, or to be at least detectable by a pressure sensor that provides the information to make the change, before the beer becomes of unacceptable quality. In this case we could go to use information ”in real time” and not calculated a priori in a more conservative way, with the probable advantage of discarding less product. Also in this regard it would be useful to have the most stable characteristics as possible. Depleturization is a necessary operation to disconnect the stem used. In this regard a special key has been created, compatible with every type of valve on the market [Man]. Due to this further process, another list of operation for the new maintenance procedure must be added:

1. Sanitize the Polykeg® valve interface (max temperature 100°C, max pressure 1.0bar)
2. Connect the valve to the filling head
3. Open the keg valve
4. Pressurize the keg to the filling pressure
5. Open the product fill valve - the product enters the keg
6. Check the amount of product in the container
7. When the keg is full, close the filling valve
8. Close the keg valve
9. Disconnect the keg filling head
10. Rinse and dry the Polykeg® valve interface
11. Put the security seal.

With regard to the sanitizing of the plant, analyzed above, a good advantage of this system is due to the limited development of the pipes between the tap and the plug: this means reducing the amount of beer discarded each time, as well as the amount of solution required. Also useful will be the possibility to connect each stem of the same type of beer to a single pipeline, even if beer from the only active stem will be taken from the exchanger and from the valves. In this way it is possible to avoid kegs too close in time without going to create conditions for which sanitation must be carried out more frequently.

As in most tapping systems, it was decided not to have a refrigerator cool the beer. This refrigerator should have a large size and it is not obvious to find one that is optimized for our solution, which would still become more rigid against future changes. It may be useful to check the temperature of the place where the beer is stored at the previously indicated temperature, to avoid that large temperature

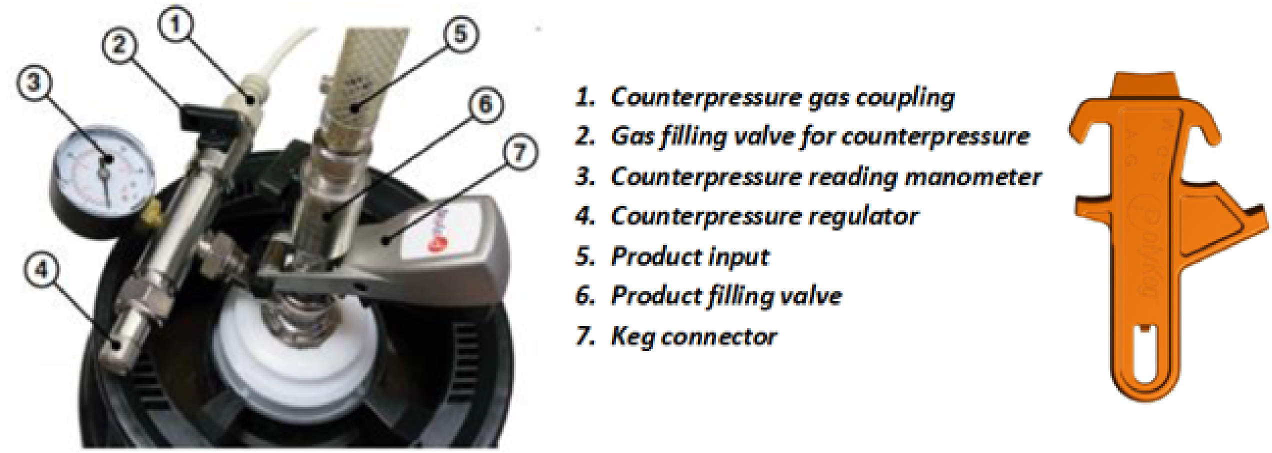


Figure 6.2: **The attachment of the Baladin keg and elements arriving from the plant pipes, with a particular on the Polikeg depleturization tool**

changes, which could occur if the system were placed outdoors, decrease the shelf life of the beer. In any case, the beer, once taken from the stem, will be placed in a special refrigeration system, in which in an insulated tank will be put in contact with a coolant, cooled by a cooler, flowing in two tubes, one in the concordant direction and the other opposite to the various tubes that go towards the plug (one for each type of beer). To increase heat exchange, this liquid is also previously poured into a coil of good thermal conductive material immersed in the cooled water of the tank, considerably increasing the exchange surface. From an energy point of view the costs of this solution are comparable with that of the fridge. A big advantage is given by the fact that beer wastes are reduced because even the one contained in the tubes and up to the column of the stapler is kept at an adequate temperature and is not to be discarded because it is degraded when the plug is reopened.

The last component on which to go to make our choice is the tap of the plug. There are different and with different price ranges, however, contained within about one hundred euro and therefore very little compared to the price of the plant, or the collaborative robot. The classic type has double movement of the tap with respect to the rest position with built-in brake, lockable from the inside, to avoid that in our application someone goes to block and change the position of that brake, making sure that maybe only more foam comes out. The movement towards the front is the classic one with a good output flow; the opposite one has a shorter movement and is used on the end to create the main part of the foam layer that will protect the beer. The second tap analyzed is solid, with a single movement to be carried out, but requires a lot of force on the part of the robot (force that the YuMi almost certainly will not be able to develop, unless the tap is of disproportionate length and difficult to move for the whole necessary arc, on which to apply a force that generates sufficient torque). The robot must open the tap with a good speed, because otherwise the ball valve inside the tap remains

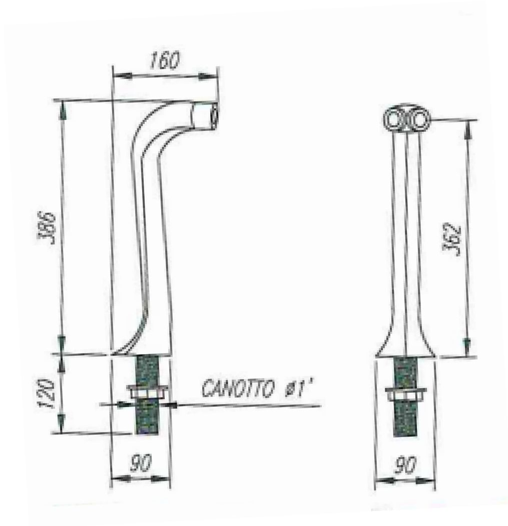


Figure 6.3: **The used tapper column**

partially open for too long time, with a large quantity of foam coming out. This happens because the beer does not completely fill the pipe and incorporates air. Another type is similar but switchable with a much lower force, probably viable by the robot, it seems the most reliable solution. A final solution is still a faucet with aerator on the terminal, that is a grid that breaks the molecules in output, releasing the CO_2 before the fall in the glass, with a similar principle to the drilled disc used for the English stouts.

This last solution was immediately discarded. It is not beautiful to see the filling phase and not even hygienic, as I should press against the plug with the glass, with the tap that comes in contact with the beer just tapped. The beer also, if of different type from the stout for which the tap was designed, would have a very high amount of foam already at the beginning tapped. Due to the too high force required for switching, the second tap presented was also discarded. The classic faucet on its side has a slightly lower force to be moved and a much more limited excursion between rest position and ON. On the other hand, the snap-action tap has only one movement to be controlled, unlike the first in which there is also movement backwards, it allows to easily adjust the flow and quantity of foam acting on the same movement and is much more precise presenting minor games of the competitor. This makes it more responsive to our needs for predictability, reduction of contingencies to obtain a reliable and the most standardized system as possible, with reduced waste. The part of the tap that connects the column to the shorter spine then, also allows you to get a little more compactness from the system. For these reasons, in the first instance it has been chosen as a tap to be inserted on the column of the tap.

This tap has been mounted on the relative column of the beer stapler, chosen among those available not to be too cumbersome but at the same time to be able to comfortably allow the YuMi the movements and the light changes of altitude that the plastic cup will have to undergo. For this reason, the dimensions for the selected column can be seen in the figure above.

Chapter 7

END-EFFECTOR

7.1 Plastic cups

One of the main choices concerned the type of glasses to be used in the station. From the point of view of the quality of the tapped beer, the ideal solution is certainly to use glasses, goblets or glass jars, depending on the type of beer taken. However, given the payload available, less than half of which can be used after subtracting the weight of the pliers and fingers, the glasses, as well as the jugs and the kicks, are too heavy. Furthermore, since the glass is disposable, its price should be amortized by making it pay to the customer. Unlike what is easy to think, this may not prove to be a big deal: in the case of the cocktail robot on Anthem of the Seas in the search for market solutions it was seen how the youtuber who turned the video paid his cocktail more than 14 $ [UnO]; however, the dynamics could be different here and the volume contraction is too important. In addition, the glasses would carry a considerable amount of other problems, storage volumes, possible breakages during transport or even during the cycle, which is likely in the long term with unwanted contacts to which the YuMi will be subjected. Of course, security problems that could arise immediately and for small fragments left on the floor are not eligible. Again, a rinse glasses, vegetable cleaners and an additional water tank would be needed, only to list the most relevant.

Another solution would be to use, if they are reasonably priced, cups of plastic instead of glasses: ideal for some types of beer such as Belgian, with a capacity that would reduce the amount of beer tapped, would have however, storage problems are insurmountable, as they are not stackable. Finally the mug would be nice to see and you could teach the robot the final movement to rotate the handle to the customer after resting the full glass at the point of delivery, but in addition to the greater weight of the mug would also have a removal from the nipper of the center of gravity load, which would make the payload situation even less sustainable. In the end, these solutions were also rejected for the same problems of cost and volumes in the storage already listed above, defining as a glass the classic disposable in plastic material such as, for example, polycarbonate.

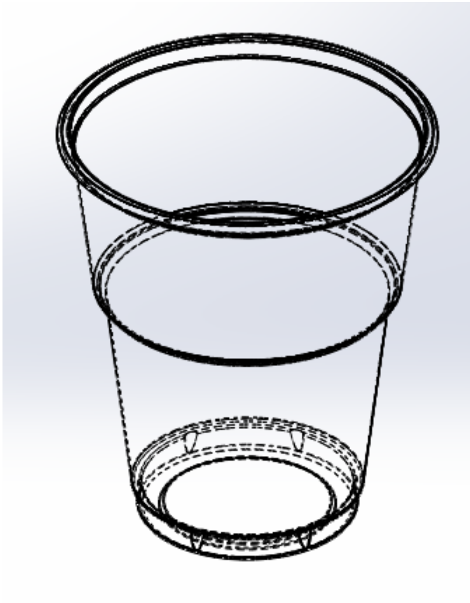


Figure 7.1: **3D reconstruction of the Baladin plastic cup**

For its characteristics and ease of retrieval, the final choice break down on glasses supplied by Baladin, with a capacity of 300 ml each. These glasses offer advantages from the point of view of pollution, since they consist entirely of biodegradable material, and above all mechanical properties, which significantly reduce the number of breakages even if crushed repeatedly, as could be due to collisions with the customer or, even if not wanted, with the forces that could be developed by the gripper. For our purposes excellent is the weight of only 8.79350 g (measured with a precision balance), almost negligible compared to other weights involved. If you want to avoid the edges as a point of capture by the end-effector, the most resistant point is next to the change of taper and diameter that is in the middle of the glass, where there is more material.

7.2 End-effector choice

In this first part of the project, it is very important to choose the type of end-effector to use, in order to develop the system, both as regards the components above and below the plan, as a consequence. The choice is however restricted to the two main types of end-effector, also present in the cycles seen in the previous observation of similar solutions expected on the market: suction cups or pincers, each with its advantages and its disadvantages. Among the advantages of the gripper are certainly to list the greater aesthetic similarity and handling in relation to a human hand, the advantage, if electrical, not to have to provide compressors for the power that take up further volume under the counter. Moreover, if the resulting moments are manageable by the robot, they have a grip of the glass much closer to the center of gravity of the same and therefore fewer moments that would tend to overturn the glass with respect to the point of grip once filled. On the other hand, the suction cups occupy a smaller volume of the pincers during the movement of the glass and above all have a much simpler junction from the glass: it is enough to reverse the air flow and have the so-called "blowing". Depositing and moving back a few mm I practically averted the possibility of touching the glass again as I move away from it. The fingers of a hand or simply the claws need instead a junction of much greater length, as well as the approach to the glasses in grip; this to avoid collisions between the claws and the glass. It should be noted, however, that the encumbrance of the nippers can also prove to be an advantage, in particular conditions: in fact, bumping into most of the possible obstacles first, they suffer the impact and make the collaborative robot detect it and stop, protecting at the same time the glass that is lost by the end-effector with more difficulty. In special cases, the condition may also occur for which the nippers lose momentarily the grip of the glass, but they manage to recover it in an almost suitable way through the frictions that are formed again between them and the glass that is slipping.

The end-effector choice is not completely disconnected from the collaborative robot to which it is combined. Each collaborative robot has its own grippers and/or series of suction cups, with its own capacities and associated volumes, which may be more or less suitable for our application. If you do not want to use the series clamps, in addition to the additional cost, consider the particular position of the terminals provided for the various power supplies and the various signals, different for each manufacturer of collaborative robots and nippers. The clamps may have been developed also by companies outside the one that developed the cobot, but even if they are not the standard elements, they are developed for a specific manufacturer. If the grippers considered to be optimal are not in this category, a plate must be provided to adapt the various power supplies and the various signals from the arm to the nipper, increasing time, costs and volumes. If you have different types of feed between one clamp and another, you will also need to insert elements to convert the signal from one type to another, such as integrated chips, or micro-valves to give the signal to the nipples. Recalling that the desired IP for our application is 54 and that except in cases where it is respected directly from the product we should also protect this additional element, we see as a whole a solution that provides pliers or suction cups, and robots not developed to be combinable with each other is bad to the whole system. Similarly it is unthinkable to build a new fan, provide for its power and having to isolate it to reach the necessary IP from scratch.

As for the gripping systems provided as standard for the YuMi, it was very easy to choose how to proceed, if no external elements are inserted with respect to the nipper, also presents in case you want to use only the suction module [YuM] while the servo-assisted module can be used with some measures and modifications to the nippers, this does not apply to the intake module, which has the ability to lift a load of only 150 g [YuM] and therefore roughly a quarter what is necessary for us. The sucker then, is in a very uncomfortable position for what concerns the movements that we would like to perform: in each of these, in fact should be considered as total volume with which do not go to bump or for which to provide the necessary space glass, which are next to each other.

Figure 7.2: **YuMi ABB gripper with suction and servo-assisted modules**

For the capacity of the cobot and the capacity that the robot must have to bring the product closer to the customer, as well as in anticipation of acceptable cycle times, it is not possible to use both pliers to move the full glass in the last operations of the cycle. The glasses will then be moved through the servo-assisted module.

7.3 Finger development

Having chosen the servo module, however, we immediately noticed how the plastic claws supplied did not correspond to our needs; the same manual of IRB 14000 recommends, always paying attention to the use of materials to avoid reducing the payload, to use claws suitable for the specific application [YuM]. The claws supplied as standard by ABB are not suitable for gripping plastic cups, primarily due to their stroke, which is not closed and can reach a maximum of 50 mm. This value, however, is not sufficient for us, given that the glass supplied by Baladin, in its most resistant point, that is at the point where the change of taper is made, is about 78 mm; the maximum opening of the claw of the right gripper must be greater than the width of the plastic cups indicated above between the two gripping areas, to guarantee a minimum of play. The stroke is not naturally variable as it is due to the internal mechanisms of the ABB claw, so in order to avoid changing the claw with the disadvantages listed above, the only solution is to increase the opening achievable by acting on the claws that we will design. It will be necessary to ensure that on these claws it is not necessary to reach an opening lower than the maximum -50 mm. Thanks to the ABB clamp, the claws do not have a typical ON/OFF configuration, but a controller is able to clamp objects of different diameters. It is therefore not necessary to find a specific measurement in a completely open or closed configuration so as not to find excessive forces on the object to be moved. This gives more degrees of freedom both from the side of the plastic cups, in which a minimum closure may be enough to grasp the cup without deforming it excessively, either on the side of the dispenser, because the two test knobs may have slightly different diameters. This means that I do not have the risk of breaking the plastic cup every time and, as far as the other arm is concerned, I can grasp the knobs of the two taps, even if they have slightly different dimensions. The other feature rather at the limit was given by the length of the fingers, visible in the figure 20. Their length is only 52.14 mm, which in a small part cannot be used due to the thickness of the part where the bracket is applied to the servo-assisted module and partly because, as already highlighted, the external part of the clamp case ends in position more advanced than the point where the claws are fixed and then the edge of the structure would hit the glass first.

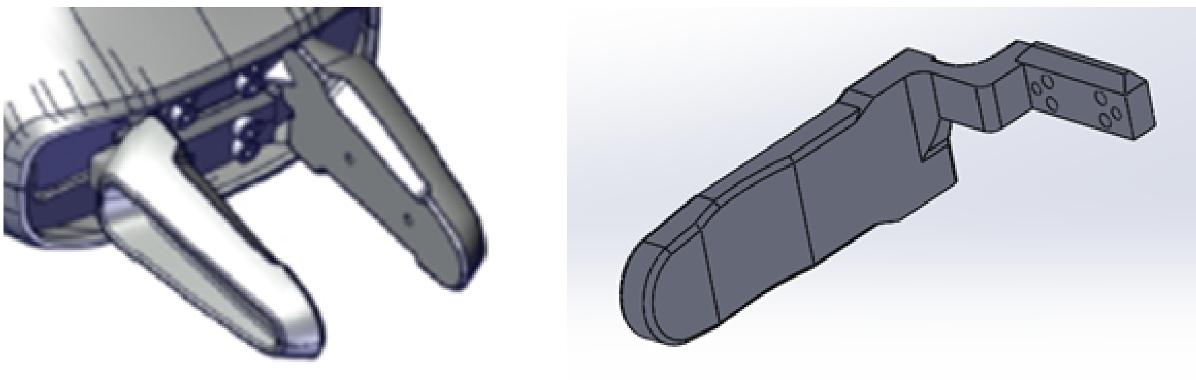


Figure 7.3: **A clamping YuMi detail and the first step of the thumb-claw**

In the 7.3 you can see a detail of the standard claws clamped to the nipper and the first step of the nipper designed for our specific application: the only part to remain identical to itself was the one related to the clamping. From there he advanced to avoid the outer part of the shell of the caliper, before re-leaning to reach the maximum opening needed to grasp the plastic cups. As you can easily see, the length of the claws has increased considerably compared to the standard ones, now of about

65 mm. The area "dedicated" to the cavity of the plastic cup then a concavity of radius similar to that of the glass in the point of grip, to invite the plastic cup itself to end up in the correct spot, compensating for minimal plays and creating thanks to the compression in grip, an area of slightly wider contact on which to transmit the frictional forces and reduce the possibility of involuntary loss of the plastic cups before the release.

The two claws of a single hand of different width have been provided to give more similarity to a human hand, a width that is greater than the standard claw. A claw reproduces the thumb (shown in the 7.4), the second the four opposite fingers. If, as shown in the figure, the area through which the claw is connected to the clamping base is not symmetrical, this will result in the birth of a "claw thumb" and a "claw finger" different for the right hand and the left hand. This occurs due to the taper of the plastic cup, which causes the socket to take place near the upper edge of the claw. From the idea of differentiating the two claws by width, we came to the development of claws that reproduced as much as possible, both in shape and size, a human hand.

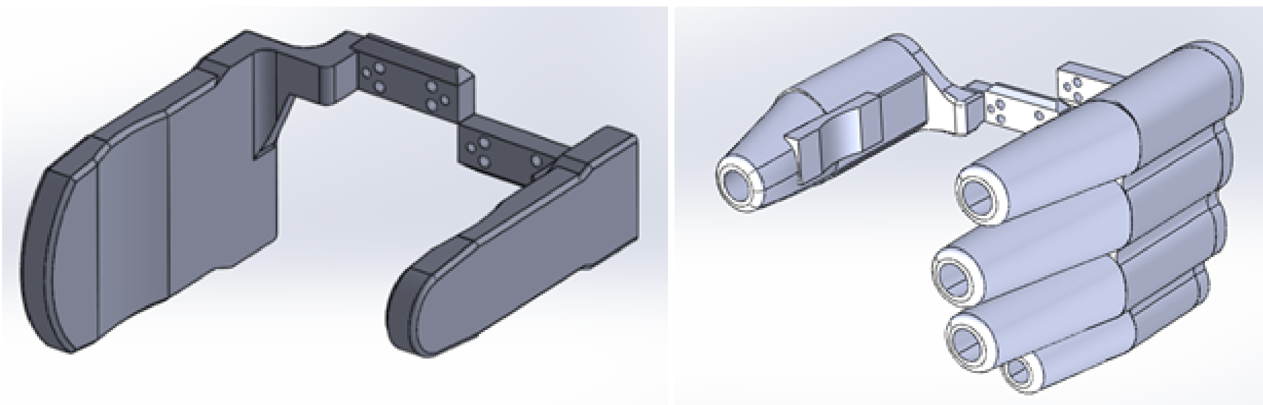


Figure 7.4: **First and final step of the 3D plastic hands.**

Once again the base where the clamping is carried out has been maintained, as well as the advance to avoid the external shell of the finger increasing the maximum opening. The development of the rest of the fingers is different, progressed in every phase with a great attention to the containment of the weights of the components.

Starting from the progress that has become necessary, it must be limited to a value very close to the strictly necessary, because it has the disadvantage of removing the center of gravity of the object taken and, to a lesser extent, also of the nipper itself. In this way the load capacity of the robot that has already been slightly exceeded [YuM] is reduced even further (and, if you choose to use the weight sensor of the ABB clamp, you must check if and how the displacement of the body's center of gravity influences the reading of the weight of the sensor itself). The disadvantage will be minimized by inserting the gripping area in such a way that the paper cup, once taken, ends up minimally even behind this second part of the base, inside the space that remains between the two open claws:

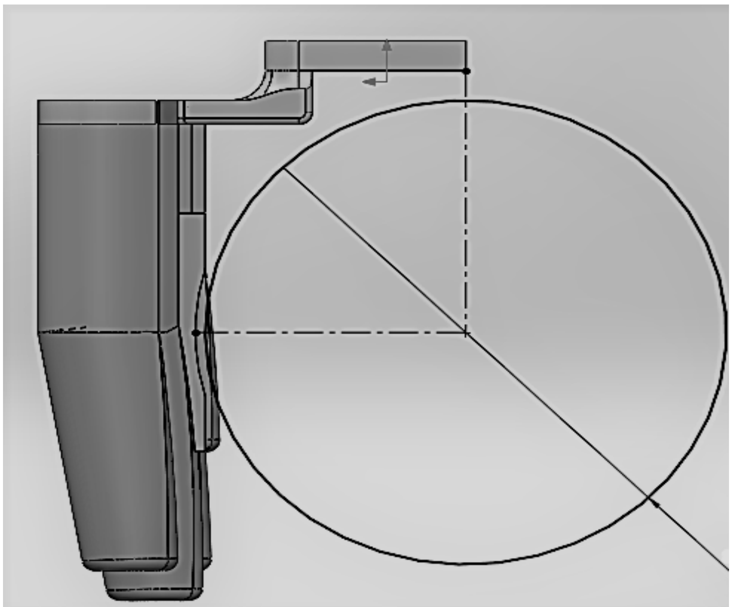


Figure 7.5: **Optimization of the gripping area to maintain the load near the gripper**

From the image above you can also see different characteristics of the developed fingers. The main one is the fact that each one has been made with two different components: the base and the real fingers. The base will be obtained by contouring (which is nothing more than a peripheral side milling operation with a special tool) on aluminum to give good mechanical properties and certainty to withstand mechanical stress, containing the weight of the piece. The increase in weight is a drawback that must be met, in addition to the fact that aluminum, an excellent conductor of heat, will heat due to the heat coming from the engine inside the nipper. The base will be able to transmit part of this heat to beer, which is not desired and will also be limited by a coating of the component. The fingers instead with material suitable for 3D printer (Accura Xtreme White) for stereolithography (technique that allows to realize single three-dimensional objects starting directly from digital data processed by a CAD/CAM software) and were realized through the specialized company Proto Labs. Among the various characteristics of the material, we hereby remark the density, equal to 1.18 g/cm^3 [Acc], therefore much less than metals, given that aluminum, considered to be a typical base for light alloys, has a density of 2.71 g/cm^3. This solution has defined the 3D printer as a method for their construction, which works by layers until the final piece is produced by adding materials, unlike other techniques where material is subtracted. In this way, creating cavities inside the pieces did not reveal a problem in terms of containing the weights, the various fingers were emptied leaving only an outer shell, apart from a limited length at the base of the fingers that allows the grip of the screws for anchoring to the aluminum base. To make the hand as similar as possible to the human one but always with a view to containing the weights, measures comparable with the dimensions of a human hand given by anthropometric measurements [Ant] were used, paying attention to keep on size anyway a little lower than the average ones. The different conformation between nipper-thumb and the opposite claw has meant that two different solutions for the thumb and the block of the other fingers are used for the connection with the respective bases. The thumb has a smaller footprint, but a single screw may not guarantee that, even if the effort is not too high, there will be a rotation between the parts that would not be tolerated. To avoid this, a guide pin has also been inserted into the base with the respective female formed in the thumb. As for the other fingers, however, the problem of a too small area does not exist and the greater encumbrance, if on the one hand increases the weight of the component and can produce greater moments, also makes it easy to place two different screws for connection with the base. The screws used for this threaded connection are M4, since their small diameter also allows them to be inserted into the plastic part between two adjacent fingers, being able to withstand greater efforts on the nipper which will inevitably be heavier.

Other changes have been made to the supplied claw: a thickness has been inserted at the point where contact between the claw and the side surface of the glass will occur, and the angulation of the second phalanxes has been chosen in such a way as to do not go to exceed this thickness. In order to have light-weighting claws, it is necessary to have a base of the fingers that widens the necessary minimum, considering also a minimum play, to avoid the glass in the approach phase. This distance must be guaranteed at every point between the fingertips and the gripping area, and fingers closed at the ends to simulate a human grip would have rendered all the previous speech useless. These thicknesses, inserted on the thumb and on the middle with respect to the opposite claw, are not symmetrical with respect to the finger to allow it to have the gripping area facing in height between the two opposite fingers, considering that the two bases are located at different height. Moreover, on these areas a cylindrical recess of the same diameter of the glass was reproduced to facilitate the grip and obtain a larger area on which there will be mutual contact, at a sufficient distance to counterbalance the small games but anyway as little as possible in order not to move further from the center of gravity from the housing of the nipper. A rubber insert can then be inserted on the housings to increase the friction with the glass and the contact surface in the grip, or even a glove, which would make everything more aesthetically pleasing. Grasping the plastic cup with the middle could however cause contacts with the index, given the taper of the cup itself. For this reason and to better simulate a human grip, the fingers have been placed out of phase to give the impression of following the plastic cup, even if in reality there is no contact with other fingers that are not those on which the thickness above is inserted.

From all these considerations, it is derived that in a completely closed configuration of the clamp that must grasp the glass must maintain an opening of 32 mm. The same opening, considering the possible stroke, does not seem compatible with the left claw: 32 mm is in fact greater than the maximum diameter of the handles on the stapler, unless you modify it specifically. This question will need to be answered later.

Chapter 8

CONFORMATION OF THE PLAN

8.1 YuMi positioning and orientation on the plane

All the choices we have just considered have not naturally been thought of in a first phase, but have followed one another as the basic system developed, to solve the various problems and to make the most of the characteristics of the YuMi. As soon as the robot on which to develop the whole station was chosen, the first station idea was the one shown in the 8.1. This station, simulated on a program called RobotStudio that will be analyzed in the next chapter, was the first step to begin to realize effectively the various ideas that had accumulated after the analysis phase of the various alternatives on the market and the choice of the collaborative robot to use.

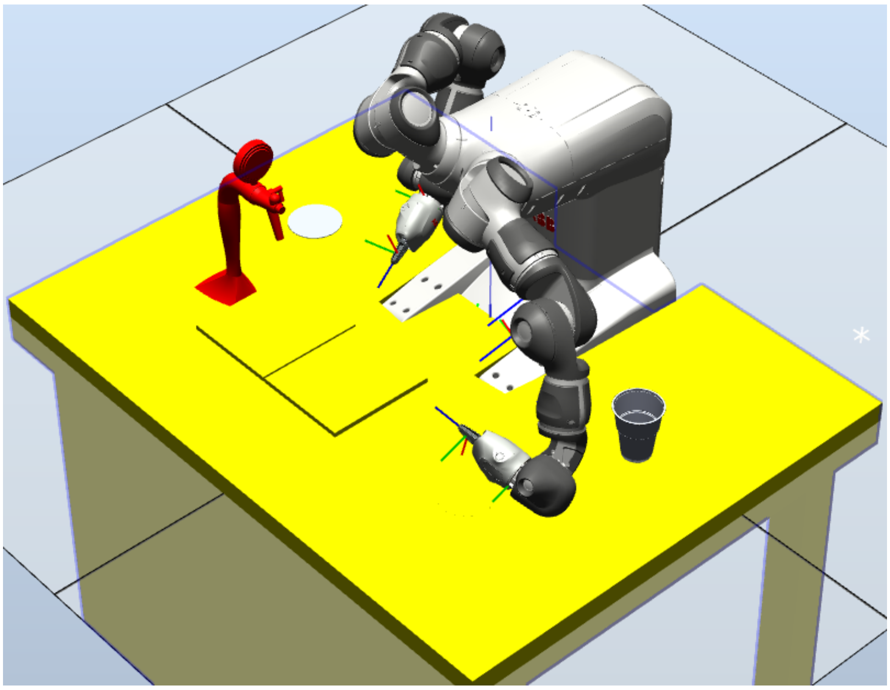


Figure 8.1: **Fist hypothesis of the station**

Having the possibility to analyze the various alternatives, pursuing the fundamental characteristics to which the station must respond (Reliability and repetitiveness, compact dimensions, ease and low impact of maintenance, compliance with the IP degree required), leads to visible and immediate feedbacks. This leads also to detect potential problems more quickly in the system development, solving them also in an analytical way, in a first phase, with great savings in terms of time and money each time a new change is made. Let's now look at this first draft of the station: already only with respect to the choices listed above can you notice many differences. Firstly, the plane on which the various elements are distributed has a dimension equal to 100x130 cm and therefore does not respect the standard dimensions of the pallets defined by the EC directive n.29/2000. In addition to the Baladin plastic cup, the coaster can also be seen, then eliminated from the system on the opposite side. The most important parameter that was evaluated in the realization of this first station design was to identify, with good approximation, the positioning of the robot in height with respect to the plane.

As we can see from the figure below, the robot has the two offshoots with which it is fixed to the table, recessed with respect to the worktop. The mutual positions between the plane and the robot were defined to optimize the area of the plane on which the YuMi would be able to operate. The raising of the floor has been designed to maximize the useful working area of the robot just above it, moving the final delivery locations in a position easily reachable by the customer. This discourse was decided at a very unripe point of the project as a whole and some quotas have been varied in development. However, this observation allowed us to put ourselves in the best initial conditions to proceed with the design of the station. The YuMi owns 7 dof per arm, which gives the robot the ability to move a human arm and considerable dexterity in the various points within the task-space, but the ability to perform movements depends on the configuration and orientation of the end-effector with which you will want to reach the points themselves, any points of singularity present that increase significantly in quantity due to the dof more and will be treated later. When the arms are fully extended, the robot has a symmetrical task-space on both sides and, above all in the area in front of it, roughly spherical, represented on the lateral plane in the 8.2:
As already mentioned, the robot is normally mounted cantilever by means of the screws present in the two offshoots of the base. The plane that is defined at this height, however, is very limited and increases considerably by lowering the robot by a few centimeters. The criterion of choice was then defined, according to the basic rules of trigonometry. The arm, completely stretched with an angle of 45° downwards, without the clamp as in the drawing above, would have defined the height of the point where the plastic cup was taken should have been placed on the plane, so it would have been exactly 70 mm above its. This is to achieve the points in the plane with a minimum dexterity, such

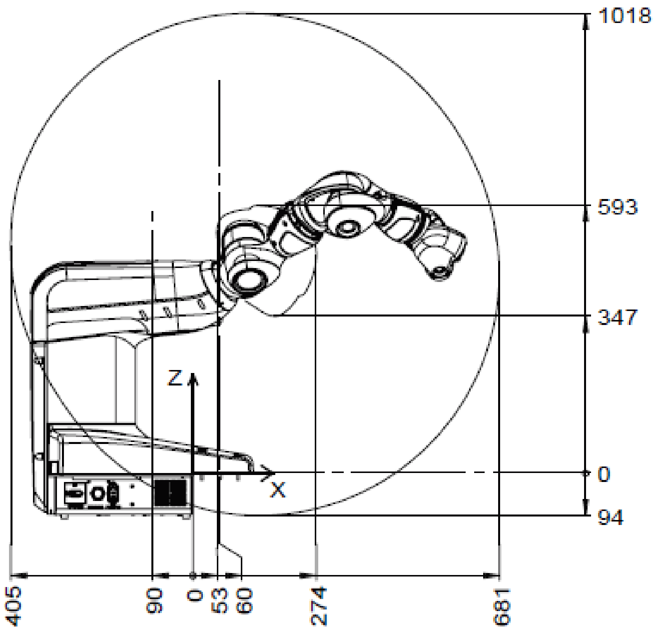


Figure 8.2: **Lateral view of the YuMi's task-space**

as, to hold the glass horizontally. Given the right arm completely extended, if the end of this arm ends 70 mm above the floor I describe an angle between it and the -Z axis: the height of the arm with respect to this point is given by the arm length for the corner cosine described, the maximum distance on the plane along the axis of the X on which the YuMi can operate from the same length for the sine of the described angle. Known the characteristics of the two trigonometric functions, we know that for every millimeter of upward displacement, with an angle inferior to 45° I would have had an increase towards the positive part of the axis of the X greater than a millimeter on the new plan to be defined; after this point, of course, the situation was reversed and therefore the advantage was not considered justified. This has led to a rise in the plan where you start thinking about placing the various elements of the system equal to 43 mm.

Now let's look at the tapper in 8.1. The column of the beer stapler, designed on CAD starting from a model in the Celli Group catalog, has dimensions and tap knob different from those that we were then given, but excellent for regaining confidence with the program and starting to get an idea of the dimensions of the component and how wide the relative movements of the knobs are. Initially it was rotated 90° with respect to the robot and on one side to make the YuMi more visible and the column would not be an obstacle in the handling phase towards the user of the full glass. After choosing to serve two different types of beer, however, the stapler was to be replaced and the type of columns compatible with the need for compactness required (T or classic multi-way) have aligned knobs, which would be difficult to move from an arm of the YuMi. The first knob would have been very close to the robot's shoulder, where, as can be seen from the previous figure, there is an unreachable zone: the second one would have had the first knob in rest position as an obstacle. On the other hand, inserting more taps (one for each type of beer) made it difficult to find places where they could all be reached. The displacement of the dispenser caused the working table to rotate, as the space on the shorter side would no longer be sufficient. This is because placing the tap in front of the YuMi in handling it, the arm would have had a very contracted position and close to the shoulder making the various maneuvers more problematic, even impossible without removing the plug-drip collection. The robot has moved back as far as possible on the plane, allocating any space obtained to the customer for advertising, graphic effects, or simply to avoid too close contact between the customer and the system, with a greater probability of unwanted interference between them.

In the first phase of using RobotStudio it was also seen how big movements from one side to the other of the YuMi are generally poorly tolerated, as a consequence of the 7 degrees of freedom that each arm possesses. The 7 dof gives to the robot the ability to move as an human arm and considerable dexterity in the various points inside the task-space, but also increase the singularity points, which in the case of large lateral displacements often occur for alignment between joints 4 and 6, as will be explained later. To avoid them, complex and unwanted movements may be necessary and therefore the work plan has been further modified over time. To reduce these lateral displacements, the robot was rotated to the right so that it was not perfectly oriented in front of the client, moving it at the same time on the plane towards the left side. In this way, space has been freed on the right and a sort of division of tasks has been decided between the two arms: the left hand will only handle the knobs of the two taps, while the movements related to the picking and delivery of the plastic cup will go to the right one. Very important points to select carefully were those of the tap, because the right arm had to reach the points under the tap and the left knob just above. For the left arm to have the origin of the first joint very far from the table is not a problem, in fact the arms of the robot can very well go beyond the projection of this table during the movements. The size of the table derives only from specifications dictated by the simplicity of transport and movement of the table to the non-active system, and when the robot is stationary, before transport, the left arm protrudes from the desired volume and can easily be completely repositioned on the table's impression. To exploit the available space as much as possible, the right angle of the rear side of the robot has been kept flush with the back side of the table, while the vertex on the left in contact with the left edge of the table. Despite this expedient, the left side of the robot was in a more advanced position than previously, with the result of having to slightly move the stator column and the drip tray towards the customer. Rotating the robot at an excessive angle would have been counterproductive since it would mean to reduce the ”corridor” of space obtained on the right side of the cobot, where glasses could also be inserted for coordinates along the X axis slightly negative. It would also have led to a position where the robot would have been little customer oriented, not making it look like something to interact with, and would limit the ability of the robot's right arm to operate in areas closer to the client, since rotation in a clockwise direction retracts the point at which the origin of this arm falls. In order not to reduce these benefits the angle of rotation between the robot and the floor has been limited to 20°: in this way it is possible to increase the space by losing only 6% of the progress towards the customer as regards the final positions of delivery (value obtained as $1 - cos(20°)$, assuming as spherical the task-space of the YuMi for non-excessive frontal angle variations).

In the 8.3 you can see the new position where the cobot will be inserted, fixed through the screws on a plane at a lower level than the worktop. This plane will faithfully follow the edge of the YuMi's external ring to make it as smooth as possible and aesthetically pleasing. On the left side of the robot you can see the drip tray with the corresponding hole to connect the system to the column of the beer stapler. On the right, you can see drafts of withdrawal posts more back on the corridor obtained by moving the robot, and potential delivery stations, more advanced instead towards the side from which the customers will interact, aligned with the Y axis of the YuMi's reference system. The division of tasks between the two arms also led to another advantage. The left arm, having to deal only with the knobs, no longer needs to have a maximum opening suitable for the plastic cup handling. The opening of the aluminum bases on the left was therefore reduced compared to those on the right, but without eliminating it, to avoid an asymmetry too evident between the two hands. This containment of the dimensions of the thumb and finger bases on the left has also made it possible to recover a portion of the payload, thus increasing the torque that can be available to handle the knobs.
The robot must then be supported and on the base, hidden from the floor, there are several ventilation openings for the disposal of the heat produced by the engines. Spaces have been provided under the worktop between the robot and the wall of the structure that supports it, naturally still larger on the side where in addition to the ventilation function must also be guaranteed the power supply with the various cables. In the event that the guaranteed spaces are not sufficient, you can then insert them into the wall of the grids to better cool the system. The structure below the robot is not strictly necessary, but it has also been designed to isolate the system components hidden under the plane from any leaks that may occur. If this precaution is useless because these components will already be sufficiently protected from liquids for their own IP degree or for differently displaced protections in

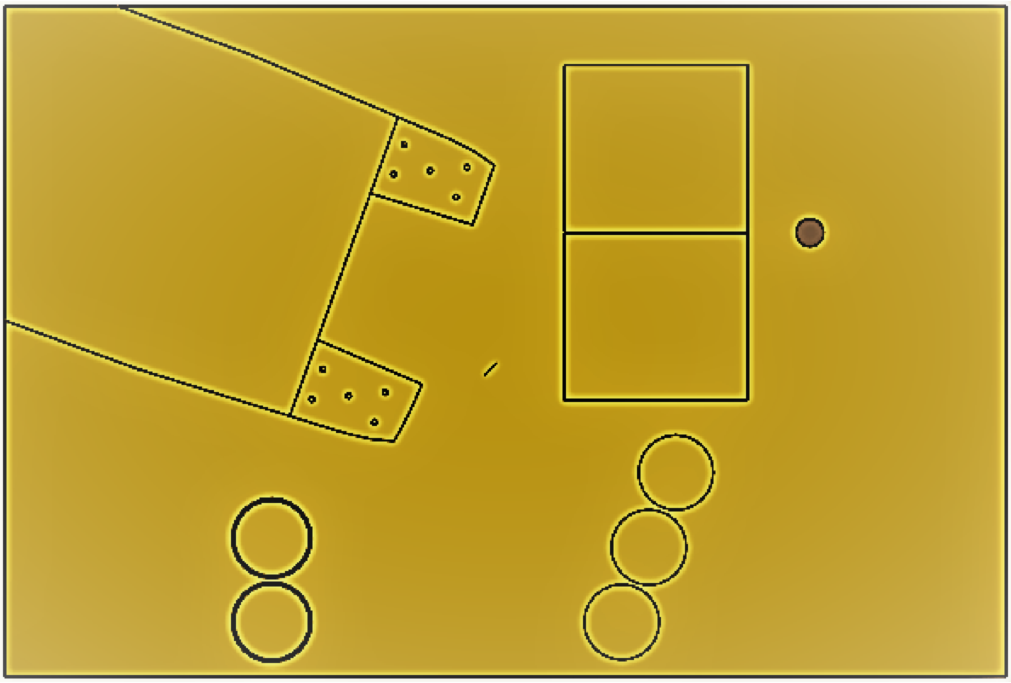


Figure 8.3: **Fig.40 Rotation of the YuMi location on the bench**

space, this plane can then be eliminated by recovering a small portion of volume and facilitating the disposal of the heat produced by the YuMi.

8.2 Choice of the hinge point of the cycles

As you can see from the previous image, in addition to the YuMi to the drip tray and the tapper, there are five other zones, three more advanced to the customer, the other two more backward. The first three represent all delivery stations: it would not have been admissible, in fact, that if the delivery point is full because the previous customer has not yet taken the beer, that the system should stop without being able to do its job. The number of stations chosen on one side eliminates this problem, on the other it seems to be compatible with the space available on the right side of the drip tray. In fact, keep a minimum distance from the latter to prevent the fingers from colliding with it while depositing the plastic cup in the leftmost position, unless the height on which the cup is placed is greater than that of the drip tray itself. The three stations are aligned with each other and not on several rows, because they must all be easily reached by the customer: their position ideally connects the work area of the YuMi with the space in which the customer works even without wanting to voluntarily interfere with the robot. They were then inserted along the same X coordinate of the YuMi and then also rotated by 20° with respect to the axes of the workbench. This coordinate was calculated keeping a minimum conservative with respect to the coordinate resulting from the 45° arm in positioning the robot in height, to be sure to reach the given points. It is probable that this X value can then be increased going forward in the development, above all for the share deriving from the distance between the center of gravity of the plastic cup and the point where the pliers are housed, that is the sum of the 84 mm of the clamps length [?] and the distance of the center of the glass from the clamping points of the claws.

The two rearmost positions represented a draft of plastic cups picking points. These points will still be modified and will be discussed in a later section of the chapter, but it is interesting to note how they are positioned rather far behind the delivery plans. Having a lot of space between the two areas has the double advantage of making the most of the corridor on the right and having a large central space with respect to the right arm, where the movements can be carried out even at low altitudes, the first to return after release of the cup at the point of delivery, without causing bumps.

Always from considerations on the situations that could have been created in the succession of the various cycles, a new question arose. The styles of tapping chosen by us are both made up of several strokes, among which a waiting time is needed, at least on the order of minutes [HEIc], [HEIb]. To amortize the various times, you can think of starting a new cycle while the plastic cup is waiting. The previous cup, however, if resting on the drip tray, most likely would be an obstacle to the new once it arrives in this area. In fact, the height of the drip tray is not so high and if the beer is of the same type as the previous one, it would hit the old one. Other bumps could probably arise even if the new plastic cup was directed to the left tap, with the cup of the previous cycle under the right tap, which would reduce the volume in which the new plastic cup and the claw could pass to the destination. Therefore, two new stations have been inserted, called Wait stations, where to place the glass between one shot and the other, waiting for the time necessary to lower the level of the foam layer. These positions must be in an area accessible from the right arm, without creating contacts with the space necessary for the arm to carry out the movements of the other phases of the other cycles and at a reciprocal distance such as to avoid contact with the gripper or fingers in the case where one station is filled, with the other one already occupied. It would also be preferable to identify an area on one side not too close to contacts with customers, on the other side as close as possible to the drip tray because anyway the movements from the latter to the new Wait positions and the return create the conditions for time optimization on more cycles, but they also have a duration, and this duration should not be longer than necessary. During the various stages of development these stations have undergone many shifts, as they were the only ones not strictly necessary and therefore dependent on positions of the other components and in particular from the final positions, which require great space behind them in order to be able to re-arm the arm at the end of the cycle. However, with time passing, it was easier to move the knobs on the left arm and this produced a small but steady removal of the drip tray from the base of the YuMi. The Wait workstation area was then moved to the area created between the two components.

8.3 Avoided components

Given the characteristics of simplicity and reliability required by the system, several choices were made starting from the elimination of some elements that would have complicated the system excessively. We maintain the initial idea of leaving the customer the choice of both as a type of beer, as a typology of tapped. Maintaining only one type of beer, without the possibility of choice for the customer, we will deal with a system that would have provided (even if in a better way) the same functionalities of the system implemented in the videos also by an industrial robot or from a vending machine. It is equally true that increasing the number of beers available drastically decreases the number of beers available for each type, making the intervention of man extremely frequent unless it increases enormously the space dedicated to the kegs. If you ordered the same type of beer, it would run out very quickly because only a small fraction of the stems contains it: it was therefore decided to limit itself to two different types of beer, then going to analyze the four main tapping techniques. This means that in the final system the beer stapler must in any case be a tapper with two taps, and the difference of position between one type and the other will then determine the relative positions used in the following in the cycles depending on the chosen beer. The choice between the different types of tapper (simply 2-way, or T-tower, flag, bridge, etc.) was then a function of the space occupied by columns and taps, which would remain within the size of the europallet with all the other components and must guarantee a distance between the knobs such that both can be moved by the chosen end-effector without interfering with the other. A plug at a minimum distance from the column can be useful to reduce the chances of impacting the column during the different movements. Each typology of tapping has evolved over the decades and centuries in a particular area to maximize the characteristics of the typical beer of the place and therefore the types of beers to be served will be selected according to the techniques chosen in our system. The customer will then be left free to choose the type of pin that he considers most appropriate, it being understood that to enjoy the beer choice the best option is always to adopt the technique of tapping for which the beer was created, so as to have a foam with the right consistency and the beer immediately below with the amount of CO_2 that was designed by the brew master.

We then analyze the types of tapping and the repercussions that would be reflected from the practical point of view on the system, while maintaining the legal and the German one. The Belgian tapping is instead eliminated due to the need to insert several additional elements: with this technique the paper cup is filled in one shot, until the beer begins to overflow from the cup. From a technical point of view this would have involved the addition of a spatula for the "cutting" of the foam and a rinsing tank of the glasses with a tap and the attached system, a gobelet to rinse the spatula or a point where to eliminate the all. The disposable spatulas would have avoided the gobelet but it would have had to provide a new area in which to store them with a cost, although minimal, one more element for which maintenance should have taken place and a new volume occupied. In fact, to be able to rinse the walls of the glass and eliminate residual foam, a real sink would be necessary. These complications are not feasible either from the economic point of view, nor from space, nor because of the increase in complexity compared to the benefits deriving from it. The Anglo-Scottish pin is instead eliminated because, although it provides a single shot, very slow and with gradual straightening of the glass, it is then characterized by a rest of 1 minute before being served. In this phase the paper cup would stop, in an ad hoc waiting area, while potentially the system could already provide a next order: the glass would however already be completely full and a distracted customer would be very encouraged to lean over to pick up the glass on his own, drinking a beer of lesser quality but above all multiplying the opportunities for contact with the robot in motion and interrupting the movements. In addition, this type of tap is designed for English beers, characterized by a very low carbonation: if other types of beer are chosen, more than in other cases use this technique instead of the one designed for the selected beer could affect the quality of the product the final.
Another component eliminated for practical reasons was that of coasters. The coasters are cardboard or cork discs that are placed under the glass to collect any drops that slide into the wall. Their presence is historical and dates back to the nineteenth century [stob] at that time the wealthy classes consumed beer in jugs with silver or zinc lid, while the mugs of the humble classes were without a lid and covered with felt cloths, which if on the one hand they prevented external interferences that involved obvious hygienic-sanitary problems, and each time they had to be washed and dried. As early as 1892, then, cardboard discs with a diameter of 107 mm (still the most widespread nowadays) were replaced in their place, which then lost their initial function for the current one.

Cheap, the coasters can however be customizable and collectible among the fans, as well as very colorful and captivating. Therefore, despite the greater movements that would have weighed on the

Figure 8.4: **A decored spatula**

cycle times, it was evaluated whether or not to include them in our solution. The elimination of the component was also due to other problems that could arise: first a new space dedicated to their storage, above or below the work plan. This space would have been not negligible, given the diameter of the disc greater than the maximum diameter of the Baladin glass and the thickness that, although a few millimeters, would become important overall if you wanted to store the coasters in large quantities for reasons of minimizing maintenance interventions. It would not have been necessary to introduce a new system to release the necessary disk in the order that is taking place to de-align it from the column of the underlying coasters, but this because the size given to the hands did not allow them to be taken to the side. The right hand, in fact, cannot reduce its opening so much, while the left should have been reduced even more, making it very different from the right one. Moreover, it would have been necessary to place such coasters in the final delivery stations, which would be difficult to reach from that arm and find a space from which to take them in a space to the left of the YuMi, which is practically non-existent. Taking the plate coasters instead, would have led to an opening to be increased still on at least one of the two hands, reducing even more the moving load.
The Cognex AE3 In-Sight vision modules or other external In-Sight cameras on the YuMi arm were not included. Having an In-Sight inside the system is primarily a cost and in some cases an excessive weight that the joint 5 of the left arm (the only arm that could afford a load increase higher than 100 grams [InS00], [InS]) should endure, risking on the other hand to decrease its torque, useful for moving the knobs. Even just inserting the standard Cognex vision module of the clamp is in practice less

Figure 8.5: **Coasters**

useful than you imagine. It would not make sense to complicate the cycle considerably, for example to check the level of beer in the glass during the tapping, because the orientation with which this module is positioned makes the process of releasing and repositioning the arm for the observation of the beer level growing very slow and in a not compatible way with the timing of tapping, that is less than 10 seconds. In the same way the reverse procedure would be slow to return to the open knob and the sum of these two times would absorb all the time that the tap should be activated if not even lengthen it, making the sensor useless. The orientation of this module also excludes that during the tapping phase it may be able to give a reading of the level if mounted on the right arm. The great advantage of this sensor, considering that in a small part we are already exceeding the maximum permitted load, is the weight of only 14 grams. The only solution would be to mount external cameras in fixed positions, such as near the tap, from where they could communicate with the central controller by observing the instantaneous levels of beer in the glass. Given the reassurance received regarding the stability of the flow of beer, it seemed once again an unjustified cost to insert these elements, preferring to delay these phases after having obtained the times with practical tests. If you notice that these times are influenced by the type of beer treated, you should repeat the tests if you decide later to change the type of beer served.

For other problems, sensors of different types can be inserted, simpler and cheaper. For example, it would be interesting to consider, during the first shot or the different shots preceding the last one, whether it is possible to use the load sensor inside the robot clamp instead of timing the phase, making it perhaps the most reliable data.

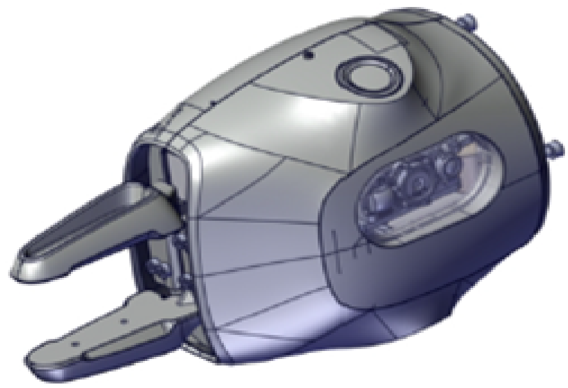


Figure 8.6: **YuMi gripper**

8.4 Plastic cup problem

Big theme was that tied to plastic cups, supplied by Baladin, with a capacity of 300 ml each. These glasses offer advantages from the point of view of pollution, mechanical properties and the ability not to create friction between them once stacked, but in this condition maintain a distance of 7 mm. This relative distance between adjacent glasses represents a major constraint, in addition to that of the size of the glass. The initial idea was to insert 480 glasses in the system, to make them uniform to the number of beers that can be obtained from the number of kegs provided. The final objective is that from the point of view of the station's autonomy, avoiding a double external intervention, one for the change of the kegs and one for the refilling of the plastic cups, making them coincide. At the same time the station must have a minimum capacity to supply the beer without continuous refills but remaining in the expected volumes. Considering the two minutes that are expected to be tapped with the legal method (the fastest, provides two tapping strokes against the three of the German), means that if you always order the same type of beer on a continuous basis the three barrels will be sold out in 8 hours. By not noting here following the feasibility of this solution, a time potentially less than eight hours between one recharge and the other was not considered acceptable. Each stem has a capacity of 24 *l*, which corresponds to 80 300 ml beers and, at least initially, the idea is to divide the space allocated to the stems equally between the two species of beer. However, if the beers are ordered in an equivalent number between the two types, then the request to refill beer in the barrels will delay and therefore there will be glasses available for all the 480 beers that the system is able to serve.

480 plastic cups, however, are already substantial and consequently also the relative size. Given the disproportionate length that would result (479 x 7 + 109 = 3462 mm), we need to resort to more columns in which to insert the cups. With a limited size plan and having to place the fridge im-

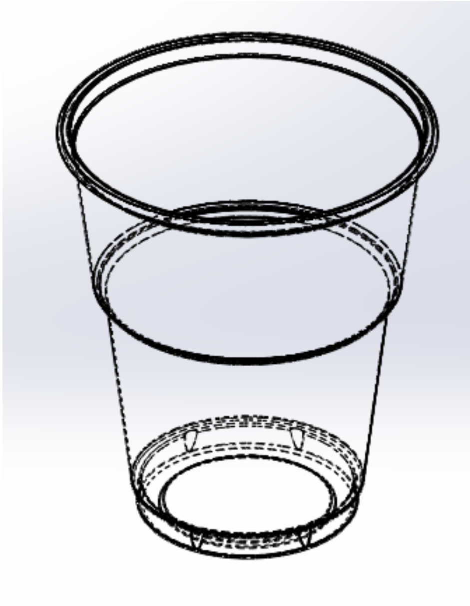


Figure 8.7: **Baladin plastic cup**

mediately behind it to contain the various kegs, having a "wall" from which the glasses come out horizontally is a solution that cannot be walked on because of space requirements. The solution from the bottom (with the stacks of glasses that come out from under the table top) would seem preferable, because it would keep the system more open to the public and greater freedom of action for the robot to take the plastic cups. However, the disadvantage that having many columns of glasses below the work surface must also be taken away from the space available for the tapping system: we should try to have as few columns as possible. In any case, the collection of plastic cups will be performed not by developing a system from scratch. Many automated solutions are available for picking glasses from above or below: these systems, although simple, must have good precision and a phase of study and development of positions and components such as springs very accurate, which would entail large costs and times in its development, with advantages that are certainly low compared to the effort required. We must therefore address the solutions currently on the market, choosing the most suitable for our project. In the case of picking from the bottom, these solutions contain a preloaded spring that provides the force to the glass to be accompanied to the pickup station, unlike the top picking in which gravity is used. Unfortunately, these cup-dispensers have a length and therefore a cups capacity limited and much lower than the height of the floor; in case the spring should be inserted where I cannot exploit the gravity, then the latter subtracts still space and therefore load capacity to the cup-dispenser.It is not possible to have 5 or 6 points in which to pick up glasses on the work surface: the cup-dispenser has a certain size and each of these positions must remain within the task-space of the right arm of the robot, remaining accessible without have contacts with other columns. The only stratagem that can be used without affecting the size of the table or the number of glasses available therefore seems to be that of inserting various columns on a rotating platform below the table top, to be moved with a small electric motor. In this way you could have more columns with a single point of grip of the plastic cup, remembering that the robot must be able to grasp the glasses without taking into account the space occupied by the other columns (the angle of approach possible of the glass will be strongly limited by this constraint). In order to reduce the overall dimensions, it was decided to place the cup-dispensers along the vertices of a regular polygon. In order to compact even more the cup-dispensers, the stratagem has been used to alternate collars on two levels to recover half of their thickness, keeping two layers from which the staggered glasses of the same collars (5 mm) come out.

The smallest solution among the types of cup-dispensers that can be purchased in Italy is given by the San Jamar Ez-Fit C2210C: the overall dimensions are almost optimized because the maximum diameter of the plastic cup that can be inserted is equal to 98 mm, very close to ours that is 96. To increase the size in this case as in all the others is the external collar, which cannot be eliminated because it is through it that the cup-dispenser is fixed to the top and contains parts for the regulation of the spring. Since the minimum diameter of the hole in which to insert the cup-dispenser is 124 mm, while the collar diameter is 143, even with the solution on two staggered planes I will have a minimum distance of about 134 mm, with the taking points at two slightly different quotas, offset by the height of this collar. In the maximum opening configuration, the robot must have a distance between the two elements on which the concavity of at least 78 mm was then built, that is the diameter of the beaker in the gripping point. Considering also the thickness of the fingers we consider the total width of the claws of the hand is 126 mm (64 between the center of the glass and the external part of the index and 62 between the center of the glass and the outside of the thumb, difference due the offset between the index and the middle on the claw with the four fingers), which means that by adopting the withdrawal procedure from the single column until it is exhausted following the diagram above, I will not have problems of collision between the clamp and the glass of the adjacent column. We know that the maximum diameter of the glass is 96 mm, which will however be higher than the pick-up point but also the height on which the nipper index is located. I will have 133 mm minimum distance between the points of withdrawal 64 will be occupied by the nipper open in position and 48 from the glass of the nearby station, thus leaving a relevant game that prevents contacts from being avoided.

This rule on the minimum distance between the various positions that can occupy the glasses will be generally respected in the development of the top, as in the final positions and Wait, adding to the 64 mm previously exposed the diameter of the plastic cup in the socket (for a minimum distance

of 64 + 39 = 103 mm). With the mutual distances just mentioned, however, it immediately became clear that a rotating platform with 5 or 6 glasses would have been too voluminous, unless we wanted to increase the size of the system to the other europallet. It will therefore be necessary to combine several rotating solutions or fixed stations, combining them with other rotating ones. The solution with 4 rotating positions plus 2 fixed places the situation too much to the limit: keeping only one mm of margin from the edge of the table coming in the best available point at such a distance that the drum would partially obstruct the channel next to the base of the robot for the passage of air for cooling. Even removing this passage completely and inserting a grid to allow the exchange of heat (possible as the weight of the robot is mainly discharged on the front of the base, that occupies the worktop), I would arrive at a distance of 1 mm from the YuMi, while it was considered to maintain a minimum margin of 12-13 mm, given the uncertainties in process, to avoid that then in practice it is impossible to move this solution. Also the solution with two rotating triangles with two withdrawal points is not compatible with the available space.
At this point, the best hypothesis would have consisted for reasons of space in a mixed solution with 3 mobile and 2 fixed positions and a total number of plastic cups available: too little.

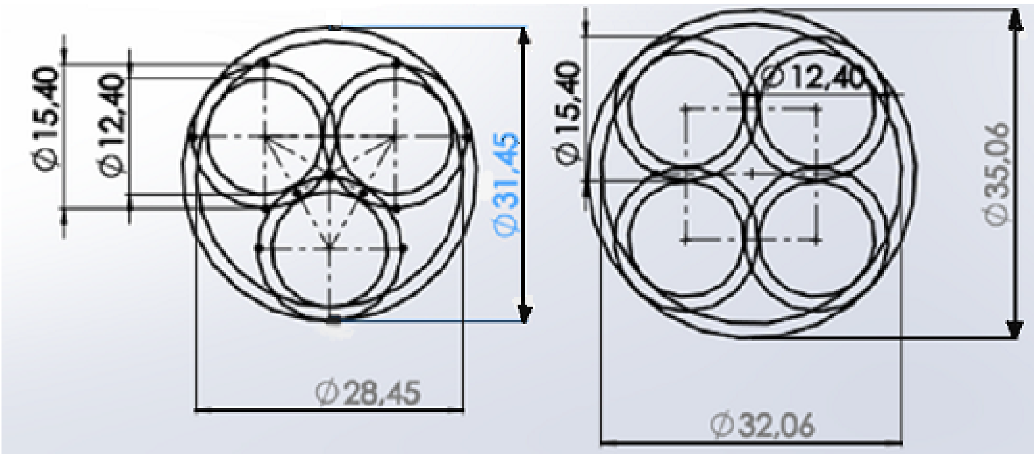


Figure 8.8: **Examples of minimum dimensions of any drums for San Jamal columns**

Insisting with a rotating solution, overturning it and placing it in a space above the robot, being able to circumvent the obstacle of the size of the plane would however be very voluminous and ugly to see (the only rotating drum would have a minimum diameter of more than 50 cm, to be able to accommodate 6 cup-dispensers) and comes out of the worktop a lot, even if it could be a light part and therefore with the possibility of being assembled/disassembled during installation. In addition, the more I occupy the volume above the worktop and the less we leave visibility to the drums stored in the pallet behind, as instead desired. At this point the best compromise is to consider a mixed solution both from the top and the bottom with only fixed withdrawal points, to reduce costs and various problems related to product manufacturing techniques, games, motion transmission, engine power, etc. Even if these small electric motors are silent, reliable and long lasting, on the whole avoiding their use will allow us to earn something also from the point of view of extraordinary maintenance.

The new stations, 3 at the top and 3 at the bottom, distribute the space also along this third direction, occupying the best available spaces. For the three top positions, we chose the San Jamar C3400P dispenser, which has the same internal geometry (tube length, limit diameter of the plastic cup it can contain). The dispensers are inserted on the right side of the robot, where the necessary space has been created to insert them. The Z coordinate will also vary slightly between the 3 positions both up and down, decreasing and growing respectively 10 mm at a time starting from the rearmost position to the one closest to the customer. This was necessary because in every possible configuration for the grip of the glasses the joint preceding the nipper assumed an angle such that the link corresponding to the forearm, which protrudes to a minimum part with respect to the clamp in a horizontal position, went to the positions number 2 and 3 interpenetrating the worktop and even more the cup-dispenser collar. Going up gradually to share solve the problem. The difference in height between the 3 positions at the top and the 3 at the bottom must take into account both the task space reached by the right arm of the robot, and the movements necessary for picking up the glasses. If in the upper positions it will be sufficient to remove the plastic cup and then lower a minimum height equal to the height of the cup itself, for the positions at the bottom it must also be turned upside down. In the case in which you start to withdraw from the positions below, the difference in minimum height between the collars of 2 facing positions is given by $109 + 75.3 + 75.3 + 109 = 368.6$ mm, as indicated in the 8.9
In order to be removed from the lower plastic cup, height 109 mm, must be brought higher up not only of its height: between the grip point and the bottom of the glass you have 70 mm, which must be present both between the point of taking the plastic cup before being turned upside down and the bottom of the plastic cup of the overlying column, both between the turned cups and the cup which in the meantime has positioned itself in place of the initial plastic cup. This height is then increased because the plastic cup has a radius at the base of 27.5 mm and then the distance of the point on that lower external radius and the center of instantaneous rotation at 70 mm in height from the base of the glass will be the measure to consider for not having contacts during the tumbling phase of the cup. In the event that you first take the 109 mm glass from the top position in the speech above, it will no longer be necessary: it is therefore more important to take the plastic cup of the top positions, which determine the minimum distance in 3 times. height of the glass, that is 327 mm. The minimum

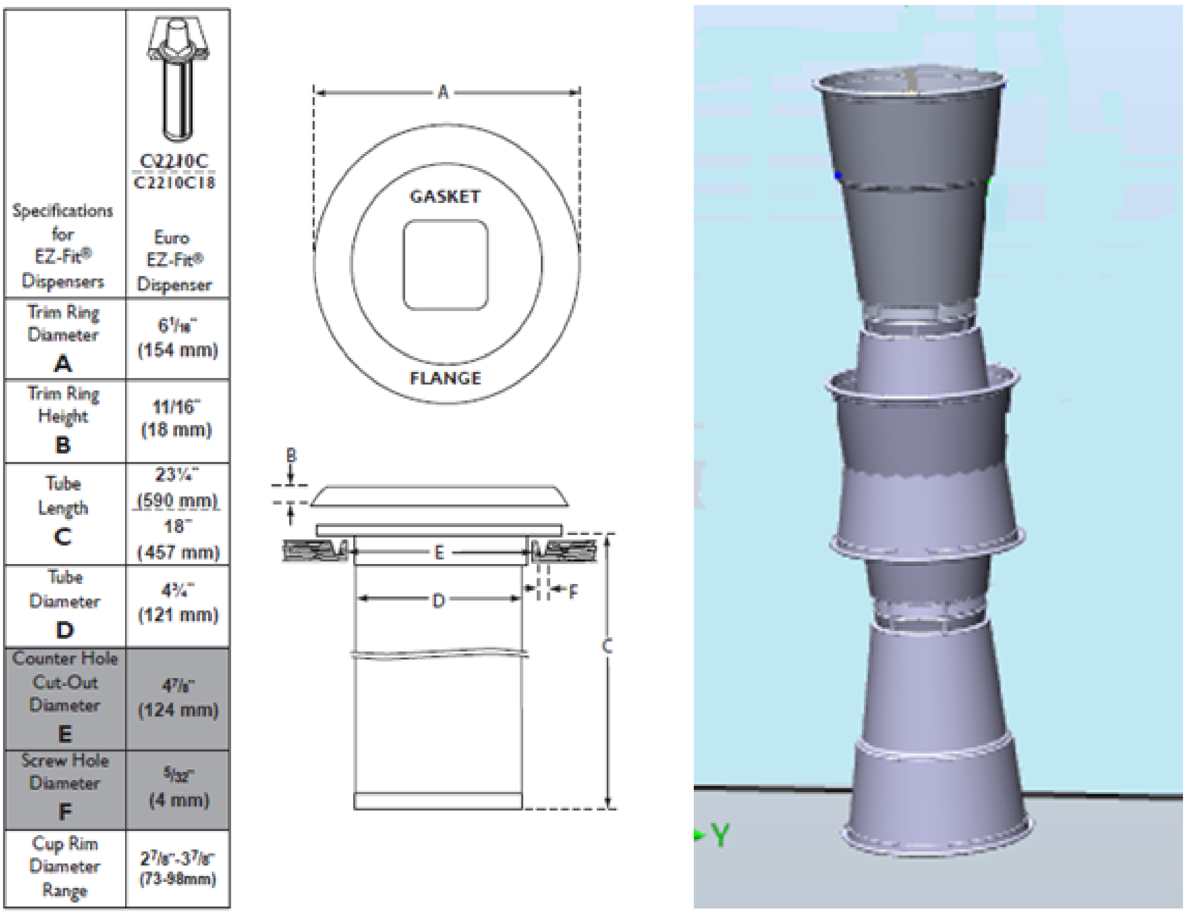


Figure 8.9: **San Jamar dimensions; Transposition as image of the minimum distance between the upper and the reversed cup-dispensers**

height to carry the TCP of the YuMi arm to make the glass rotation down will still be:

$$\text{Final dimension} = \text{Starting height of the glass base} + 109\text{mm} + 75.3\text{mm}$$

Unfortunately, it was not possible to mirror the top and bottom positions: by turning the robot I moved away from the right side of the table, but this was partly compensated by this rotation. In general, for the three top positions, the retraction movements are in a position very close to the robot's shoulder and it becomes much more difficult for the robot performing the movements required in these areas. Less problematic in general are the bottom positions, which despite the increase in height of the plane compared to the robot maintain a coordinate Z sufficiently distant from the one where the origin of the right arm is placed. As for a possible intermediate location facing the one below, the quote that should be reached to remove the cup from the column in which it was inaccessible by the YuMi arm: this also if you wanted to maintain all within the projection of the table, even moving the column to the outside, or by varying the angle of approach, or by adjusting the height and at the same time keeping the two adjacent columns reachable. It was therefore necessary to change the location of this withdrawal point. The intermediate column has been repositioned at the top in the old position closest to the client, undergoing only a small adjustment of position (1 cm) to avoid a corner of a joint that will lead to singularity and interpenetration of the structure in the disengagement during the withdrawal of the glass. An even more advanced island was created, but easily reachable, to allow the robot to remove the glasses from the last column. The only disadvantage, necessary, is given by the increase in volume that must contain the three cup-dispensers at the top. This volume has been reduced to the minimum necessary also by the indications originated from the actual simulation: also the station 1 was positioned facing the underlying one and therefore very close to the robot's shoulder. This meant that the robot's arm, in order to overcome these difficult movements, would in any case interpenetrate the volume of the crankcase at the top, or block itself to avoid self-penetration and impacts. Inserting the board on the edge, in line with the other two, would have been logical and immediate but would have entailed the interpenetration of another point of the top dispenser container in other movements. Therefore, the angle between first and second position was reduced but not eliminated, but the alignment with respect to the robot axes was lost, as in the positions below. It should be emphasized that the interpenetration (visible in the simulation program, detailed in the following chapter) or the fact that the robot still currently touches the case of the upper volume is never to be attributed to the claws, but to the different YuMi links in the movements made. This means that I should not have interpenetration, now that the movement of approach to the station has been terminated, even if I had to change or replace the ones made ad hoc. It will be sufficient to report the offset variation, with the advantage that it will be enough to work on 2D angles, as in each movement the last link, from which the pliers originate, is parallel to the working plane.

The container of the three cup-dispensers will be almost completely empty except for the dispensers themselves and the plastic cups contained in, but to make the various stations accessible to the robot the area that supports it and the link to the floor has been greatly reduced. In order to prevent the resulting bending moments from compromising the operation of the system by varying the coordinates with respect to those provided, the connecting part has been strengthened by extending it slightly beyond the edge of the plane and continuing it along a length along the edge. By fitting these extensions appropriately to the lateral surface of the plane, I obtain an arm able to generate the counter-tilting moment necessary for the static equilibrium of the system. Although the stations are fixed, by programming the robot adequately, you can first free the rearmost positions and only then move forward: doing so will not have the bulk of the previous columns to hinder the movements of picking cups. In this solution, the length of the cup dispenser (23.5 inch) in the case of the top picking becomes completely usable and given the length of the tube should be 85 glasses for each of the 3 dispensers at the top.

In the bottom-up solution it is necessary to take into consideration that the fully compressed spring subtracts a portion of space at the tube length anyway; for the C2210C dispenser the internal tube length in these conditions is 520 mm, which corresponds to 74 plastic cup per column. Changing the solution, inserting so also the upper points of storage, it is therefore able to accommodate a larger quantity of glasses, increasing the capacity of the system from 350 to 477 glasses. This number is still less than the desired 480 plastic cups, but is part of the estimates of beers considered to be sure of being able to provide an adequate quantity of beer for each product, net of the uncertainties that have on the stability of the system, of waste due to a prolonged inactivity. The change will be managed in an automated way, to prevent an operator from intervening every time. By detecting the outlet pressure from the various kegs, when this is lowered beyond a certain threshold value, the drum valve will be closed to avoid starting to serve a beer containing only more foam and the command will be sent to open the next stem of the same type. This will produce a minimum residual beer residue in the stem, which if reduced to physiological levels may however be reduced to a saving on the overall system and its maintenance. When a certain number of beers of a certain type have been consumed, maintenance must be alerted to allow them to intervene by changing at least all the barrels of that type of beer, making the system able to continue its service.

If, as a result of future indications, the number of plastic cups stored has to be reduced, the three positions at the bottom should not be eliminated; depending on the decisive reduction, the top pick up positions could be eliminated or decreased. Only then will it be studied which of the columns should be removed, then redesigning the case and the structure that connects it to the table.

Chapter 9

ROBOTSTUDIO ENVIRONNMENT AND FLEX-PENDANT

RobotStudio is the ABB program, for offline programming and simulation, and is an environment on which it is possible to carry out a variety of actions. Since this program is not specific to IRB 14000 but is common to all ABB robots, you can find many examples of various applications and tutorials on Youtube to understand as it can be used, while the detailed operation of each usable function can be found in the manual [RAP15]. First of all it is possible to recreate the environment in which the real robot will operate in real conditions. After defining and saving the new station file, by going to the "ABB library" icon it is possible to import all ABB robots available on the market, while on "import library" it is possible to import some accessories including the various final actuators: in our case the two clamps were imported, with the associated core claws. Very important is also the possibility to import external files, created through CAD, into the program, after having transformed them into ACIS format (**.sat*), as done in the figure at the beginning of the previous chapter: this is possible by clicking on icon "imports geometry", then going to look for the allocation of the desired file. Without this format change it is not possible to import components due to licensing problems. It is then possible to relate the position of the various components or connect them together (as in the case of the robot grippers to the respective arms), or by inserting the coordinates and angles with which the object is oriented in space through the "modify position" command.

Once the different components have been inserted, it is possible to move in space, modifying the zoom, moving by moving with respect to the system or by rotating, actually in a rather cumbersome way. To rotate, in fact, it is necessary to press two or three buttons at the same time (the simplest way is by pressing the wheel and right mouse button) and after several rotations the system can no longer execute new ones. The "view all" snap was therefore useful for adapting the overall dimensions of the system to those of the screen; even the zoom is not very intuitive and works in the opposite way to that of SolidWorks one. Going on the "Robotic System" and then "new system" icon, a virtual controller was then inserted: this controller will then be the tool through which the actual simulation will be developed, following the coordinates and the data points in programming and linking them with the graphical part of the program. Since behind this controller there is a math of a certain weight, also due to the many degrees of freedom YuMi, every time the controller will be reactivated a certain waiting time will be required for its re-initialization. The current status will be indicated by the appropriate status panel of the controller, at the bottom right of the screen, red if disabled, yellow if active in manual configuration, green if in automatic configuration.

Figure 9.1: **Controller status bar.**

Figure 9.2: **The manual movement commands**

Once the physical system as a whole was defined, it was possible to move the YuMi manually using the three icons in the upper menu to move joint, move linearly, move reorientation, after selecting the clamp or the link to move. In "move the joint", only the single selected joint was moved from time to time, while for "linear displacement" the position of the end-effector was changed on 3 axes: while the TCP was moving, the angles of all the joints to follow the imposed movement, if approachable. Each joint has limit angles, as already seen. To be able to vary them having information on the possible proximity to the joint angles of this configuration or not, it is very useful to use the "move joint" command, which can be reached via the "Modify" drop-down menu. Joint by joint, the current values of the various joints, the limit values and the current arm configuration are shown. This can become very important in the finishing phase to understand how a displacement in an area at the limit affects this joint, and even before to show which joint reach the limit angle in case you try to move in a point not reachable by the robot in the chosen configuration; so as to be able to intervene with the appropriate corrective measures. Below is also another box, which indicates the current configuration with which the arm reaches TCP.

Since the system is completely defined, or at least it will simply subject to some corrections, the time has come to really enter the program, defining the movements that will have to be simulated. The

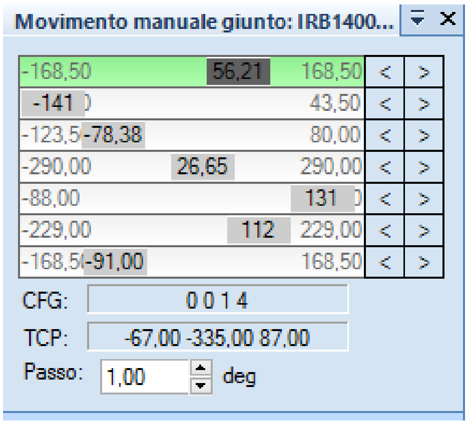


Figure 9.3: **Manual joints movement**

movements will take place between the various points that we programmers will pass to the program. These points can be entered in two ways: by moving the robot manually and once in a position considered appropriate to store it as a point in the program, or define the point through Cartesian coordinates, inserting the coordinate values on the 3 axes and the angles wherewith the TCP in the point is rotated with respect to the general system. We need a certain precision compared to some well-defined positions during the design of the table on SolidWorks in relation to which the YuMi will perform movements with a certain precision, in almost all cases to define the various points we used the second method. These memorized points are called tasks and are defined with respect to a well-defined object, the WorkObject, which can be by default or can be an object defined by us (such as the plastic cup to be moved). These WorkObjects can be really useful especially if we have different orientations from the main system and new tasks must be inserted that depend on the object in question. To find the points of the movements around these objects it will be possible to insert the deviation from the origin of the latter, if it is less complex from the point of view of the calculation than do it with respect to the universal system. This function has initially returned to us very useful as regards the coordinates relative to the movement of the two-way beer stapler knobs, not oriented perpendicular or parallel to the system axes. Through the Home menu at the top, to create a starting point or destination for the movements of the YuMi, go to the "Create Target" icon, to create a WorkObject on "Other" and then on "Create WorkObject". In both cases it will then be necessary to define the coordinates and the orientation of the object. The movements that the robot makes moving from one target to another can be mainly of 3 different types: MoveJ, MoveL and MoveC. The structure of a movement command is as follows:

MoveJ p1, vmax, z30, tool2;

in which p1 is the target "destination of movement", the maximum speed with which it occurs (in mm/s, in the case where, as in the example, the maximum speed of the robot used, ie 1500 mm/s for the YuMi), the zone and the WorkObject; as a starting point, the program always considers the one currently occupied by the robot. The zone indicates the proximity with which the destination point must be reached: if you must arrive exactly at this point you will insert the word "end", otherwise, if it is a point of interpolation between movements, it will indicate that precision with the *"z"* plus a number, which represents the radius of curvature in millimeters with which the two movements will be connected. MoveJ is used to quickly move the robot from one point to another when no straight line movement is needed: robots and external axes move in a non-linear way, but all reach their final value at the same time, reaching the destination point, so not so easily predictable but very fast if you do not have the presence of obstacles that can create collisions. There is also the MoveAbsJ variant, with which the YuMi is obliged to move in the position indicated with the chosen configuration, even if it approaches a singularity or there is ambiguity about how to reach the destination. The movement along a straight line, with the axes of the robots that vary their point-to-point values to be able to describe it, is obtained with the MoveL instruction. The MoveC instruction is used to move the TCP (Tool Center Point) in a circular fashion to a certain destination. Depending on the variants, the tool's TCP can be moved in a circular fashion at a constant programmed speed, or be constantly redirected during the circumference development. The MoveC statement presents a grammar that provides one more point:

MoveC p1, p2, v500, z30, tool2;

In fact, two points are needed to define in the space the direction and radius of curvature of the circumference. The first curve has the function of interpolation point, and the more it is near the median angle of the arc development, the more precise the circumference will be obtained.

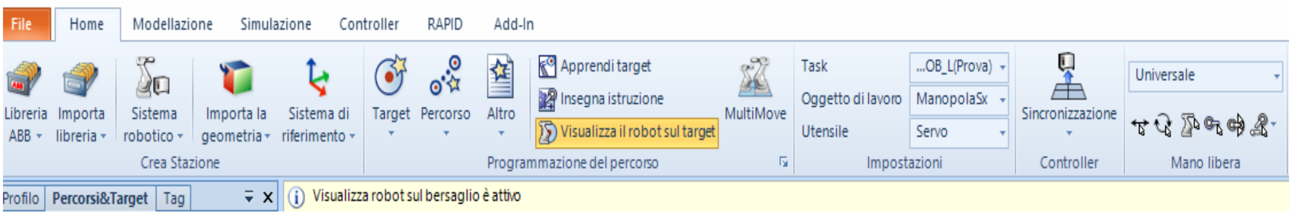


Figure 9.4: **The home menu on RobotStudio**

Now let's move on to the definition of the path, selectable through the so-called box and then clicking on "Create path" from the drop-down menu in Home visible above. The path will be associated, as well as the Task and WorkObject, to a specific arm between the right and the left, as the YuMi unlike the other robots of the range has two arms. To select the correct arm, go to the left column, if you are in the Home menu and select "Routes & Targets". At this point, choose the correct arm and set it as active, before defining on it targets, WorkObjects and paths; to avoid ambiguity and confusion it is never possible to have both arms active. The path is defined as a sequence of movements that the robot will follow to complete its cycle. Once the path and the parameters of each instruction have been defined, select the "synchronize with RAPID" icon. RAPID is the programming code of RobotStudio, the language that both the simulator and then the real YuMi will use to execute the commanded movements. In this language the program is divided into modules: each of these starts with the "MODULE ModuleName" line and ends with the "ENDMODULE" line. After starting the new module, if defined by the user, it starts the list of the various "CONST robtarget TargetTarget" targets with the associated coordinates and the configuration that the robot must have at this point. Although these points have been identified and defined by Cartesian coordinates, the point is identified here by quaternion. Quaternion algebra is a 4D space (1, *i, j, k*) in which *i, j* and *k* satisfy the following anticommutativity properties [Bas]

$$i^2 = j^2 = k^2 = ijk = -1 \; ij = -ji = k \; jk = -kj = i \; ki = -ik = j$$

Using this method to define the various points, there are good advantages in the rotation of matrices from the computational point of view. The configurations, for the points defined by us, have a default configuration (0,0,0,0). The four digits, characteristics of each configuration, identify the quadrant in which each of the axes will be located to reach the point in the desired way. The first integer specifies the position of axis 1: it is positive if the rotation is counter-clockwise, 0 for rotation between 0 and 90 degrees, 1 between 90° and 180°, etc. and negative for clockwise rotations. In the same way the second digit specifies the position of the axis 4, the third integer specifies the position of the axis 6. The fourth integer specifies the position of the axis named *X*, a virtual axis used to specify the center of the wrist in relation to the other axes. These numbers are sufficient because, unlike what happens in the UR3, none of the joints has infinite rotation (see **Chapter 6.1**). As can be seen from this definition in the course of a movement, even linear, the configuration may vary, even if it is unlikely to be distorted. At first, however, with the aim of obtaining points that could be reached by the various movements of the cycle, we tried to have for the points related to the same area with the same or as similar configuration as possible, in order to perform less corrections in the simulation phase. By executing the program, you can choose whether or not to activate the configuration control: if disabled, the robot, if it is possible to execute the movement, will choose among the various configurations the most similar to the previous point. In general, this control is activated and follows the configurations given in the first lines of the module: the ConfJ or ConfL instructions are used for checking or lacking control of the configuration. In our specific case we always checked the different configurations, to be sure about how our robot would move. In fact, the robot without this control could perform this movement in a different way from cycle to cycle and the cycle could return to the final position differently from the previous cycle. These deviations could be unacceptable, because the robot in linear movements could end up the available movement of the joint and then stop without being able to carry it out, while for linear movements this could translate into complex movements, large, with a high risk of collisions. This is due to the simple fact that ours is a system with many elements that can generate collisions on several sides of the YuMi and because the orientation of the TCP of the plastic cup and therefore also of the cup itself must remain fixed in most of the cycle even for MoveJ movements. Deactivation can be useful only if you do not program offline, so with the robot physically present; in this case, if the point where the robot is currently stored is stored, configuration control can reduce the movement capacity of the robotic arm.

Returning to the RAPID code, after inserting the various points, insert the lines containing the various cycle instructions to be made to the robot, contained in blocks called PROC (procedures). Each of these begins with the "PROC BlockName" line and ends with the "ENDPROC" line. There may be multiple PROCs in one module, but one and only one of these must be named "PROC main", and it will be the one executed by the program. The program lines inside as it happens also in many other programming languages, are concluded with the ";". The symbol used to insert a comment for the rest of the current line is given by "!". These lines may simply be those indicated above in the explanation of the most common movements such as MoveL, MoveC, or they may contain some other specific instructions among the multitude. In the following we indicate the instructions that were used in the execution of our cycles:

- *AccSet 70, 100*; This instruction is used to reduce the acceleration at the beginning of each movement after the previous point. The second number, 100, indicates the nominal acceleration, which is the maximum, while the former expresses the percentage of acceleration imposed with respect to the nominal one. The default value set is equal to the rated acceleration. If, after having lowered the acceleration, you want to go back to the maximum value, you have to insert the instruction *AccSet 100, 100;* into a new line. The maximum acceleration expected for the YuMi is 11 m/s^2, for a time of 0.12 m/s to reach a speed of 1 m/s from a standstill. You have to work on this parameter, in our case where the available payload is out, because with the nominal acceleration a torque is requested from the motor that he is not able to supply.

- *WaitTime 10*; Wait for the specified number of seconds before proceeding with the next command line.

- *WaitTime \InPos, 0*; This instruction is used to make the point of destination become a standstill one. In practice, the robot will stop at this point after having reached it for the very short amount of time the information will be sent to the controller. The latter, as soon as the information is received, will give the command to continue the cycle. This instruction can be useful in case you want to give a command on the other arm through the SET/RESET signals when a precise position must be reached.

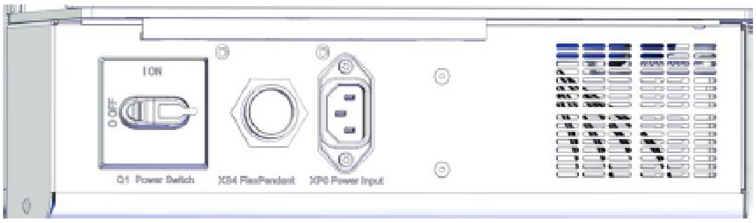
- *SingArea \Wrist*; It allows to go beyond a singularity point for alignment between the joints 4 and 6 in a linear way, with the possibility, however, of losing a little the orientation of the TCP. It can be deactivated with the *SingArea \Off* instruction.

- *CirPathMode \PathFrame*; Instruction that allows you to insert a variant of MoveC such that the TCP is continuously oriented along the circumference.

Below is a short main loop as an example:

```
PROC main ()
        MoveJ Start_stop,v500,z10,Servo\WObj:=Bicchiere1;
        MoveL IntConsegna,v200,z10,Servo\WObj:=Bicchiere1;
    SingArea \Wrist;
        MoveL OffsetFinale2,v200,z10,Servo\WObj:=Bicchiere1;
    SingArea \Off;
        MoveL Finale2,v50,fine,Servo\WObj:=Bicchiere1;
    WaitTime \InPos, 0;
        MoveL RibassoFinale2,v50,fine,Servo\WObj:=Bicchiere1;
        MoveL SvincoloFinale2,v150,z10,Servo\WObj:=Bicchiere1;
    AccSet 100, 100;
        MoveJ Start_stop,v1500,z10,Servo\WObj:=Bicchiere1;
ENDPROC
```

The SET/RESET signals used are those inside the controller (8 signals are present), while the commands *g_MoveTo*, *g_GripIn*, *g_GripOut* deserve a separate mention. These commands in RAPID are not instructions of RobotStudio, which presents the *SETDO Do_Finger, 1*, *SETDO Do_Finger, 0* instructions associated with a digital output (DO) instead for the last two instructions. They are instructions of the FlexPendant, which is the terminal through which the YuMi controller can be programmed directly and can be executed by the RAPID. The FlexPendant is connected to the internal controller of the YuMi through the central connector on the right side panel of the base of the YuMi schematized in 9.5:



xx1400002125

Q1	Interruttore di alimentazione
XS4	FlexPendant
XP0	Ingresso di alimentazione Connettore dell'alimentazione CA di rete, IEC 60320-1 C14, 100-240 VAC, 50-60 Hz

Figure 9.5: **Left side of the YuMi base**

You can also view the FlexPendant from RobotStudio, through the icon of the same name in the "Controller" window. Once switched on, the menu in 9.6 appears on the touch screen:

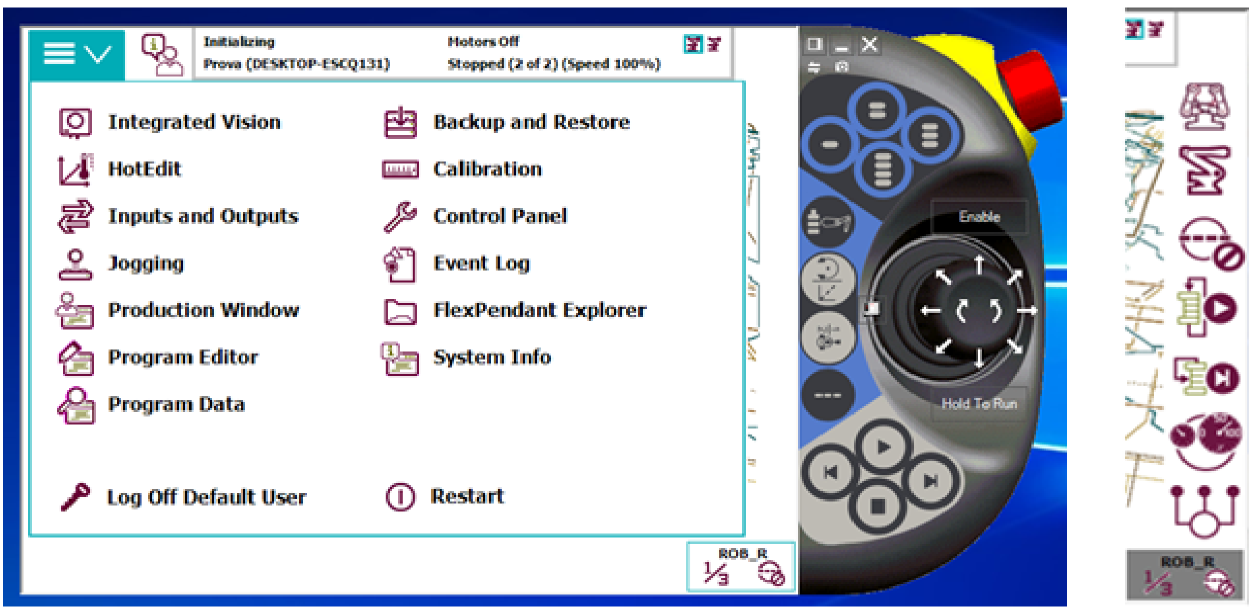


Figure 9.6: **FlexPendant menu with, on the right, a detail on the hidden commands column**

To the right of the touch screen there are "physical" cleaning of the terminal. At the top right you can see the red emergency button, which if inserted must be manually disarmed before you can make new changes or the YuMi can do new movements. Still on the side edge of the FlexPendant but at the bottom there is another input, through which external hardware devices can be connected to the terminal. At the center is instead the joystick, used in manual mode to move/rotate the arms of the robot. The four buttons at the top are programmable, allowing us to associate the most useful commands for easy use, while the 4 below are the classic stop/play buttons or to run forward or backward only one program line at a time. Also important are the two central buttons to the left of the joystick: the top one allows you to define the movement, whether linear or joint, the one at the bottom defines the movement as manual or automatic (default setting). In manual mode, if the joints are controlled, they cannot be moved together, but 3 at a time, each time associating the vertical and horizontal displacement of the joystick and its rotation to each currently controllable joint. The joints that can be controlled are indicated in the box at the bottom right of the FlexPendant: 1-3, 4-6 or 7-9 (which would actually be the only joint 7, having each arm 7 dof). In the 9.6 on the right there is the column that is seen half hidden in the main image, with the various icons: the second icon is important, from which it is possible to define Workobject and tool (in our case the ABB grippers) connected to each arm. The fourth icon, with allows you to run the cycle once or continuously and the last icon, through which you can activate or deactivate the two arms of the YuMi independently, are also important. In the case of a real FlexPendant and YuMi, I can connect from a PC to a controller via an Ethernet cable and communicate what files to load on the controller itself, then going to run them. To do this, I first have to go to the ”Add Controller” icon in the RobotStudio controller menu. The YuMi controller is then added and displayed. By clicking on the top ”File Transfer” icon, I can go and get the files from the PC to load them on the real controller and then on the FlexPendant.

Naturally, before loading the program it must be checked on RobotStudio, through the following steps:

- Check that each inserted point belongs to the robot task-space and choose for each one a configuration from those available, observing how the robot reaches the chosen points.

- After synchronizing with the RAPID, run the simulation. If there are syntax errors in the program, the program is not launched; correct the program. In this case, the output window at the bottom helps us, where the various system messages and the various errors are indicated in temporal order. From this we can go back to the line of code in which the error is present and to its type.

- After launching the simulation on RobotStudio, observe that the movements implemented by the program are those desired and that they are performed correctly. At this point you are ready to go to the real controller and move the YuMi directly.

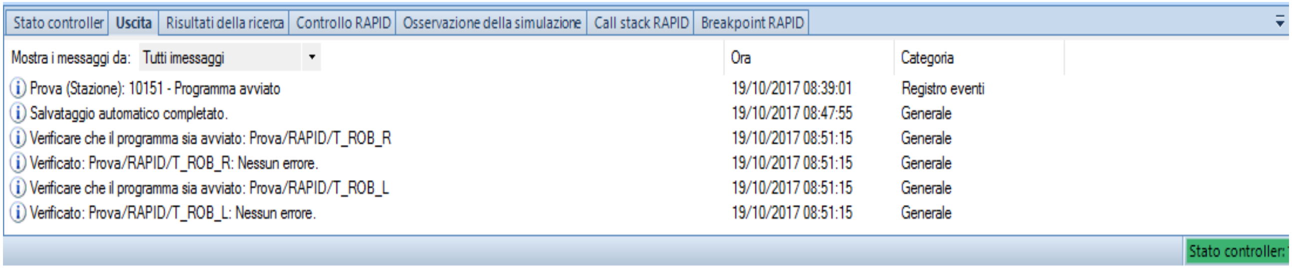


Figure 9.7: **Message window**

There are also commands that do not have the names of functions available on RAPID, but which are instructions provided by the real FlexPendant and which provide precise instructions to the robot controller. This is the case with the *g_GripIn*, *g_GripOut*, *g_MoveTo* commands listed above. These three commands refer to the position of the fingers of a nipper: the first is used to completely close the fingers, the second to open them. g_MoveTo commands the YuMi to open each nipper of a precise size, indicated in the number that follows this instruction: this number must necessarily be between 0 and 25, equal to the maximum stroke of the single claw in millimeters.

To modify the program once it has already been inserted on the real controller, you can act in two ways: you can edit directly from FlexPendant, through the "Program Editor" icon of the menu visible on the previous page, or directly from the PC. To avoid unwanted changes and licensing issues, if you need to modify it you must first give the ok from FlexPendant, where the cancel button also appears, to be clicked once the changes have been made and saved on the RAPID through the command on the RAPID menu of RobotStudio "Apply Changes". The Input/Output icon is instead used to insert the digital inputs and outputs to which the SET and RESET dependent instructions are linked, while "Calibrate" is to be used in case the program requests it, to ensure that the system recalculate with precision the position and the current orientation of the claws and therefore know how to behave in the case of commands that determine the position. Surely the most important icon is the Program Data, through which I see the program currently running and where it is located. Once entered, you can launch the program or upload a new one or a more recent version of it. Through "Upload" you access the controller folders, where all the various files are present; you go to select the one you want and load instead of the program currently on the arm on which you were previously. Clicking on the play button commands the execution of the program, while with the button on the right it is towed with the possibility to execute one instruction at a time, risking the same button. Both on the FlexPendant and on RobotStudio the program line currently being executed is indicated by the program pointer, an arrow on the left. Using the pause button the pointer remains in the line where the program was located, clicking instead on stop the pointer is reset to the first line of code of *PROC main*; the first instruction executed will therefore be the first movement of the cycle, even if it is not in the initial position of *Start_Stop*; we must pay attention to this in simulation to avoid collisions. The play button can also be useful for the continuation of the program in the event of a sudden interruption, such as following a collision. Even here, for safety, before restarting the cycle, FlexPendant must be confirmed for the resumption of movements.

Chapter 10

THE REAL PROTOTYPE STATION

10.1 Status of the station used to define the real prototype

The actual tests have been developed on a prototype system, at the company EPF Elettrotecnica srl of Carrú. In order to realize the prototype station, it was necessary to arrange the various components, paying attention to the fact that the solution led to a system whose dimensions were as close as possible to what studied in the system implemented on RobotStudio, to obtain significant information from the prototype, useful for refining the work developed on the station through RobotStudio. We tried to built in the best possible way the correspondence between the height quotas, starting from the dispenser supplied to us. The stapler, identical to the one recreated on SolidWorks, through quotas taken from life, was supplied to us on the cooling system that has a size that we have to deal with. The system (cooler) from which the base of the dispenser came out has a height of 288 mm, while the base on which the stapler is mounted (we can see it in 10.1), 31. The quota to which the YuMi is located is given by the height of the base on which the cobot has been fixed cantilevered, of 702 mm. As a result, the height of the floor on which place the cooler should have been really small to compensate for the difference between the two dimensions, much lower than a normal table. To make sure that the two heights were as close as possible to each other, the base was then tessellated near the edge of a mezzanine floor in the company, while the table was placed on the floor. With this choice, 205 mm were recovered, and the relative displacement of the model studied at about 30 mm was reduced by placing the cooler on the present element of the most suitable height.

In this way it was necessary to revise the various quotas relative to the tapper, which is lower than in the station studied on RobotStudio, but it has been maintained on similar dimensions. The points that can be reached in simulation will probably continue to be the same in the prototype, keeping the movements and even the same configurations adopted on RobotStudio, to avoid singularity and unwanted movements which can even cause collisions. However, since the distance between the drip tray and the two tap mouths is considerably greater than the height of the paper cup, the recreated situation is good because every movement and every functional point in the prototype station would have been in the next real one, with the only difference being the beer, falling from three centimeters higher, it could form a greater quantity of foam. The difference in the quotas on the useful points of the stapler is of acceptable value: the tolerance margins are reduced, but still allow all the other points of the system to be kept at the same height expected on RobotStudio, at most with minimum adjustments to increase the margin in handling considered more at risk. Even considering, for example, a paper cup of a previous cycle in the *Finale1* station still to be taken from the customer, I can foresee to move with the new cup above or near the full station without going to impact the mouth of the tap while I try to reach the location for the tapped. The first step will be to insert these corrections into RobotStudio, giving only the correct offset regarding the coordinates relative to the stapler, checking first the reachability of the new points and then the ability of the YuMi to carry out all the movements with the configurations of the axes used previously. I can therefore easily go back to the real system immediately afterwards, without having to upset the movements following the picking up of the paper cup to move from one part of my work plane to the other.

For clarity it is essential to dwell on the following point. The system was composed of many individual elements that faced the plane or around the robot, such as the collector, the cup-dispenser collars, the various stations, etc. and have over time variations in size, shape and even number, to meet all the specifications that were gradually defined by us on the station. The same fingers made by CAD have still undergone minor changes during practical tests on the prototype, to allow them to easily grasp and release the paper cup and compensate for minimum games or differences from nominal quotas. It therefore seemed very expensive to define the geometric positions and characteristics of each of them each time, to evaluate directly on RobotStudio whether there were contacts between the glass or the robot and each of these components; more reason was given to us by the fact that the forms usable to define the occurrence of these contacts were limited, and it would not have been possible to accurately define, for example, the volume and shape of the plastic cup. The simulation phase of RobotStudio was used to define the maximum positions of the components with mathematical calculations, to avoid gross interpenetration between the clamp and the various components imported via CAD, in each movement to be carried out. Even here, however, there were the standard nipper and not the fingers, which have the effect of clearly increasing the volume of the end-effector: this means on the one hand that on RobotStudio the glass was not actually taken every time, and on the other hand, that for extreme situations the presence or lack of light impacts, often such as not to cause any arrest, has been verified directly on the prototype. On RobotStudio, even when the interpenetration took place, did not involve the interruption of the simulation but were identified by us and involved the need to change the type of movement or the tasks and their configuration.

On RobotStudio the analysis of the YuMi's right arm was above all of fundamental importance. The division of works between the two arms has in fact led to the advantage of having the left arm much less burdened by work. Since both the system and the robot are present in the real prototype, the robot can also be moved directly on the prototype itself, with the YuMi set in "teach" mode, which stores the coordinates directly from the movements that are taught. Possible calibrations and/or movements of the column can be directly decided on the spot, modifying if necessary the position of the points, always taking care not to interfere with the other positions and to keep both knobs accessible to the left arm of the robot. As for the positions on which the right arm goes instead to operate in this phase, the physical system is still completely to be built. Performing the various movements necessary to avoid interpenetration, impact in specific cases and difficult to list comprehensively during the simulation phase, could be studied before go by to the final system only through this phase. The attempt was made to make the test system as similar as possible to the one simulated previously; then, for differences in the order of a few millimeters, the coordinates on the RAPID were readjusted, verifying from time to time that these small variations continued to allow the clamp to reach the estimated points with the set configuration (which is compatible with the sequence of other points in the cycle).

Besides aligning the various parts of the system in height, it was then necessary to report also the correct distances between the parts on the plane. Consider the distance occupied by the front edge of the base plate on which the YuMi was fixed with respect to the origin of RobotStudio: in addition to the side of this plate was added a minimum margin compared to the edge of the raised floor, used for safety in the tessellation of the base itself. Adding the distance between the end of the cooler and the origin of the column at this distance, the latter would have been too far from the origin of the system compared to the simulation. The element on which the refrigeration system is placed must then be rotated by 20° to bring us back to the ideal configuration, moving it further away from the YuMi (only the top of the cooler would have been kept flush with the raised floor). Since, however, the column of the stapler is held in place by a ring nut, by rotating it 180° I could turn the entire system on the side where the column is closer to the edge, unlike before, recovering space. By turning the stapler around its 20° angle hole, the relative one between YuMi and the simulation plane, I can keep the table and the cooler parallel to the edge of the base, reducing even more the space lost and bringing me back about 574 mm from the program, which may still be subject to change. To recover even more centimeters compared to the RobotStudio dimensions on the X axis (more than half the residual deviation from the robot's reference system), we have modified the height of the refrigeration system support by a few millimeters, so that the upper edge ended just below the top of the base on which the YuMi was mounted. Paying the maximum attention to the stability of the cooler, it moved the same so that it escaped a small part of the support flush with the floor. In this way the quota relative to the distance between the origin of the tapper and the edge of the drip tray is respected, despite the rotation between the small base of the dispenser and the drip tray leads to a relative displacement between the components. In fact, by rotating the column I have to move away, because the drip tray will remain rotated (as well as the column) with respect to the base of the tap of 20°. Since the column is located at a different Z level than the one foreseen on RobotStudio and slightly lower, also recovering the minimum distance due to the base above the plant on which the column is fixed, would have decreased the difference in height between the drip tray and the tap from which the beer is tapped at an insufficient value.

At this point a work plan was recreated on the base of the robot in which all the coordinates of the picking, waiting and final delivery positions of the glasses were contained. The top is made of wood and consists of a panel only 5 mm thick and therefore very flexible for large loads. The panel was fixed to the same base on which the cantilevered robot was mounted and therefore, for simplicity and speed, while paying attention to what will then be the real plane was oriented according to the axes of the YuMi. However, it is suitable for the minimum weights to bear, that are the full or empty plastic cups and the elements built to recreate the height dimensions of the simulated system. Keeping us at a lower altitude than in the simulation, for all the quotas, except those relating to the drip tray, you can return to the correct ones with compensating elements coming out of the panel, which is not feasible if the floor had been in similar position but slightly more raised compared to how much simulated. Moreover, having positioned the panel a few centimeters lower than the table top made on CAD (here the plane is only 5 mm above the origin of the axes of the YuMi, equal to the thickness of the panel) I get a larger volume, which could theoretically also be exploited. Moving back the right arm from the delivery stations or approaching those of Wait, it could happen that for trajectories of type MoveJ part of the fingers, pliers or nippers go under the old floor. If this would bring clear benefits to the cycle, this solution will be re-proposed in subsequent developments. As can be seen from the image related to the prototype here is the system that rotates around the robot and not like on RobotStudio, in which a base for housing the robot that is rotated with respect to the table itself has been realized. Small card disks elements (fast to be made and modified, as well as light) were obtained to bring the values on the Z axis to the simulated values: this operation was made for all the remarkable points identified on the simulated plane. The elements were united within them to reach the desired height and fixed by screws to the plane to ensure their position and at the same time not make it too difficult to change their position in case it was necessary to review the relative positions.

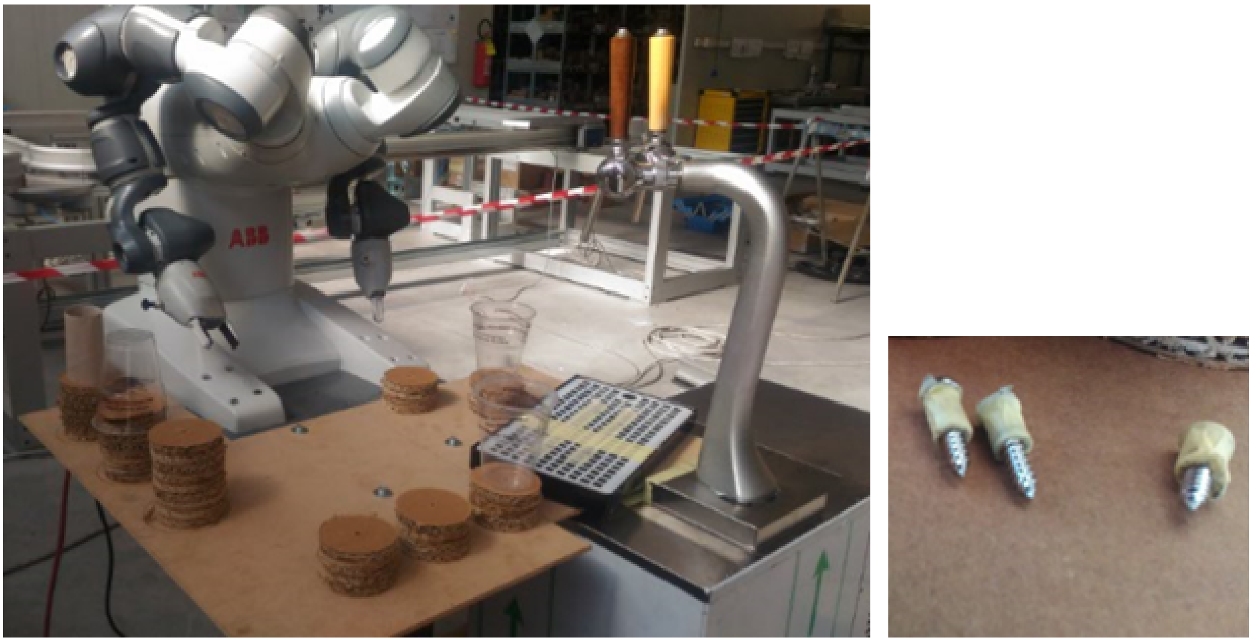


Figure 10.1: **A first phase of real prototype system building and the elements used to maintain the plastic cup fixed before the withdrawal**

At first the first three inverted paper cup taking stations were not realized, because it would have been necessary to realize the supporting structure of the container that contains the three cup dispensers in a very short time. It was therefore fundamental to study the volumes of these positions, the mutual positioning between them and with respect to the positions at the bottom of the simulator, avoiding surprises in the form of small or large interpenetrations. Later, for greater completeness, the top ones were also made. The structure that housed these latter positions also had to meet the requirements of stability and rigidity in order to maintain the required coordinates and avoid partially following the cups taken, creating dragging that would have prevented the robot from picking up the glass without stopping for safety reasons. The necessary stiffness is much more difficult to obtain, for the position in which the case is located and the fact of being anchored also to the worktop panel, which already has its own flexibility and will also transmit a part of vibrations.

To limit the oscillations of this part of the wooden structure within acceptable limits, the upright was fixed not only to the worktop, but was firstly fixed to the ground. In fact, as for reasons of time the structure was made with a single upright, even minor forces on the top posts would have found little resistance and a large arm at the base on which is fixed the panel of the worktop, that is a plywood and so he very flexible. In fact, since on all sides except the one outside the pick-up position of the plastic cups there will be no material in order to avoid collisions with the robot arm, even the slight forces that the YuMi is able to bear and create can produce significant discrepancies due to a excessive flexibility. Also to reduce the bending, this time of the top plan with respect to the upright, a horizontal axis was positioned for a T structure with some small reinforcing elements, placed diagonally and screwed to both the upright and the horizontal axis. The upright then, in addition to the working pine panel, was fixed with another element directly on the metal base roughly changing its behavior. The height to which the upper panel has been fixed is also a function of the method chosen to position the plastic cups, not having yet available the San-Jamar cup dispensers, which would have been excessively heavy for the structure just explained. The height considered was 7 millimeters greater than that in which the top edge of the plastic cup of station 1 would have been found, the highest of the three at the top and therefore, as the cup will be grasped at a height of 70 mm (out of the total 109), the height of the panel will be 46 mm greater than the amount included in planning for the picking of plastic cups in position 1. After identifying the positions on which the cups of stations 1, 2 and 3 had to be inserted, we have lowered from the floor with different thicknesses to reproduce the programmed quota, increased of 46 mm, also for the other two positions. In each of these stations a plastic cup was fixed, under which the cup to be taken from time to time would be inserted, with friction seal. The support glass of the station 2 was cut below the collar, to prevent the clamp from colliding with a glass of the station 3. Here, in fact, the support glass in position *Presa2* continues to occupy a volume that in reality it would already be free, free all the glasses of your cup dispenser.

Already in the first phase with the sole positions below has already been possible by simply placing the plastic cups in the right positions to make the grip, verify the occurrence of any problems during their picking and handling, such as the verification of the behavior of the YuMi in practice when it is subjected in the last stages of the cycle (therefore in a non-continuous way) to a load that goes beyond the payload given by the supplier. Another important check was necessary in the grasp of the plastic cups: the cups supplied by Baladin can be subject to deformation without suffering breakage, deformations that will be light thanks to the controller present in the clamp, which can adopt in grasp positions of the claws different from those open/closed, and also should present friction between a plastic cup and the other due to the wall angles with which it is made. Also by supplying the gripper with the *g_GripIn* instruction, closing the claws, we can see how the cup is deformed without breaking, unless it has undergone more deformations previously. For the three positions from the bottom you had to see in practice if the sensitivity of the hand of the robot, however less than that of a human hand, would allow to take the plastic cup without grabbing or move from the sampling point even the plastic cups/the subsequent cause of potential frictions between them, which could be formed when the one to be withdrawn is deformed. For a true simulation of this phase I should have available also the cup-dispenser chosen: in fact, the cups remain in position before the gripping despite the preloaded spring pushing upwards for the opposite action given by the rubber annular sheath on the side walls and on the final edge of the glass. It should be understood if this friction will be sufficient to disengage the glass inside compared to the outside due to the force exerted by the hand of the robot, if however the friction that would be created between the two plastic cups would remain greater, if it would also disengage the first plastic cup from the hand that should grab it. In extreme cases it could also play an important role in the release speed of the glass: at high speed the rubber sheath could be enlarged during the passage of the plastic cup and not be able to return to position to disengage a second cup taken by mistake together with the first, or interfere partially and in "dynamic friction conditions" which, as known, is lower than the static one; at low speeds it could instead return to position to disengage the two containers. If the problem were to occur and no alternative solutions were found, even by slightly moving the gripping point to bring it to the taper change (the stiffest point of the plastic cup), the only solution would be to provide only pick-up points from above, or changing the cup and using a stiffer one. Among the disadvantages that would certainly result in the latter case are to list the increased cost of the cups, the overall weight that would go up again slightly, the fact that we should re-establish the optimization of the stations to maintain adequate autonomy. Since, however, the right side of the robot has already been completely used, choose the first solution would be to impact violently on the robot front, with the result of making it much less human-friendly, as received by the user as a further part and "less accessible" than the system.

After the first tests, the possibility of taking two plastic cups together seems to be avoided, given the low force that the pliers are able to exercise. In fact, initially whatever the closing of the claws could be impossible to take the plastic cup unless it is irreparably deformed, if another was present below. For closing commands greater than the minimum necessary the resistance provided by the two cups, crushed, in some cases acting as a spring going to re-enlarge the fingers of the caliper, which was not able to exert the necessary force, frustrating the coupling. With a lower closing of the fingers,

however, the generated friction was not sufficient to disengage the cup to be taken from its position. In order to make the collection possible, it was necessary to insert a sheath in the thickness recess of the claw, with the aim of increasing the friction between the glass and the hand, which is not sufficient at the moment. It will then be necessary to check that this friction is sufficient even then when the cup-dispenser sheath will resist or if it is necessary to increase it again. Given the minimum games, this additional thickness could however put at risk the possibility of the end-effector to reach the exact position, since a minimum distance of more than 78 mm was no longer guaranteed for all points between the fingertips and the TCP. The space has been recovered going to completely cut the part of the thickness towards the fingertips, also facilitating the invitation of the plastic cup that was then stopped once reached the TCP from the end of the area with enough space to allow relative sliding.
It was then confirmed that the large node to solve to be able to use loads slightly above the payload is that related to accelerations. In manual mode, with accelerations cut compared to the nominal, in fact, the robot is able to withstand loads that slightly exceed its payload. In automatic mode, without any intervention on accelerations, also for reaching low speeds the maximum acceleration is set, which the motor of the joint 5 is no longer able to impress. The acceleration must therefore be reduced to avoid stopping the engine. This is not a big problem in our case, because the payload will be useless in the phases in which the plastic cup (which naturally has no lids) is full and high accelerations could cause the loss of part of the content: with any eventuality it would have been necessary intervene on accelerations in any case.

On the other hand, the behavior of our collaborative robot is very problematic, in case of unwanted contact that generates a type 0 stop. The robot grippers (due to the rotation of the joint 5) fall "dead weight", pouring contained beer. Therefore it will be necessary to intervene trying to make sure that in every movement in which there is a beer inside the cups, the link 6 downstream of the joint that "falls" is placed in such a way as not to be subject to rotations of the joint 5, because this would put at risk the possibility of developing inside as a stand-alone station. Therefore link 6 must therefore necessarily remain parallel to the work plan. However, if this can be done in the last phases of the cycle, it is not possible to do it during the "first shot". During the first phase of tapping avoid producing foam the plastic cup is initially held at 45°: it is precisely this inclination to reduce the violence of the impact of the jet that falls on the wall of the glass and to prevent the formation of large bubbles of carbon dioxide that would ruin the quality of the same pin. In case of contact by the customer with the YuMi during this phase the cup would fall due to the failure of the arm that supports it, potentially pouring part of the content that would not even be completely discharged through the drip tray. Moreover, due to contact that generates an emergency stop of type 0, the functions of both arms are interrupted: this means that during each phase of tapping I would have the problem of the behavior of the left arm, which would no longer be able to control the beer stapler. The beer would continue to escape without obstacles for all the time in which the engines would be cut the transmission of power and waste the process, while falling into the drip tray, with possible splashes. With the same type of stop the controller YuMi commands in the case where the torque required to the motor exceeds the maximum deliverable. As our load exceeds the maximum allowed, we must intervene by cutting the maximum acceleration values from the controller: it is proportional to the torque, which is maximum if maximum acceleration is applied to the maximum allowed load. It is therefore not even sufficient to use lower speed values than the maximum ones, which would already be naturally limited, because the movements in which the load is exceeded are also those in which the plastic cup is full of beer, which could be poured due to sudden movements.

Consequently, the tap chosen for the ability to be reliable and repetitive (and consequently have a more automated and simple system) not having a spring that allows a single equilibrium position, is the cause in the event of a collision of a serious behavior on the part of the tapper that goes against the functionality of the system. As the controller reacts to the contact by going to cut the power to the motors for a few seconds, it is not even possible to foresee an emergency movement on the left arm in case of accidental contact. From this consideration found in practice, it was then decided to go back to the classic tap with the knob to a single stable point. In this case it is in fact possible to exploit the emergency fall behavior of the YuMi to release the hand from the knob, making sure that the joint 5 can rotate approximately perpendicular to the ground disengaging itself and letting the spring bring the knob back to the OFF position, interrupting the flow of beer. In practice this idea has proved to be decisive only in the case of the right tap, because for the left choose the configuration in which the joint 5 can rotate on a vertical plane means at the same time going to invade a portion of volume in the vicinity of mouth of the tap already occupied by the right hand and the relative plastic cup that must be filled.

By choosing to keep the joint 5 horizontal, this is naturally released once the power has been removed from the engine, pushed backwards together with the knob, from the tap spring. In this way it does not go to fall even in other areas where it could potentially create problems; in the same way the hand on the right tap, which disengaging and descending simply goes to lean on the horizontal column of the corresponding tap that supports it. The gripper should move the knob only by means of the nipper on which the four fingers are fixed, with the claw open, in order to allow the disengagement. The described disengagement is also possible thanks to another characteristic of the knob, which has much smaller excursion with respect to the previous tap between the opening and closing positions, which decreases from 74° to 19°, approximately. It is so much easier to keep the claw approximately vertical, avoiding that it rests on the dead weight knob and interposes the inertia of the arm to which it is connected to the return to the rest position with consequent interruption of the beer flow. The reduction in the angle between the two positions also allows easier programming for the switching of the knobs, because it is much easier for the robot to travel a limited range of development. The only residual problem is on the right arm, in case the unwanted contact occurs during the first tapped stroke. It starts with the glass away from the drip tray rotated 45°, then it is rotate on the end. The initial problem was in any case strongly limited, considering that, since the plastic cup is placed above the drip tray, most of the content would be discharged without going to flood the floor below. With the change of tap, the coordinates of the notable points and of the corresponding targets used in programming will change naturally (tap mouth, grip point of the knobs and center of rotation of the knob). Fortunately, this variation is minimal, in the order of a maximum of 2-3 cm and therefore there are no particular problems in performing the movements of both arms starting from what was previously studied. Once the types of beer treated have been defined, you must also intervene to lock the lever on the dispenser which regulates the pressure and consequently the quantity of foam produced. The advantages of small adjustments that are possible to obtain the best condition in each situation are minimal compared to any damage that could result from the fortuitous or intentional change in position of anyone who handle that regulator.

The movements between two different points are subdivided into three main categories, renamed by RobotStudio Linear, Joint and Circular. In the first the TCP of the robot moves following the straight line that joins the two points distributing in a linear way in the meantime, if present, the variation of the angles of the claws between the start and end point. In the case of a joint movement, however, the robot is free to move between the two points with trajectories identified by the controller, which may deviate slightly from the linear trajectory or result in complex changes that the arm must perform to satisfy the movement between the various points, above all for obvious changes of configuration between the extreme points of the stretch. In general, in order to avoid complex and potentially damaging movements as much as possible, we tried to make the various linear movements, leaving however where necessary joint movements provided that there were no knocks or that the plastic cup was inclined if containing beer. The only exceptions are the collecting and releasing positions of the


Figure 10.2: **The final real prototype system, with the final delivery position at growing high from left to right (from the YuMi point of view) and the new knob to give a bigger lever; on the right, a comparison between the two taps used in the different development phases**

plastic cup, in which reaching and releasing must have conditions of minimum deviation from linearity for the required precision.

From the tests it was highlighted a problem related to the delivery of the plastic cup in the *Finale2* station, which was performed without giving errors in the simulation but contained a point that could not be reached, as it went slightly beyond the limit of rotation allowed to the joint 4. It is therefore necessary to modify this delivery location, noting that initially decreasing the angle of approach of the gripper parallel to the ground and at the same time increasing the height of final delivery in height could be brought back within the limits. Returning back to the releasing phase, however, we saw the achievement of the constraint for joint number 2 before moving away sufficiently from the released glass; the only solution has then become that of advancing the position towards the customer. By optimizing the position to obtain coordinates as close as possible to those of departure, being able to reach them and disengage from them, we have finally reached a new configuration in which the post has been advanced by 25 mm and raised by 10, and has been changed the angle of the clamp bringing it from 90° to 80° (a further decrease would have worsened the corners again on the joint 2). Consequently, the *Finale3* station and the trajectories of passage over the stations were also modified to avoid collisions with any glasses that a previous customer has forgotten to pick up.

10.2 Examples of single cycle program

In the development of the variants of the cycles performed, several points were identified through which the robot's TCP could be passed, to perform the various cycles present, some matched to the right arm of the YuMi, others to the left. In the examples that will be inserted will not be present the coordinates related to each of the points, but only the series of movements characteristic of the current cycle. However, it is useful to go on to present below all the points that may be present, despite the names that often recall the function they perform, for a greater immediacy of comprehension on the part of the reader.

Let's start from the right arm, the one entrusted with the task of grabbing the plastic cups. The cycle was built on some pivotal points, consisting of the six picking stations, the three delivery stations, the two of Wait, with the offset due to the increase or decrease in height between the point where the glass is placed and the height at which the grip is made. The names of the points below, easily identifiable, represent these points:

Presa1	Presa2	Presa3	Presa4	Presa5	Presa6
Finale1	Finale2	Finale3	Wait1	Wait2	

Each of these points has been associated with standard points: for example, before each taking station an offset point, called approach point, has been inserted at the same height but spaced on the plane, in the same direction that the hand would have to head towards the plastic cup, to avoid contact between fingers and cups, heading towards the point of capture. In the same way a new linear movement was foreseen as soon as the plastic cup was gripped, vertically (downwards for the stations 1, 2 and 3, upwards for 4, 5 and 6), to bring us to a position to avoid contacts once the lateral movement begins to take us to the taps.

ApproccioP1	ApproccioP2	ApproccioP3	ApproccioP4	ApproccioP5	ApproccioP6
SvincoloP1	SvincoloP2	SvincoloP3	SvincoloP4	SvincoloP5	SvincoloP6

As for the picking, an offset point with different dimensions or even different coordinates on the plane was placed above the Wait and final delivery locations. For the latter, one also had to disengage from that point, without dragging the plastic cups behind it. For this reason, even here a new linear movement of the cup release point has been foreseen.

OffsetFinale1	OffsetFinale2	OffsetFinale3	OffsetWait1	OffsetWait2
SvincoloFinale1	SvincoloFinale2	SvincoloFinale3		

Let us dwell now on the actual tapping operation. For each of the chosen techniques, there was a first shot in which one started with an inclined plastic cup to end vertically. To do this, we chose to make the TCP run a circle arc to straighten the cup. As indicated in the explanation of the program, for the *CirPathMode* *PathFrame* instruction it is necessary, to cover an arc of a circle, to indicate between points: one of beginning, one of end and one of interpolation, better if median. The interpolation and end start points obtained for the right and left tap respectively are shown below. For the second shot and possibly the third, instead the plastic cup stood under the plug but resting on the drip tray, in points identified in the third row below:

InizioSpillDx	InterpDx	RubinettoDx
InizioSpillSx	InterpSx	RubinettoSx
SecondoColpoDx	SecondoColpoDx	

Other points were then used to connect the points just described between one area and the other of the plan, to avoid optimizing each zone in its own right and then find an incompatibility between the various configurations, and to avoid large displacements without a direct and unambiguous control on the movements of the YuMi. Several points have been chosen to connect the withdrawal area to that of the taps and are listed below. If a number appears in the point, this means that it has been identified exclusively for the indicated pick-up point.

InterpVS	Interp2VS	Interp3VS	VersoSpillatore

Two other points have instead been used to connect the stations in which the last shot took place to those of offset above the delivery points of the finished product:

Uscita2e3	IntConsegna

From the very beginning it was also identified a single point from which to start and in which to end each cycle, called *Start_Stop*. From this point, every time a new beer is commanded, head towards a pick-up point. The following points are used to connect Start_Stop to the various cup-dispenser approaches:

Interp1	Interp3	Interp4	Interp5	Interp6

Likewise, a start and end cycle point is provided for the right arm: however, these points do not coincide with the cycles that lead the gripper to the right and left handgrips and therefore you will have to go from one to the other in the case in which two consecutive cycles are not characterized by the same type of beer. In reality, the robot in these two points has the TCP with the same position and orientation, with the only difference of the angle of the various axes, which help to define the configuration, to avoid problems towards the point of interpolation to the right. Since the left arm has only the task of operating the knobs, it will be the points of the knob in the initial and final position, with the *Start_stop* points, the main points of the cycles:

StartStopSx	StartStopDx	PresaSx	PresaDx

As for the opposite arm, other points have also been defined around these two points. In the same way that in the case of pick-up stations, the points of approach to the knob have been defined to avoid collisions between fingers and the knob itself. In the same way that for the first stroke of tapping on the opposite arm, the arc of circle that had to be recreated on each of the taps to open and close the knob, was realized with the instruction *CirPathMode* *PathFrame*, with the related end points of development of the arc and those of the intermediate angle.

	OffPresaSx	OffPresaSx	
IntRotSx	IntRotDx	PresaSxON	PresaDxON

Other points have been foreseen, with the only function to control the translation of the TCP from the initial points of the cycle to the point of offset of the knobs and vice versa. For a movement that is as harmonious as possible, two points have been provided to move towards the offset point of the left tap, while only one for the right one where a first movement was already made to move towards the new position of *Start_Stop*. The fact of not always returning to the left had the only goal of simplifying the cycle in the case of two consecutive cycles facing the right tap (also important because in our intentions represents the one where there is the beer of greatest consumption).

Interp1Sx	Interp2Sx	Interp1Dx

Each of these points then, was on RobotStudio in a different position from the real one, for the differences that were created after the development of the new claws, with 49 mm TCP instead of 30.5 as the standard ones. To overcome this problem, in an Excel spreadsheet for each point the difference in height was calculated on the plane (given that the gripper always had to be horizontal) thanks to the sine and cosine of the angle with which the gripper was oriented in space, multiplied by the difference of 18.5 mm between the two TCPs.

Chapter 11

VARIATION ON THE SYSTEM FROM TESTS ON THE REAL PROTOTYPE

11.1 Emergency stop issues

Various modifications have been made to the system during the simulation phase, by necessity, for greater knowledge of the simulation language (RAPID environment) or of the robot kinematics and of the consequences of the relative positions in the various movements to be performed during the cycle.

A major change was made necessary by the behavior of the robot as a consequence of an unexpected collision. Two limit values are defined for the robot, called fatigue load (the maximum that can be reached by the robot in operation) and maximum load (which if reached produces an emergency stop) respectively [YuM]. In the event of contact which causes the maximum load to be reached, power is momentarily removed from the robot's motors at the joint 4 and in those downstream of the latter, on both arms. Probably this happens as an interpretation of the UNI EN ISO 13850: machine safety - emergency stop function - design principles (category 0) [Arr]; in this way, anybody would be closed between the hand of the robot and an element of the external environment would not remain trapped between them. In the same way in case of overload, which could also be due to a minor impact, the robotic arm of the YuMi stops and returns slightly behind its stop point. From a practical point of view this means that for an emergency stop the gripper falls to dead weight by rotating around the joint 5, which from our point of view is totally unacceptable on the arm. In fact, if a contact should occur during the movement between stations of the tapper and waiting positions (or vice versa) or between the tapper and the final positions, thus in the phases in which the plastic cup contains liquid, the latter should be lost and poured on the floor, with the problem that the robot could not perform its task, and the customer would pay without no possibility to drink something. In addition, the liquid, if not poured into the drip tray and then sent into the drain, would degrade causing stench and hygiene problems, since the robot has not been programmed to clean the floor because it would not be able to perform satisfactorily. The only solution is therefore to try to have configurations in which the link between the joints 4 and 5 is always parallel to the ground: in this way the axis of the joint 5 will be vertical and gravity will not cause the fall of the plastic cup. The only acceptable exception would be that of an empty glass, or at the limit where, partially full, it falls only partially losing its contents, but in correspondence to the drip tray, from where the lost beer can be properly discharged without going to cause bad smells. Also in this case it would be useful to have a system able to understand if the glass is full or not, to decide if it should be thrown together with the content and then start an identical cycle from the beginning without requiring a new payment or continue the current cycle.

To avoid beer spills on the drip tray, a solution can be to tap the beer with the plastic cup resting: the problem is that increasing the distance between the tap and the cup increases the speed of the beer when it bumps with the container, with the formation of a larger amount of foam that would be more likely to wait at the Wait location (and therefore an increase in cycle time). The solution adopted by us is therefore composed of movements in which the glass is placed near the mouth of the tap during the first stroke, initially inclined at 45° and then straightened, while it is placed on the drip tray in subsequent strokes, as well as the techniques that we have chosen. This is because the amount of beer introduced in the subsequent strokes will be smaller and consequently should also be the foam that developed. In any case, the flow of stapled beer will not be too high, due to the limitations of the YuMi: in fact more the flow regulation tap is opened more the amount of liquid under pressure inside creates resistance to the opening of the knob: as the robot torque is limited, the test could not be completely opened. The times identified in programming have been chosen in relation to the flow that is currently possible to obtain from the tap with a sufficient safety margin. However, it resisted a critical point for the configurations adopted: for the *Finale2* and *Finale3* stations, the joint between the mouths of the two taps and the delivery stations, the joint 4 underwent a rotation of about 180°, thus finding itself during the passage in a vertical configuration.

Likewise, the behavior in the event of a collision of the YuMi ABB has serious repercussions also on the left arm, the one that moves the knob. The tap mounted on the real system during this first phase is in fact a bistable "snap" tap, ie stable both in open and closed configuration. This means that in the event of an active stapler collision, power would also be lost to the left arm: configured either to lean on the knob and not to fall away from the operated tapping point, or to release from the active point, not I would have nothing to call the tapper to the OFF position. For a few seconds at least the flow of beer would continue to fall on drip tray, plastic cup or hand of the robot without anyone being able to intervene, with waste of product and sketches on the entire floor. The only solution is to reconsider the classic monostable tap, which also has a few more play, requires a slightly greater activation force and excludes successive a priori more refined solutions in which for other reasons the left arm can disengage from the knob during the tapping phase. In this way, in fact, the knob, if not constantly pushed, automatically returns to the stable position, interrupting the flow of liquid. Moreover, another considerable advantage of this type of movement is given by the smaller excursion necessary to command the opening of the tap: now there is a rotation of about 16° (the inclination with respect to the vertical in the OFF position is about 5° and 21° in the ON configuration), against the previous 74°. Here below is shown, with the relative dimensions, the tap used until this moment. Given the low torque present on our cobot, the knobs, which can normally be screwed and unscrewed by the screw that protrudes just above the pin for the opening/closing of the flow, was immediately different from that indicated, to obtain a lever major on which the YuMi would have acted.

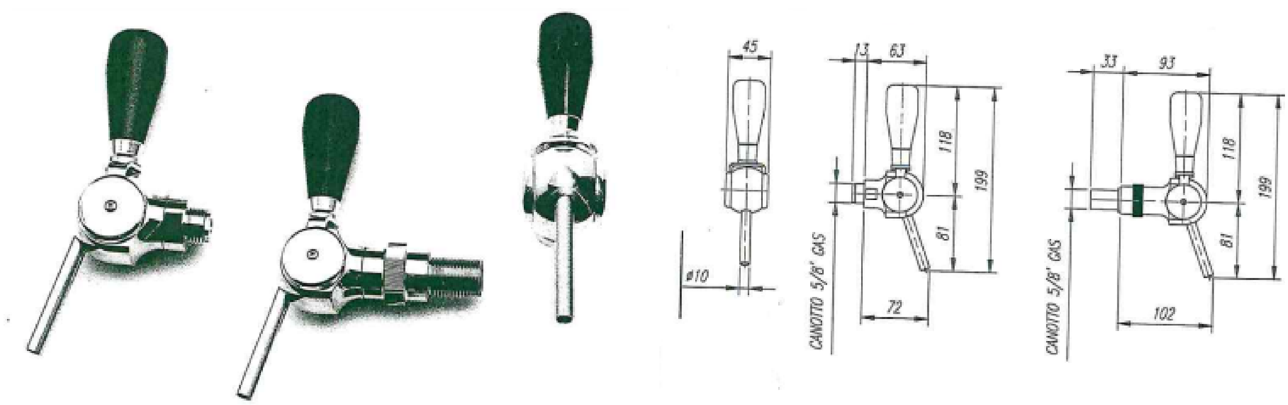


Figure 11.1: **The technical design of the first tap used**

The arc of circle for this movement will be closer to the linearity and much less wide, and therefore can be performed more easily by the YuMi. With the progress of the cycles, it was seen how the limited torque of the robot could represent a major problem from the point of view of reliability of the system: with the lever that was obtained by taking as high as possible the knobs that we had entered, the system normally it worked but it could have been enough a change of temperature or pressure to find us unable to switch the plug. These knobs were then modified with cylindrical plastic parts, light, longer and allowed a lever greater than about 50%, and the drip tray was moved a few centimeters away. Such an important increase was possible thanks to the low arc developed of the new tap. Indeed, especially for what concerns the configuration of the right arm, the position of the right tap is very close to the shoulder (the origin of the arm) left and given the inability of the robot to operate too close to it, this position also determines the minimum relative distance between the tapper and the robot. This distance must be kept within acceptable limits both to be able to approach the OFF position, but above all, remember, because the positions under the taps must also be accessible from the right arm and therefore cannot be located outside their task space. A certain distance however remains also because in order to reach the right knob the YuMi, failing to go behind the left knob to approach the right knob and make the opening without colliding with it, must necessarily pass in front. For this purpose the angle of 20° between the orientation of the robot and the tapper, which opens a light between the two knobs, also plays in our favor. In this way, in fact, the right tap is at a slightly longer X coordinate, making it easier to avoid the other knob during the approach, passing between the left knob and the base of the YuMi. The interruption of the flow from the plug is one of those few aspects that will be much simpler to handle in the case of a single arm or in any case when two different systems dealt with the right arm and the left arm. In these cases, in fact, it would have been possible to insert a signal associated with the emergency to be put in AND with the signal of the correct end-effector position: in this way, as soon as power was removed from one arm, the other arm or device would be given orders for a quick release or a tap closure, so as not to harm. This is not possible here, since both arms are controlled by the same controller. In addition to slightly changing the coordinates in the plane, the change of taps also changed the share of the spout of the plug, lowering it and getting even closer to the drip tray. An excessive proximity would be a problem with regard to the movements to reach the *Wait2* station, having to pass over a possible plastic cup in the Wait1 station: at a certain point it would come to the collision, avoidable only with more complex and long movements. The tappet, then slightly recessed in the top, was raised to avoid possible impacts with the plug, while trying to maintain a not excessive height so that the left arm could continue to use a wide arm to move the knobs.

However, we must ensure that in the event of a collision during the opening of the tap, the hand is effectively released from the knob allowing the return: first we must avoid tightening the knob between the fingers but the robot will be programmed to pull the knob towards you only with the nipper formed by the four fingers: this choice has involved, in programming, that the task of gripping the knob on the plane does not coincide with the position of the knob, because it is not in the center with respect to the two claws. It was then observed that the force of the tap spring is sufficient to allow the knob to re-enter, but in the case where the inertia of the robot hand must also be dragged behind, the resistance opposite to rotation for the return of the knob increases. It will be necessary to adopt a configuration in which this link is vertical and all that is downstream using gravity rotates around the joint 5 and autonomously disengaged in the event the power supply to the motors downstream of the elbow is removed. To facilitate the reciprocal sliding between hand and knob the reasoning to be done will be different from that used on the right hand: too high friction makes it difficult to disengage and the hand would remain roughly in position, with the spring unable to completely bring back the knob with the inertia of the weight of the hand added. This solution could have the only drawback of limiting the configurations with which the knob of the stapler is opened, and not necessarily among the available positions will be part of those in which the arm operates following a harmonious movement, similar to what the barman would do.

To improve the system both from an aesthetic point of view and from a practical point of view, the waiting positions were inserted in the programming of the left arm, which are points in which the left arm moves after being freed from the knob during waiting periods. These points have been inserted yes to make the robot's behavior more similar to the human one, but they also have advantages on the cycle in case of unwanted contact with the YuMi during these Wait phases. In fact, after an interruption, the YuMi to resume the cycle that has been assigned it tries to go to the next point of this cycle (which in our head is the midpoint of the circumference to open the knob) in case the system was in motion, or in the one from which it was moved, if a signal was waiting to execute the next instruction. After the impact, however, the final part of the arm and the gripper rotate around the joint 5, sliding downwards in relation to the OFF position, which was the point at which the robot first stopped during the Wait phase. The TCP of the left hand was however found in a lower position than the previous one and after the stop to "cut" to the next position would have come to run against the knob returned to rest, with a new stop, entering a loop from which would have had no way out. In the case where the hand by inertia in addition to going down revolved around the joint 5 going to disengage from the waiting position, to then try to return with a simple MoveL or MoveJ in the OFF position went to hit the knob with your fingers, with a situation similar to the previous one. By inserting these separate waiting stations instead the hand is in some cases released from the knob but goes through the approach phase avoiding contacts. If instead, as expected for the right hand, it is lower than resting on the tap, the TCP will not move down again, creating less chance of impacting the knob to try to reach the OFF position, and in any case succeeding then to reach it. From this point of view it was also advantageous to replace the knobs, which now have a smaller diameter and therefore have greater play between the fingers in open configuration, reducing the chances of accidental contacts. The waiting points obtained are indicated in programming as:

AttesaSpillataSx	AttesaSpillataDx

The YuMi series claws in simulation on RAPID have been replaced by real claws made of aluminum and 3D printer material only in a second time. In addition to weight differences, these fingers have much larger dimensions that previously could only be hypothesized and that in some cases created bumps and sliding with the plastic cups. In the first phase in which the YuMi was available, before the arrival of the fingers, thanks to a small cardboard cylinder of diameter compatible with the base claws, it was possible to do some rough tests, but final adjustments were then made wherever needed. Some interpolation and approach positions studied previously have been moved to avoid unwanted contacts and, given the greater length of the fingers, we first tried to increase the distances to linearly approach the intended gripping stations. During the approach to the glass it was then possible to observe in practice also the consequences that could occur as contact between this latter and the clamps in case the *MovePresa* command could be made only as MoveJ and not as MoveL: as to reduce the weights the plays between the open gripper and the diameter in the socket of the glass are minimal even slight deviations from the linear trajectory could create reciprocal contacts, even quite important, overloads, interruptions of the tapping cycle. After having taken the positions at first the glasses were placed and kept still by hand, not having on the test bench the cup-dispenser with its own resistances and plastic cups after the one taken at the time to unwanted movements. Subsequently, in order to avoid accompanying the glass inside the hand, recreating a much simpler sample of what it would have been in reality, conditions were created to stabilize the plastic cup, previously only supported, by the tangential forces that developed during the gripping movements. The same junction distances have been increased.

11.2 Variations on the prototype system and cycle time optimization

Once the set-up phase has been completed in order to obtain working cycles for each pick-up point, each final position or Wait, we have measured the duration of the various cycles in order to be able to take into account the productivity of our system, its capabilities in the event of a commitment close to continuity. Initially, the duration of the cycles for legal tapping, excluding the time spent waiting for the Wait station (1 minute), stood between 1'07"and 1'28" of only robot movement for each cycle;

for the German tapping it will be necessary to add the movement time between the tapper and the Wait and return station. The duration of the cycle is controlled by the movements of the right arm, as the withdrawal time and positioning under the chosen plug are in any case less than the time taken to approach and grip both the left and right hand grips of the opposite arm; in the same way the delivery time of the glass and of the final product is greater than the time of release and return to the resting position by the left arm. Until now, however, the sequence of points to be reached had been chosen to obtain a functioning system in each phase, without trying to minimize the overall length of the movements and their duration for each workstation, differentiating the points for each variant of the cycle. The goal of each of these is to make the tapping operation as similar as possible to the human one and therefore also the handling times of the YuMi should approach as closely as possible to those used in the operation by a barman, which can be in the order of 40 seconds, including the rinse of the glass [Mas]

With a view to reducing cycle times, the first operation was to increase handling speeds compared to those initially set. This meant an intervention especially in the early stages, those that had already higher average speeds. The phase preceding the approach of the intake and the subsequent one of lateral displacement from the junction to the tap have been brought to the maximum speed (1500 mm/s): now that the risk of large contacts is no longer present and as the trajectories are already been verified, these are phases in which the glass is empty and does not need millimeter precisions. On the other hand, the acceleration values were maintained at 50%, a value that allowed the movement despite the overflow of the payload and will be subject to a subsequent evaluation. This acceleration cut starts at the moment when the glass, after the first shot, is directed towards the Wait position, ie at the moment the total load arrives to be close to the robot payload. Subsequently the caps were inverted during the lateral movement towards the tap after the release from the pickup station for the positions 4, 5 and 6 not in a separate control, after checking that the different volumes occupied do not create new impacts, recovering for these cycles immediately a couple of seconds.

After this first phase, we analyzed the movements between the tap and the Wait positions. These movements were first corrected to avoid the elbow of the left arm during the opening of the right knob, which unlike what is shown on RobotStudio, whatever the chosen configuration interferes at least partially with the robot hand and the glass. Since, however, with the best configuration the interpenetration would have been minimal, it was enough to change the coordinates of the two offset positions, taking them to the right of the robot, thus avoiding the elbow that would have caused the impact for cycles in which the right tap was used . The Wait descent is no longer purely vertical, but also advances towards the Wait station, which has not been moved not to affect the robot's forearm, which must remain horizontal in the exit from the last stroke and in the delivery phases. This entailed an increase in length for the movements of the glasses coming from the left tap, which are relevant because after the first shot the glass is translated at a low speed. The increase in time required in the case of destination *Wait1*, which is likely to be the location towards which most of the glasses will converge, was still proportionally more impactful. A new point has therefore been identified, in fact splitting the offsets of the *Wait1* station according to the origin of the glass, reducing the movement of the glasses coming from the left tap by almost 2 seconds. The names given to the two new points identified for *Wait1* position are:

OffsetWait1S	OffsetWait1D

On the other hand, it has not been possible to change the situation, which is less impactful, relative to the *Wait2* station, and therefore it was preferred to optimize the point described above by redefining the position reducing to a minimum the length of the movements to reach it. For this position, raising the glass portion before going back under the tap is of fundamental importance to avoid contact with a glass that may be present in *Wait1*, while for *Wait1* it is not necessary to rise much of altitude, with the consequent loss of time. The increase was limited to a value such as to remain a few millimeters beyond the height of the drip tray. As for the tap, from practical observations it has been observed that the 3 seconds initially hypothesized to let the tap drip at the end of stroke were excessive. By reducing this value to 2 seconds for each stroke, a certain margin was still maintained, necessary because the tests were carried out with water and not with beer, and the different surface tension could produce different situations.

Moving from the tap to the final positions, first of all the increase in the tap quota was eliminated before going to the following points: they are already located higher, so getting up first is just a waste of time. In the case of the position closest to the drip tray, the final Offset position was also lowered to a value that avoids collisions, but limiting the development of the trajectory to a minimum.

For the positions *Finale2* and *Finale3*, however, there was a large residual problem, which made it impossible for the system to perform its functions in a collaborative way. During the passage between the tap for the last stroke and the offset position, there was a rotation of the joint 4 of 180°, with a full plastic cup. Since the joint 4 determines the orientation of the axis of the joint 5 with respect to the working plane, this rotation is not permissible because it presupposes that during the displacement (precisely just before reaching the position *Finale2*) the joint 5 is obligatorily located work perpendicular to the plane. As already explained, in the event of a collision with a part of the robot, during this movement the whole content would be reversed. The rotation of the joint 4 is not strictly necessary, because without it, none of the joints would reach the limit of its working range, but the robot was designed to avoid finding itself in a singular point. Joints 4 and 6, going from left to right, would pass through a point where they are aligned, without a univocal way to follow the given trajectory. First of all, it was decided to reprogram the movements of the final positions with an angle of the joint 5 rotated by 180°, similarly to those of the movements in the area of the stapler, to avoid rotation. This on the one hand led to the removal of the position *Finale3* from the robot, to keep it in the task space. On the other hand, it resulted in a good time saving for delivery at stations 2 and 3, because the robot made a lateral movement that was simpler and less close to the limit of the joints, maintaining higher speeds. Moreover, once the glass was placed, the joints of the clamp had angles much closer to those of the *Start_Stop* position, speeding up and making the final re-entry of the right arm more harmonious. It was possible to eliminate the inconvenient point *SvincoloFinale2&3*, which was previously necessary to avoid contact with the glasses in the phase of release but bad to see because it is not very harmonious, as it provided for complex movements to be achieved. In the meantime, the same phase of the junction has also been changed: after opening the claws, the caliper now descends downwards to create a greater play between fingers and glass before moving back for the release, with more freedom of movement and the possibility of slightly change the angle of the joint 5 if this generates advantages. The new points identified under each final delivery location on RobotStudio have the following names:

RibassoFinale1	RibassoFinale2	RibassoFinale3

To avoid contact, even slight, between the hand being returned and the glasses delivered, partly thanks to the advance of the position *Finale3*, it was then possible to lengthen this linear retraction movement. It was also necessary to lower the work table by 10 mm (but keeping completely unchanged all the points obtained in programming!) To prevent the new corner of the forearm (link 6) from creating knocks and slipping on the work surface, because of the voluminous rubber protuberance present on the link 6, now turned completely towards the floor. Even with these improvements, the singularity in the rightward shift remained and the joint 4 instead of rotating 180° now rotated 90° before returning to the orientation it had previously, creating the dangerous situation explained above. Then we went in search of a new command that would allow us to cross the singularity, so as not to overturn everything. This property was found in the SingArea command, an instruction that defines how the robot must behave in singular points: since however there are infinite possibilities of movement from a singularity, each variant of this instruction sets a priori certain parameters to be able to move in a deterministic way . The instruction that could play in our favor was *SingArea* *Wrist*, in which singularity in which joints 4 and 6 are aligned, as in our case, the angles of the joints are changed in a linear way between the starting point and the final point handling; what is left free however is the orientation of the TCP itself. The *SingArea* *Wrist* command has also the effect of limiting the speed of the movement: as in the final instructions the speed is already very limited, this aspect has no effect in our specific case.

By inserting this instruction, a simulation of the arm of the forearm with respect to the plane of 30° was obtained in the simulation, absolutely unacceptable in the event that I am handling a full glass. This inclination is because the forearm during the movement is inclined upwards to overcome the singularity, that is, in the elbow it is lower than the wrist, with the joint almost horizontal, which must therefore vary its angle in a relevant way. to correct changes in everything that is upstream. In this case, due to the chosen command *SingArea* *Wrist*, the first joints are blocked and the subsequent ones are moved linearly, without considering the orientation of the TCP. The maximum inclination does not change either by shortening the distance between the two points on which the command is activated, but only the space in which the command takes effect is restricted. This means having a sharper "gap", with greater damage than the benefits, especially now that the beer reaches a level very close to the edge of the plastic cup. In theory, to solve the problem we could also "reconstruct" the lateral displacement using the MoveAbsJ instruction, but according to the assistance service we would have obtained a jerky movement between the various points, which is ugly to see and very risky, being the commands concerning the totally full plastic cup. Not having alternative solutions, we tried to optimize the coordinates of the final positions to see how the maximum inclination could be eliminated or at least reported within acceptable parameters. By inserting this command, a new point (called *Output2&3*) has also been provided to control in a univocal way and optimize the length of the section on which *SingArea* *Wrist* had effect. Varying the coordinates of the points of the last two delivery stations we saw how lowering the altitude and moving away from the robot the situation improved: the forearm remained constantly closer to the horizontal position; advancing, always keeping within the limits of the task-space, it is also given more space to the robot to move back, thus lengthening the possible distance of release in the final return.

Since with these new corners it has been possible to reach places located even closer to the client than previously, and having free space, also the final positions 1 and 2 have been aligned with the third. Advancing, the X axis has been followed to keep close to the drip tray, then checking in the practice of not going to incrypt us in descending towards delivery in position 1; on the other hand, it is easier to release it from position *Finale3*, which now has more space. The size of the drip tray itself has been slightly changed, to allow the necessary spaces to the final positions and all the movements, considering that the important thing is that it was present under both the taps and in the only area left in which the arm could, slowly, fall for type 0 stops. It was therefore identified the drip tray with the smallest possible size among the standard ones of the market, going from 40x22 cm to 34x18. Advancing the coordinates is therefore possible, but lowering them required greater changes because the margin considered to pass over the glasses was already minimal. It was then decided to change the order of the end positions to lower the average coordinates and optimize each location so as to have a link 5 as close as possible to the plan. This solution allows to never have to pass over other glasses and, by shortening the development of the delivery movement by lowering the offset, to lower the coordinates. The change in altitude down from the final offset was reduced to only 20 mm. As this movement was carried out at very low speeds, the drastic decrease in its development also led to a good time saving. The most critical point is now located immediately after the delivery point *Finale1* and in this area the quota must be kept very low, but too low altitudes would be counterproductive for the corners of link 5 with respect to the plane. We have therefore tried to progressively increase the number of stations going to the right: the new *Finale1* station is now 20 mm higher than the *Finale2* station and 40 of the *Finale3* station. With these changes the maximum inclination of the glass has been reduced from 30° to 11°: it may not seem like much, but the parameter to consider is the cosine of the angle, which goes from 0.866 to 0.982. In other words, it means that (not considering for a moment the taper of the glass) if the plastic cup would remain full only for more than 86.6% in height, at the point of maximum inclination I would have had some leaks of liquid/foam. Now it has passed to 98.2%: relate to the height of the glass, the hair of the beer will have to stay lower than the edge of the glass of 2 mm, against the 15 mm I had previously. Given the levels of beer reached inside the plastic cup, we returned to an acceptable situation.

At a first test on the real system, it has been seen that however slight angles of the joint 4 with respect to the plane (of the order of 25-30°) were sufficient to create rotations of the part downstream of the joint 5, due to the beer load that it creates a greater moment than the empty cup. We therefore tried to further optimize the coordinates in order to minimize the displacements of the joint in each phase from the position parallel to the plane. In this regard, the offset angle of the new *Finale1* location has been changed and, after verifying that this did not constitute a problem and that the stations even if at the limit continued to be reachable, it was decided to further lower the work plan (and consequently

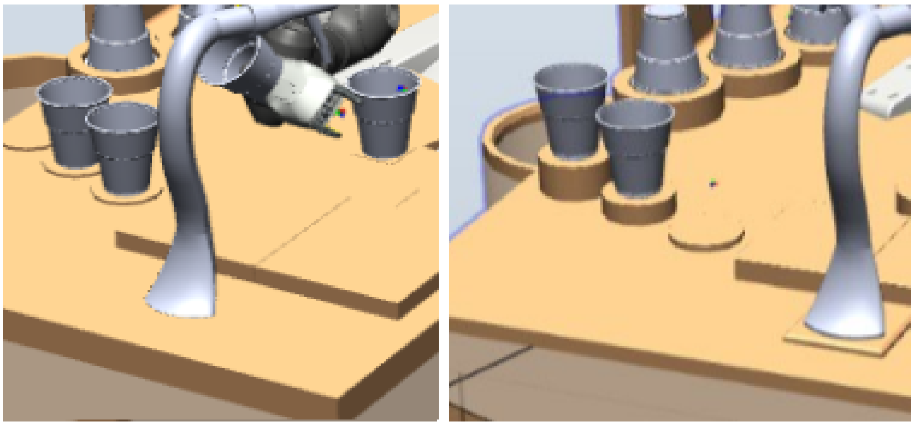


Figure 11.2: **Development of the final positions**

the various end stations) and the drip tray, respectively 10 and 20 mm. The lowering of the points related to the various lateral displacements in fact decreases the angles that can occur, making sure that even when fully loaded once out of the drip tray for any contact the system is blocked but the right arm does not rotate pouring the beer. The only points where this continues to happen, even if slowly due to the reduced angles, are in the area above the right side of the drip tray, while the arm moves after the robot has already completely filled the glass. However, having lowered all the coordinates, the rotation is slow is minimal before the base of the plastic cup rests on the surface of the drip tray, with an angle that can cause reduced losses and in any case immediately discharged, with minor shocks that do not generate splashes.

After having corrected and optimized the final phases of the cycle, the approach has been optimized and the withdrawal into the withdrawal ones: first of all the position of the *Interp1* point has been changed, used by almost all the cycles. It had a Y coordinate of -350, when none of the sampling stations is at a coordinate less than -335 on this axis, creating movements longer than necessary; changing this coordinate made the movements faster and more harmonious. In the case of position 1, *Interp1* together with *Interp2* goes around the plastic cup 1 for the approach passing in the narrow corridor between the glass and the robot: changing the position of *Interp1*, we approached the robot even closer, without causing contacts. A minimum of extra margin, in addition to saving time and handling jerky was given by the increase from 10 to 100 of the area in this point. Moreover, this task could not be inserted during the descent after the release from the station, thus reducing cycle times. A huge saving of time has been obtained on the station 3, more moved forward and in the middle compared to the others: using the common points in fact, before you move back after the release moving further on the Y axis, going to the right and then move to the left. Therefore, new dedicated points have been provided to immediately move towards the two taps. For station 2, after having also made the upper part of the structure with the 3 sampling stations, it was seen how the plastic cup taken collided with that of the next cycle while moving it towards the tap. To solve this problem we have applied three improvements:

- The retraction position has been lowered to near the joint limit.
- The angle of grip has been changed and therefore the approach position, first oriented with the X direction, so -Y and now displaced from this latter by 10°, because increasing this angle would have meant that the arm would have gone to hit the station 3. The corner was then increased to arrive at the junction, increasing as you go down, up to 45°; changes were also made to the configurations previously chosen.
- The position of to move towards the tap has also been changed slightly, providing a dedicated one, with the overall result of not having more impact.

Reconsidering the overall times it was then seen, as we can see from the example in the next page, how the time for picking from station 2 was much lower than in station 1, unlike before. Since the two stations do not influence each other, the order of withdrawal was reversed to initially have an average time per cycle lower. For station 4, on the other hand, points have not been eliminated, but they have been added to avoid contact with the glass during the descent towards the approach station. During this phase you are very much at the limit with regard to the backing of the caliper and I cannot retreat further because of the joint 2 that would fall outside of its working range and if placed a few mm later it would collide with the cup. From this point, to simply go down along the Z axis of the reference system, it is not possible to use MoveL, and the movement between the two produces an arc towards the right that creates a sliding between the fingers and the wall of the plastic cup. To eliminate this inconvenience, two intermediate points were created to break the movement and create circular arcs between the various points that gave rise to a much smaller deviation than previously. The connection point between the *Start_Stop* station and the approach area of station 4 has been redefined and repositioned. The new points present in RobotStudio, have the following names:

IntDiscesa4	Int2Discesa4	InterpD

In position 5, the rotation from the initial position for picking up the plastic cup in a previous longer movement was anticipated, while as previously stated the rotation was to lengthen the movement time, with a greater overall time. A new offset point was then created with respect to the approach point also for the station 6, first in common with the station 5, to avoid unnecessarily lengthening the trajectory. We then proceeded to the optimization of the interpolation points from the junctions of the various sampling areas to those of the taps to speed up these movements too: if instead of the two foreseen points only one is used, the total times of the movement decrease. From this discourse the cycles related to the picking in the positions 3, which owns completely different points, and the station 2 (ex post 1), which necessarily requires both points to make sure that the arm during the junction are not touched do not go to collide with the robot. Regarding the positions 4, 5 and 6 directed towards the right tap, the position of the point closest to the sampling stations was optimized in order to maximize the speed and minimize the length and complexity of the trajectory. This point, however, even before the optimization, could not be used to move towards the left tap because the linear feed along the X coordinate created a contact with a possible glass stored in the *Wait1* station. It was slightly modified then the another intermediate point, which was already more advanced both along the axis of the X, than on that of the Y, creating two sections of handling both quite long and linear, since the lateral displacement is wider while the point used for the glasses intended for the right tap created a first short movement compared to the second. Finally, as a last detail to reduce the time and the jerky movements increased during the radius of connection with the interpolation points and where this did not involve shocks, we moved from MoveL to MoveJ. Especially in the case of slight deviations, MoveL is nothing more than MoveJ movement with some interventions by the controller to constrain this movement to the equation of the straight line to follow: this is very important where precision is needed, but otherwise lowers the speed average by increasing the total time.

CYCLE TYPE					CYCLE TIME [s]		
Technique	*Taking*	*Tap*	*Wait*	*Delivery*	t_1	t_2	t_3
L	2	S	1	3	2'06"	1'58"	1'53"
L	1	S	2	1	2'16"	2'06"	1'54"
L	3	D	1	3	2'12"	1'57"	1'45"
T	3	D	1	3	3'50"	3'32"	3'21"
L	4	S	1	1	2'21"	2'08"	1'58"
L	4	D	1	1	2'19"	2'07"	1'57"
L	4	S	2	1	2'23"	2'11"	2'11"
L	5	S	2	2	2'23"	2'10"	1'54"
T	5	S	2	2	4'07"	3'48"	3'40"
L	6	D	1	3	2'06"	1'59"	1'44"

Tab.5 Time for various kind of cycle

We can now reconsider the cycle times, after the various improvements and optimizations performed. These times have been significantly improved, as can be seen from the table representing some of the cases examined above. In the columns to the left of the table are indicated letters and digits that together identify the cycle, among the 144 available variants:

- *Tapping techniques*: L (legal), T (German, in Italian "Tedesca"),
- *Taking position*: 1, 2, 3, 4, 5, 6
- *Target tap*: S (left, in Italian "sinistra"), D (right, in Italian "destra"),
- *Wait station*: 1, 2
- *Delivery station*: 1, 2, 3

The three columns on the right have three times for each of these cycles, which indicate how, during the optimization phase, the overall cycle time has decreased considerably. These times are cycle times, ie they represent not only the time taken for the handling phases, but also the time (or times, for the German tapping) passed, still, in the Wait station. To the times in the table to bring back to the times of movement must subtract 60" in the case of legal draft, 90" for the German. It should be underlined again that the code identifying the cycle is related to the new arrangement of the sampling and final delivery stations, distributed in the space as shown in the 11.3:

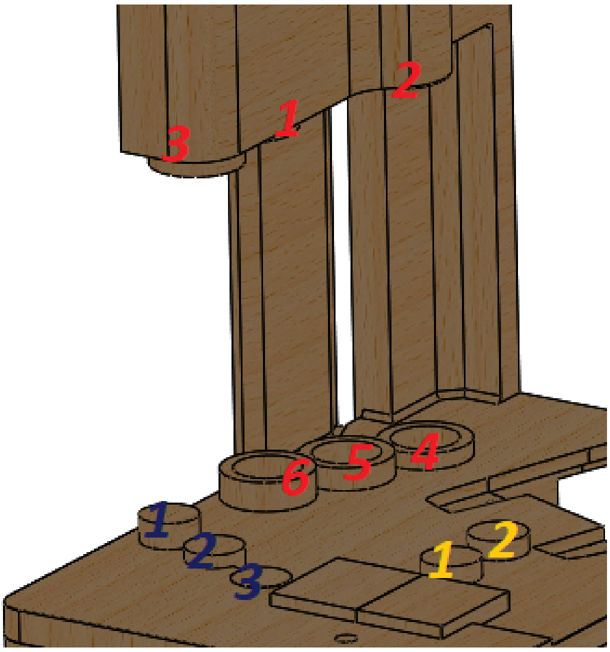


Figure 11.3: **New delivery and taking positions order**

Chapter 12

DATA MANAGEMENT

12.1 Logical steps in the cycles

Unlike what has been realized in the real system, where the positions and movements of each cycle have been re-adjusted, corrected by inserting the individual different cycles developed one at a time, the real system must be able to autonomously follow the correct cycle according to customer request. Through a graphical interface or app the customer will help to define the cycle through the two questions to be answered during the order, in addition to the payment of the necessary amount of money for the purchase:

- Do you want a blonde or red beer? → B: blonde; R: red
- What tapping technique do you prefer? → L: legal (2 strokes); T: German (3 shots)

These characters (related to the characteristics *Beer* and *Taped*) will be associated with a variable identifying the cycle, so that by inserting the Wait stations with possible change of plastic cup to amortize the Wait times, the same cycle can be interrupted to start another; in general it is not to be taken for granted that a cycle that starts before another must necessarily end first. This variable is not a progressive number that identifies the cycle number from the beginning of the system service: the number identifies the cycle since the last maintenance occurred on the system, which corresponds to the last time the cup dispensers were reloaded. The number will be used by the controller to determine the beginning of the cycle for the right arm. The picking of the plastic cups must follow a certain order because many of the stations have movements of approach towards the pick-up points in which the robot or the taken plastic cups go to occupy volumes in which previously had been stored other cups, which must therefore already have been taken. As for the remaining choice that we can implement, we ordered the stations in order to download those with a lower time first (in case the dispensers are reloaded before the glasses are exhausted, so the average time is lowered). By ordering the stations with a progressive numbering from 1 to 6, the scheme that associates the pick-up station to the cycle counter will be:

CASE $1 \leq N \leq 85 \rightarrow$ GOTO *Taking.Position1*

CASE $86 \leq N \leq 170 \rightarrow$ GOTO *Taking.Position2*

CASE $171 \leq N \leq 255 \rightarrow$ GOTO *Taking.Position3*

CASE $256 \leq N \leq 329 \rightarrow$ GOTO *Taking.Position4*

CASE $330 \leq N \leq 403 \rightarrow$ GOTO *Taking.Position5*

CASE $404 \leq N \leq 477 \rightarrow$ GOTO *Taking.Position6*

DEFAULT ($N > 477$) $\rightarrow$ interrupt $\rightarrow$ *ERROR, missing glasses*

IF N = *ValueSole: Give signal to request maintenance*

As can be seen from the numbering, the plastic cups are taken first from the top positions, which can hold 85 cups and then those from the bottom, which can hold only 74 because part of the volume is occupied by the compressed spring that must guarantee the necessary force to push the plastic cups upwards and counteract gravity. It is considered that the maintenance is always done quickly and that the threshold value is chosen with a margin that foresees that until the maintenance are always present both types of beers. However, if the same is reached at the end of all the kegs of one of the two types of beer we cannot let the robot tap anyway as if there was still beer, because the selected beer is used in greater percentage than the other and therefore not the total threshold value of the threshold has been reached. The only way to avoid this situation with one variable would be to set it to a very low value, as if you always ordered the same type of beer. However, this leads to more frequent and in some cases unnecessary maintenance. We therefore proceeded to insert two new variables, that will be the cycle counters related to the selected beer type, called *NR* for the choice of red beer and *NB* for the blonde. These values will also change according to the choice on the division on the stems of different types of beer and then could then be reprogrammed over time. Each of these two constants will be associated with a threshold value (respectively *ValueSogliaR* and *ValueSogliaB*) which, if reached, also provide for remote maintenance. The last IF of the previous command lines then becomes:

IF N = *ValueSole* OR NB = *ValueSogliaB* OR NR = *ValueSogliaR: Give signal to request maintenance*

With the variables received in order and the cycle number, it will be possible to know a priori what the characteristic cycle of the plastic cup will be, net of the Wait and Final position in which it will be addressed. The unit responsible for the control will then associate, according to these variables, the characteristic cycle times, ie the various times of tapping and waiting strokes. Meanwhile, depending on the beer that has been chosen, the left arm will be directed to the left hand grip rather than the right hand side. Depending on the sampling station and the tap to which the plastic is then destined, it is also possible to associate an estimate value of the time necessary for the sum of these first instructions. The usefulness of the associated constant will be made known in the continuation of the chapter. As probably the beer chosen in most cases will be the blonde, again with a view to decreasing the average cycle time the blonde beer was connected to the right tap, closer to both the taking and the final positions, and the red beer left tap. Under the mouth of the corresponding tap, the right arm will be directed once the cup is taken, towards the *StartSpillaturaDx* or *StartSpillaturaSx* position respectively. The start of the cycle part relative to the left arm will be directly controlled by the right one, which when reached the position decided by the programmer after taking the plastic cup, starts the instructions on the opposite arm through the activation of a digital signal Set/Reset, synchronizing the two cycles in the best possible way. In this way the left hand will come to the knob a few moments before the glass is placed under the plug, in a more natural way than that which would happen with a wait of several seconds. Unlike the right arm, the left arm can start the cycle from different positions: in case the arm is not momentarily engaged, just start from the first command of the cycle, choosing it according to the type of beer ordered.

IF *Beer* = *B* → *the left arm will go to the D-knob*

ELSE IF *Beer* = *R* → *the left arm will go to the Left Handle*

If the previously completed cycle used the same tap as the current one, we will already find in the starting point of the new cycle without having to run the first command, otherwise I will have to change the configuration in the point:

- IF *PositionL!* = *From Pos.InitialL* → *MoveJ to Pos.InitialL*
- IF *PositionR!* = *From Pos.InitialR* → *MoveJ to Pos.InitialR*

Even more simply, you could still make the movement towards the initial position of competence according to the Beer parameter as the first instruction of the cycle: in the case in the previous cycle it was performed for the same type of beer, the command is performed in a normal way is without creating inconveniences, but simply has no effect because the destination point already coincides with the current one, then immediately passing to the next line of code.

If, on the other hand, a new order is initiated, leaving the previous one suspended in *Wait.i*, it is necessary to distinguish the case in which the new cycle is directed towards the same tap of the previous cycle or, on the contrary, on the opposite tap, because this will cause different movements on the left arm to go to approach the correct knob. In the first case it will be enough to wait for the right arm to head towards the tap and switch the *Set/Reset signal.3* to leave the waiting position where the left hand was stationary. It will head back to the *PresaOFF* position, ready to make the first shot a new order. If instead the tap selected is the opposite one, I have to activate the knob change operation to find me ready when the glass goes to the tap. As this operation requires approximately 7 seconds to complete, the switching of the Set/Reset signal is combined with an earlier point than usual, that is at the moment in which the right arm reaches the point *Presa.i* (with the = 1, 2, ... 6). There is also to consider that if you make the change if the YuMi went to the waiting position, as soon as it closes the plug it should head from that position to that of *PresaOFF* and then start the cycle of change, for a total time too much high. It is therefore advisable to move the decision in the moment when the right arm reaches the Wait position: if you do not need to change the plug, the left arm goes into the waiting position and waits for the signal to switch, otherwise the procedure just described starts.

At this point, choosing the movements based on the above, the right arm goes to the offset of the location *Prelievo.i*, take off the plastic cup, rotates it and brings it to the *InizioSpillatutaDx/Sx* point; the left arm is directed from the starting point in which it is located to the Offset and then to the *PresaOFF* point of the relevant tap, waiting for the signal to switch. The knob is opened (discarding if necessary the first beer that was stationed in the tap, so the theoretical beers obtained from six barrels will be slightly less than 480) and the glass brought into place. A t_{1CL} or t_{1CT} time is then awaited, depending on the expected tapping, after which the knob is closed with the left arm. At about the same time the plastic cup straightening, begun during the stroke, ends with the right arm. When the knob is closed, bring the cup to the Wait position. In the Wait and final positions a photocell (or a piezoelectric sensor, reducing costs to the minimum) will be inserted to warn me if the station is occupied or not through a simple binary signal, allowing the controller to decide from time to time the destination of the glass.
The second station of Wait is a solution designed to have the preparation of several ”contemporary”

beers. With a view to reducing cycle time the first station closest to the plug to be filled will always be the first, with the usual structure, where like before the value 0 refers to the absence of the plastic cup and 1 to its presence:

IF *Wait1Free* → *Standby station = Wait1*
ELSEIF *Wait2Free* → *Standby station = Wait2*
ELSE *("Full Wait stations") AND interrupt*

The values of these load cells will also be used at the beginning of the cycle to verify that the system is capable of handling a new request or has to put it on hold. At the beginning of the cycle:

IF *(CellaW1 AND CellaW2 == 1)* → *"Could not take new bookings"*

Since the presence of plastic cups has already been considered, if the cycle starts and then the Wait positions are both full after the first tap shot means that an external subject is loading weight on the first free Wait or has moved a plastic cup to it area. In this last case, above all, if I went to that position normally, I would have to pour the contents of the glass that was moved by the client, pouring the contents onto the plan. This question therefore, even if at first glance may seem superfluous, it is necessary and in addition to interrupt the cycle I must also print on the interface a message to the customer of the type *"Remove the beer improperly positioned in the position behind the stapler"* in order to resume operations. If at first the system will be destined to a position with personnel that is still close, even if not dedicated, the message will be sent to the latter for the intervention.
After the waiting time, I retake or pick-up again the plastic cup which is already partially full after the first shot. At this point the cycle is divided into two parallel branches depending on whether I chose the legal or German tapping: on this basis I will have a different time with which my glass will be filled, identified by the 2 constants t_{2CL} and t_{2CT}. If in the first case the second shot is also the last one and I will have to finish with the full cup, in the case of German tapping this time will be slightly lower (with the foam that will develop it will still seem full, but leaving it will create a small emptiness on which to go to make the last shot). Anyway, at the beginning I will raise the plastic cup and I will go to place it under the chosen beer tap but this time vertically and resting it on the drip tray. I will go again to approach the point, unlike before only from above, and only when I get in contact with the drip tray the command will be given again to the right arm to reopen the tap for a time that will be one of the two previously indicated. Starting from the *Wait2* station with *Wait1*

occupied I will have to raise the plastic cup of a greater height to avoid contacts during the transfers (without however remaining so high to impact in the taps), otherwise it will enough to stand up to approach position of the second position (a few mm higher than the drip tray). If the selected tapping technique is the German one *(IF SpillataCiclo.i == T)* the last phases of the cycle will be carried out again, with the movement towards the Wait point and then again towards the tap for the third stroke, where the only difference can be given by waiting times.

At this moment we move towards the final coordinate of the delivery point, with a certain altitude, high if I have to position myself in position 1, lower as I approach the thorns. For the delivery stations I proceed similarly to Wait, with a difference. The final positions can be filled in full, if previously already partially full, even without starting a new cycle. It will be enough that the last available station is filled without taking a new glass but going to recover the one previously left in the other location of Wait, whose order was still to be concluded. If I repeat the query on the values of the load cells from the Wait station even when I retrieve a plastic cup in this position, apart from when I start a new cycle, then I refer to the situation of the waiting positions, where the only reason why the cells can be activated all is given by an external unwanted intervention. Similarly, if the situation occurs, the cycle will be interrupted and the message *"Remove the beer improperly positioned at the delivery point"* will be sent out, this time referred to the customer, as it is an area in which he is allowed to intervene. The IF-ELSE cycle through which the final position will be chosen will be:

IF *Finale1=0* → *End station = Finale1*

ELSEIF *Finale2=0* → *End station = Finale2*

ELSEIF *Finale3=0* → *End station = Finale3*

ELSE*interrupt* → *TPWRITE (or write to device "No delivery location reachable! Free a sta tion")*

The following criterion was decided to order the plastic cups: to avoid obstructions during delivery, after the change of coordinates and the insertion of the *Wrist \SingArea* command to eliminate the problem previously explained in the lateral movement from the tap, the preferential order of cups delivery was changed. In order to minimize the angle of the joint 4 with respect to the plane at each point of the translation, it was indeed necessary to keep much lower than the previous quota: on one side they were expected to have positions climbed to an increasing altitude, as already seen for the taking points, on the other to reverse the order with which to fill the stations to keep the low altitudes during the command without finding other plastic cups during the movement. In this way and by reducing the final offset to the minimum necessary in height, I can also reduce the length of the movements with very similar times for each final destination, optimizing all the cycle times and not only one of them. With the stations at increasing height, if the sensors tell me that even the positions on the right are free (via the variables *Wait.i == 0, Fin.j == 0, with i = 1, 2, j = 1, 2, 3)* I know that I can also occupy the volume above the stations on the right, without touching the work surface (contact and risk of inadvertently activating the load cells). The verification instruction to start a new cycle expressed before for Wait positions can be generalized as follows:

IF *(CellaW1 AND CellaW2 == 1)* OR IF *(CellaF3 == 1)* $\rightarrow$ *"Could not take new bookings"*

It can be seen that in the case in which the stations 1 and/or 2 are free but with occupied positions on their left, they cannot however be reached according to the lines of code above. This is because in order to avoid pouring the contents onto the plane the only possible solution was to lower the coordinates of the command that takes me from the tap to the *OffsetFinale.i*. This means that passing close to each final position, if this is full I would go to impact with the plastic cup delivered previously and not withdrawn, risking to waste two orders. The solution to avoid in case of unexpected contacts to pour the potentially full glass, has the main disadvantage of reducing the overall storage capacity of the final positions. Once the correct location was chosen, the gripper descend, the claws open, then we will have the release and return to position waiting for the new order.

Let's now analyze some situations that would lead to the change of plastic cup during the cycle and to their management. If there is already a beer in one of Wait positions and a new order has been accepted, I will probably have to proceed on the two beers alternating the two taps to optimize the time. The minimum waiting threshold has been currently set at 60", but this threshold is not standard and may vary according to the type of beer and the type of tapped. Since the types of beer can also vary over time, we do not have a clear idea of the gap is the different expectations that there may be and if this gap will still be less than the withdrawal time and the first stroke of tapped or not. It will then insert a waiting time variable attached to the cycle called *TempoAttesa* on which the time elapsed since the position has been continuously subtracted (with consequent activation of the connected load cell), measured thanks to a Clock, defining a new variable connected to the cycle:

TempoResiduo.N = TempoAttesa.N - TempoGiáAtteso.N,

where N is always the number associated with the cycle. In the case in which activating the new load cell when the Wait station is reached filling both stations, then I will compare the residual time of the two stations choosing to continue the cycle of the cup with inferior *TempoResiduo.N*. I can therefore remain on the current plastic cup in the grip or I will have to activate a special procedure to release from the plastic cup opening the fingers of my hand in the grip, lowering and withdrawing and then heading to the other cup. With the change of glass I consider the cycle associated with it and change the variable that declares which is the current cycle, which is the cycle for which I will have to follow the next part of logic.

$$\text{IF } TimeStart.i < TimeResiduo.j \text{ AND } TimeInitial.i < TimeResiduo.k \rightarrow Current\ Cycle == Ni$$
$$\text{IF } TempoResiduo.j < TempoResiduo.k \text{ AND } TimeInitial.j < TimeResiduo.i \rightarrow Current\ Cycle == Nj$$
$$\text{IF } TimeResiduo.k < TimeResiduo.i \text{ AND } TimeInitial.k < TimeResiduo.i \rightarrow Current\ Cycle == Nk$$

I'll have to see if the type of beer of the two plastic cups coincides or if I have to go and command the left arm to begin the change-knob procedure. We could also evaluate an aspect not considered at the moment in the future. The German tapping is done in a rather long time, and delaying it further could make the wait incompatible with a good tap. In fact, very long times, considering that the glass is made of plastic material and thin and therefore has little ability to maintain the temperature over time, would lead to the service of a beer that has already increased its temperature. In order to solve this catch and favor the withdrawal of these cups, it could give precedence to beers with this type of tapping defining a constant to be subtracted from the *TempoResiduo.N* variable for comparison.
If, on the other hand, I have a full load station, I will compare this value with the threshold value to decide whether to go to complete the cycle on that plastic cup or start a new order. To optimize the choice there may be different constants, determined on the basis of the cycle counter and therefore on the basis of the sampling station used and the tap used, to check which is the most convenient choice from the point of view of time. If there are no new orders at the end of the cycle, this constant will be set by a very high value (Ex. 1000 s) to proceed immediately to the conclusion of the tapping for the glass stored in the waiting positions. For the same reason, as soon as a cycle has ended, it is necessary to disassociate this cycle from the Current Cycle parameter to avoid that the values associated with it are erroneously compared in the future. Fictitious very high time values can be used as waiting time for empty waiting stations. To avoid that in the absence of orders and plastic cups in Wait stations new random operations are started, for safety it will be necessary to command the start of the new cycle only if the time corresponding to the comparison will be less than that set for the constant representing the absence of glasses/orders.

At the moment of leaving the tap after the blow, each time a variable of time reappears, depending also here on the type of beer stapled: the variable will be called *TB* for the cycles concerning the blond beers, *TR* for those concerning the red beers. Otherwise the value continues to grow and informs about the time since the last tap. When I start a new cycle, if *Ti* < *Tinactivity.threshold*, where *Tinactivity.threshold* is the limit value beyond which I delete the first drop contained in the tap, nothing changes with respect to what has been said. If instead the value exceeds the threshold, instead of waiting for the command of *Set/Reset.3* to operate the left arm, I immediately send it to eliminate the beer present in the tubes, opening the tap for a minimum time and re-setting the corresponding variable, before to move to the standby position and wait for *Set/Reset.3*. In this way, I optimize the amount of beer used, reducing waste, without inserting a station just before the *InizioSpillataDx/Sx* position for each tap; in the case of continuous tapping it is not necessary to discard this beer.

The RAPID program contains an instruction in RobotStudio called *LoadId* (Load Identification) with which the system, through the *GripLoad* command, can detect the load associated with the arm. For every point in the cycle since I start tapping on, this value could be used to make a primitive check on any beer losses from the cups. In fact if no contacts have occurred and the value of the weight goes down from one position to another (always associating the load to the cycle, it does not have to be in the case of a procedure that activates the change of the glass) means that I have had a loss of liquid from the plastic cup. However, it will still be necessary to investigate this aspect for several reasons: the system could realize that the load that is present after the last tap drafts the payload and interrupts the cycle, making the command counterproductive. Or this instruction may not be sufficiently precise, or it could still be used only when the glass is still (because it cannot compensate for the effects of movements and accelerations in reading), making it useless in a system in which it was important to optimize the times. If the command turns out to be usable I could activate a "trash" procedure. The trash was positioned, as has been identified the position with relative configuration of the joints from where to release the plastic cup, but was not physically realized in the prototype due to lack of time and residual doubts. The movements have been identified to go to the trash can from the different points with a "collection point" for each area (taps, Wait stations, one for each final position) to direct me towards it, as explained in the next chapter. At the same time, a new waiting cycle similar to that of the discarded glass will also be inserted to serve the customer who paid the order. In the second shot location the load value could be used as a check to verify that the beer is full enough to be delivered, by entering a threshold value; in case it is not respected, it will be delayed to close the knob for the left arm until the condition is respected. This operation, however, is also delegated in the future, after having verified in practice the reliability and accuracy of the value provided by this command, in addition to the speed with which the controller computes this value.

12.2 Microprocessor or PLC

For the management of the variables associated to the cycle and the communication of the signals to the control unit of the YuMi we can also manage everything from the internal control unit with some limitations with respect to variations that could be realized in the future (for example, if one wanted increase input and output numbers). The internal controller would also have the ability to manage time-dependent variables, such as those that would be used explained in autorefChapter12.1. However, there is the disadvantage of doing so only by communicating with an ABB terminal of the CP600 series through ethernet in a similar way to what is happening, during the design phase, through the FlexPendant. Once the IP address has been associated, the terminal is detected by the central unit, as it happens for example for the smart-gripper. ABB has already provided the communication protocol between the panel and the YuMi: other solutions cannot be supported. A communication protocol is always necessary when there are several components that communicate with each other through a single cable. We need to provide a series of rules, called protocol, to provide for multiple and simultaneous access by transmitting data correctly and as quickly as possible. If you want to communicate using an APP, you need a PC interface and access to the communication network. If you want to keep more free with regard to future developments of the system, easily expandable, you have to evaluate two options as an alternative to delegate the entire task to the control unit YuMi: you can rely on a hardware device or a PLC. A hardware platform consists of a series of electronic

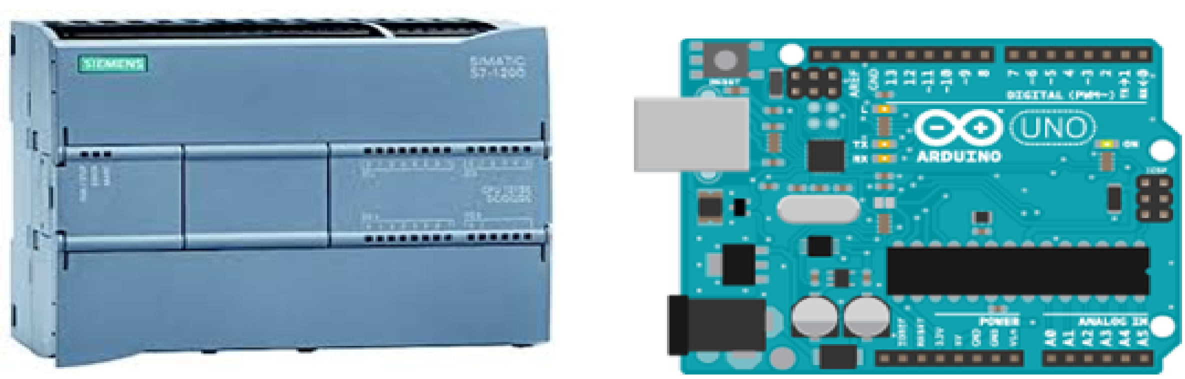


Figure 12.1: **A Siemens S7 1200 PLC and an Arduino UNO board**

boards equipped with microcontrollers, plus an IDE (Integrated Development Environment) [ARD]. The IDE is an integrated development environment, thus a software that allows the programming of the device and signals syntax errors during the writing process. It is called integrated precisely because inside it there are several components:

- A source code editor
- A compiler or interpreter
- An automatic building tool
- A debugger

Among the various hardware, our choice would fall on Arduino: the advantage of this solution is mainly the low cost of the product, as well as the strong versatility in communicating with a very wide range of other electronic devices. It is also available in many different versions depending on the required use (for example depending on the number of inputs/outputs required) and circuit diagrams are available as free HW (but it is a closed-source hardware, for example it is not possible to intervene to modify it or to provide reverse engineering). If it was planned at the time of the purchase of the card, to expand the components at a later time it is sufficient to connect the new elements or sensors to the previously excess connections, then reprogramming the card to manage the new signals, but continuing to use all the components already present.

The alternative is represented by the PLC. The PLC (Programmable Logic Controller) can execute a program using analog or digital input signals from the external environment and providing output signals to the outside as DC voltage values. It is a modular hardware object, in the design phase according to need, it is possible to choose different input and output cards (usually digital), which together with the CPU and the power supply form the PLC. In the case of handling operations, the PLC also houses the axis control cards, which are very fast cards that allow to manage displacements and positioning, which in our case is implemented by the YuMi. The CPU is the area that makes the PLC able to manage the program, interfacing through BUS with the various cards present. The memory is often external, as in the case of EPROM memory, with greater ease of programming and modification of the program.

Among the advantages of Arduino there is certainly the cost, both of the equipment itself and of the accessory elements, cost anyway in the order of a few hundred euro: in our case, with a PLC probably it would not be necessary to initially insert a small PC to manage the system, but even if done would produce only a slight increase in cost, easily amortized by the great saving of time in design. As it is easy to understand this problem would be transmitted not only in the costs but also in the volume that it is necessary to make available by subtracting it from the tapping system and other parts of the system. The PLC has other undoubted advantages. The main advantage, which is probably the most important feature of any other in these considerations, is related to the reliability and stability of the system. A PLC is specially developed to work on industrial machines (which will actually be our system), it is less sensitive to interference, vibrations, dirt, humidity and temperature variations and gives more guarantees to repeat its procedures always in the same way, something of vital importance in our application, resulting even more durable as a component over time. Another advantage is in the development time necessary to interface with the central unit of the robot. With external hardware it is necessary to develop a communication protocol between the hardware and the YuMi Control Unit on both sides, a long and complex process. Considering the Siemens PLCs, among the most widespread on the market, there are two different communication systems already developed and widespread: PROFINET and PROFIBUS.

The PROFIBUS (PRocess FIeld BUS) is a field bus that allows a single cable to connect the various nodes that make up the network, between the units predisposed to the command (master, like the PLC) and sensors, actuators (slave). Defined by the IEC61158 [CCID] standard, they guarantee on the maximum transmission time, thus guaranteeing a minimum speed and have their own safety systems. The PROFINET (PRocess FIeld NET), is a fieldbus system developed by Siemens and is based on an international standard for the Ethernet communication protocol (IEEE 802.3 standard). It is a technology much more recent than PROFIBUS and ensures extremely short time for both data transmission (0.25-1 ms) with very limited jitter, and for diagnostic operations to be performed on the system. At the same time, in case of non-criticality from a temporal point of view, slower communications are also allowed. The PROFINET (developed for the Totally Integrated Automation) is then very versatile and compatible with many other devices, also allows you to safely manage the system (with shutdowns of type 0 etc., according to the normative, which in our case under the jurisdiction of YuMi). For all these advantages, for the possibility of communicating with external devices without the need for a cable (facilitating maintenance), this solution is undoubtedly the best of both.

The PLC can communicate via PROFINET. In this way the protocol is already developed and it is only necessary to set variables for the passage of information between one unit and another; for Arduino it would be necessary to develop the protocol both on the hardware and on the robot side. This method of data transmission means that the PLC CPU works differently from the previous one,

reasoning on a "mission" and managing in first person the cycle and the various timers to decide the cycle that will have to be done in the immediate future. Not, as happens in the computer world, on a program with several parallel branches that can be covered or not depending on external conditions, with a different approach and a development a bit different from a cycle developed on RobotStudio. Communication with the outside via PROFINET is very fast, probably even faster than it would happen with a hardware card like Arduino. With this system a certain number of bytes will be reserved for the communication between the two components, on the one hand on the output to the PLC, on the other on the input to the robot. Each bit can be associated with the value of a binary variable or a certain number of bits or bytes in the case of an integer or real variable. From the values of the variables received at the input the robot chooses the next operation to be performed.
Another advantage of interfacing with an external system could be related to the possibility of future developments: providing a PLC or board with a minimum *I/O* revenue allowance would add new variables in the future, expanding communication with the external environment without having to revolutionize everything. Since it is made up of modular blocks, it would be enough to add some of these modules if the expansion should lead to the need for greater computational capacity. Starting from a management completely entrusted to the control unit YuMi, the risk would be to even move from a robot-only programming to a system with an external interface, completely revolutionizing the programming, with enormous waste of time.

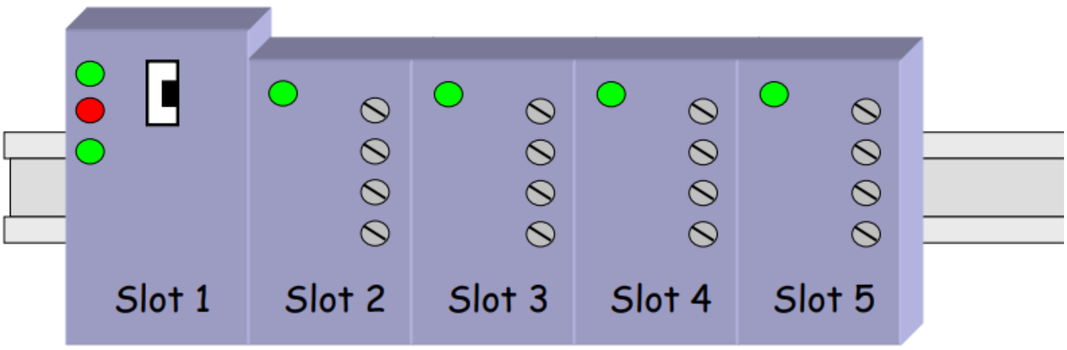


Figure 12.2: **The modular concept of the PLC**

For all these reasons, keeping as many times already mentioned reliability as the main choice parameter for our system, PLC seems the best solution that can be applied, even if at the cost of a certain volume decrease under the work plan. As it will be adjacent to a tapping system, even if it is under the bench, it will be necessary to assess how to protect against external inclusions both the PLC (those hypothesized have an IP rating of 20) and a possible PC, ensuring at the same time the exchange of air for cooling.

12.3 The PLC

The PLC can be easily programmed remotely, has reduced time and ease of interfacing with an external terminal. In addition to the YuMi, we will interface with a small, basic and functional touch screen on which the customer can make choices. Also this terminal would be on one side economic, on the other convenient to use and rewarding for the eye, while the development of a special app will probably be only a next step, where then go to improve the graphics, quickly explain the story of each staple available and because it matches that type of beer, or the importance of a correct tapping or foam, etc. In this case it will also be necessary to decide which decision level leave to the robot and which one give to the PLC instead. The robot could therefore receive only the information from PROFINET to start a certain part of the second cycle of the variable supplied via the bus from the PLC. Making a concrete example, the PLC could be supplied with the cycle counter variable since the last time the plastic cup magazine was filled. The PLC, after checking that at least one Wait and the *Finale1* station are free, that pressure and temperature in the system are normal, plus a series of further checks, depending on the number of the variable *Ncycle* will activate a different signal output, represented by a binary variable. For example, the bit in position N of the variables used at the interface for data exchange, will be representative of the request status to the robot of the taking position *Presa1*, the next of the request for the taking position *Presa2*, etc. In this case the YuMi is simply delegated to the carrying out of the movements related to the taking position *Presa1*, acting as a pure performer and leaving the entire decision-making power to the PLC. Mixed solutions can also be decided, in which, for example, the PLC, after executing the initial controls, commands the operation taken, which consists of several CASEs in parallel inside it programmed on the robot side. Depending on the input variable of the cycle counter, it may be the robot to direct it to one rather than to the other sub-cycle to move towards the correct pick-up point. With a PLC it is much easier and faster to diagnose the external environment, to monitor the situation in real time using the information coming from the various sensors. This diagnostic will be continuously repeated to provide the system with the necessary interrupts in case of need.

A quick search was also made between the various Siemens range PLCs to get an idea of what could satisfy our needs so as to evaluate the necessary investment required. These PLCs can be programmed through the Step7 program, which also uses the very common ladder language, among others. There are different categories of PLC, depending on the properties, the internal memory present, the number of inputs and outputs, and so on. In our case, for instance, the classes 300 and 1200 were taken into consideration: observing the specifications, however, the latter seems the best because it also has the

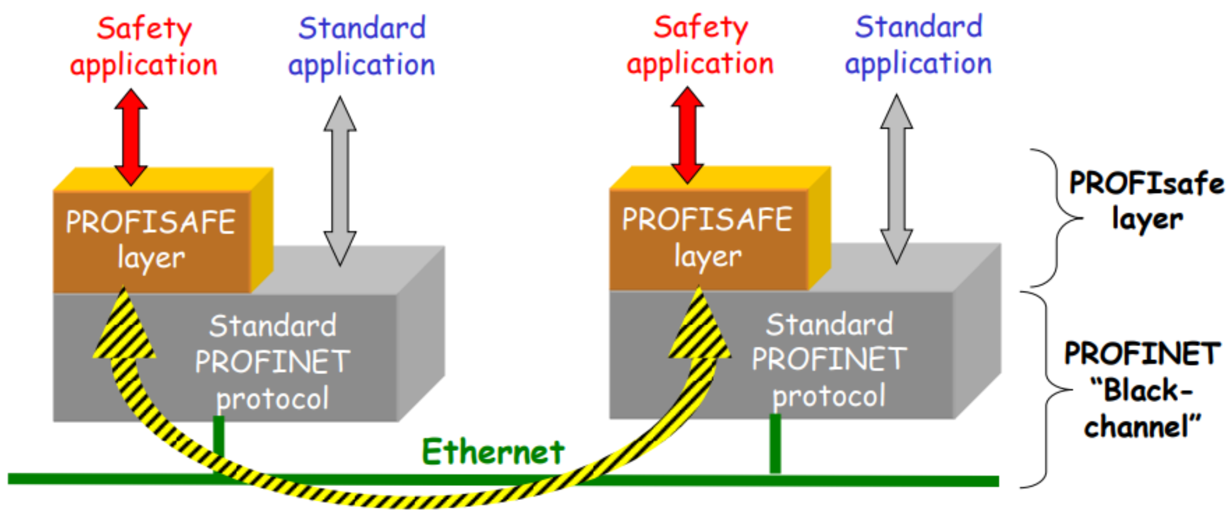


Figure 12.3: **PLC inner communications**

ability to receive two analogue inputs, while the signals that can be managed from the 300 are only digital. For instance, analogue signals that could be useful for the control of the system would be the data concerning the temperature of the plant or the controlled temperature environment in which the cylinders are stored, or the pressure inside the kegs to control from PLC the switching of the solenoid valves to the exhaustion of the keg in use. These PLCs also have the characteristic of being modular and therefore compact and easily expandable. Despite the fact that PROFINET allows many external devices to interface with the PLC, here too, as for the case where the management is entrusted in full to YuMi as explained above, SIMATIC terminals developed for this brand of PLC, with different capacity, costs, dimensions [Bas12]. The cost must also be weighed here to limit the overall system, but we must make sure that anyone can easily interface with it to order the product and be able to do it on a touch screen panel. Therefore, the choice between the different panels is limited to those with a touch screen of a minimum size of 7 inches. The integrated PROFINET is in fact available from this dimension, which we considered necessary, already from the Basic Panel line. From the aesthetic point of view, then, very good the fact that, if chosen in color, the screen has high resolution and 64 thousand colors, so you can reproduce even more complex environments and also have different Viewer, for example to display archived files in *pdf* format. On the other hand, from the point of view of security and system functionality, it is important the integrated system diagnostics and that sufficient energy can be buffered to terminate the active archives and save the already archived data. Really excellent and reassuring even the use temperature, between -30° and 60° C. The two main dimensions between which to define our choice will probably be those of 7 or 9 inches of the Basic line, named respectively KTP700 and KTP900: the first one has a price in the order of € 600, the second one of about € 1000.

Figure 12.4: **A SIMATIC KTP900**

Chapter 13

NEXT STEPS

13.1 From the prototype station to the real plan

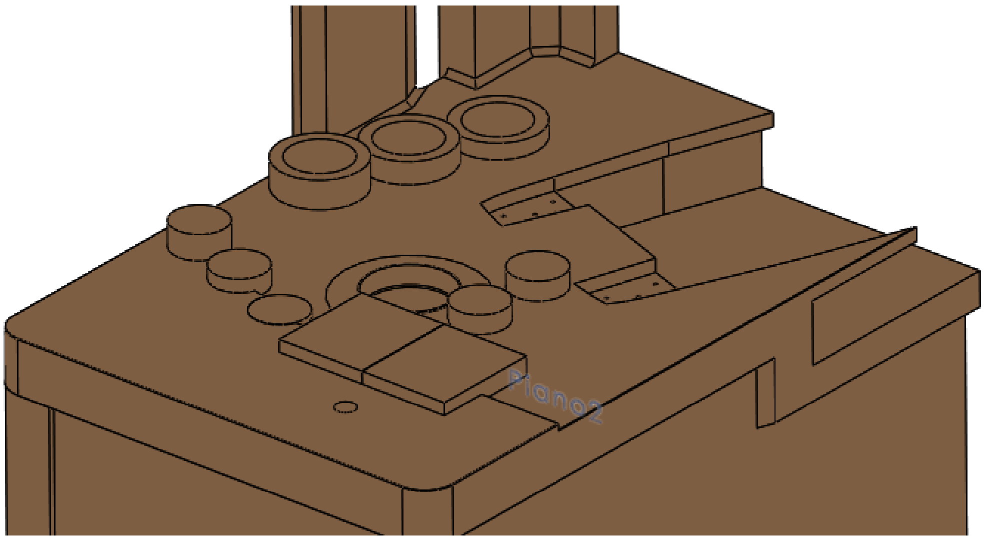


Figure 13.1: **The final workplan design with the trash can position idea**

An important development on the table can be made towards the main element that has not been created in the actual location: the trash can, as can be seen from the image above, to avoid increasing the volume outside the impression of the table. This operation has been postponed after the others as it is ancillary and dependent on the positions of all the other principal points of the cycle. The hole in the top to allow getting away the plastic cups has been identified at about the position of *Wait1* on the abscissas and of the *Finale1* position on the ordinates but even closer to the drip tray. This proximity is due to the fact that in addition to reaching the point it is also necessary to provide enough space to move the clamp away without it or any other part of the YuMi arm coming into contact with other components. This new position certainly brings advantages from the point of view of time to get rid of the broken plastic cups, because if the load sensor will be usable, it will be able to notice the leak in an area between taps and Wait stations, and will not have to cross back across the bench to throw it all. This latter movement would also have the disadvantage of spreading liquid for most of the floor, with the usual problems of oxidation of the liquid over time, a negative aspect to be limited as much as possible. The hole has a diameter of 130 mm, greater than the maximum diameter of the glass that is 96 millimeter in area much lower than the dustbin provided previously: this is because the slow rotation of the cup above the dustbin is no longer required before it is released from opening the claws, necessary because the maximum opening of the fingers is still less than the maximum diameter of the glass. This operation would have provoked sketches first (unless the rotation is really slow, at the lowest possible altitude), even more annoying if the station is central and close to all the others. Moreover, even having such a large void in the center of the table would not have been nice to see.

The upper edge of the hole is raised 10 mm compared to the rest of the top, for a very precise reason, in fact allows the nipper to place the plastic cup partially in the hole before freeing from it. This height is useful and theoretically could have been even greater (up to 24 mm I did not hit the plane with the fingers of the clamp) but increasing it further would have meant collisions with the edge being released from the *Finale1* position. Here the problem arises of the release from the plastic cup without the 180° rotation: I cannot release it simply by opening the claws and then placing the lower part of the side wall against the edge of the hole. Since the opening of the fingers is not sufficient to make the glass fall directly because it is still smaller than the maximum diameter, the cup would slide slightly before being placed again with the fingers thanks to its taper. Moving back then you would bump with the dustbin's mouth with the base of the plastic cup, while the friction at the top would create a tipping moment, not towards the trash can, but towards the floor. This would create a strong probability that part of the residual beer will be poured onto the table with discriminations that cannot be controlled as the mutual friction between the plastic cup and the fingers or the quantity of beer still present in the plastic cup at that moment. This way is therefore not feasible, also because it presents the need for long movements for the release in restricted spaces. To the classic release which foresees to move back so as to bring the fingertips away from the edge of the cup directed towards the nipper (with a minimum movement of about 90 mm) it should also be considered that the beginning of the disengage would occur only when the edge of the hole comes in contact with the wall of the plastic cup. This causes a loss of another 5 cm, which cannot be recovered because there is no possibility of further moving the dustbin's mouth. It is therefore necessary to provide a support base to the table top on which to place the plastic cup, which is kept in a mechanically open position by means of a solenoid valve or another actuator only when the robot's hand has finished disengage it, to discharge the all in the trash can below. If this solution is chosen, the actuator will have to be powered and will complicate the system, but at the moment it seems the best solution to eliminate any glasses that break during the cycle. In addition, the door remaining closed for almost the entire time, will also provide a further obstacle to the spread of bad smells over the work surface.

Given the actual very central position of the dustbin on the floor, a simply cylindrical downward hole, developed as before, would have made the waste bin itself to be uncomfortable, on the other it would have "broken" the volume present for the plant underneath the work plan, making it really difficult to find room for all the necessary components. Therefore, after having provided for a vertical drop of about twenty centimeters from the hole, the dustbin, an inclined plane is provided which causes the plastic cups to slide outwards, up to the side wall close to the cup-dispenser of the station 6. In this way without taking up too much volume under the bench, the necessary space is provided for the cups and it is more convenient to pick them up for disposal from a door inserted at the bottom on one side of the system, on the same side of the carter where the picking positions stand. The only precaution was to provide enough space for the glasses to slide to the bottom of the available volume, without getting stuck due to a too narrow entry. Even if the plastic cups do not remain in correspondence with the hole but a bit lateral, to avoid the development of bad smells it will be necessary to empty and clean the dustbin at every maintenance intervention. A small hole could also be provided at the base of the bin which, if opened, would allow the beer to drain out of the cups before opening the door (risk of pouring liquid everywhere).

In addition to the dustbin from the physical point of view, the various movements have been planned in order to reach it and free itself from it. Since these operations are subsequent to the development of the real prototype system and it is not said that this solution is effectively applied in the final system, the search for the points and the simulation have only taken place via RobotStudio. So we tried to find points that would ensure we can reach the dustbin and come back from it, without going too far to worry about the harmony of the movements or the time needed for this phase. This harmonization will eventually be done in a phase following the development of this elaborate, above all because the discourse is linked to the behavior in practice of the sensor through which the control unit of the YuMi can detect the weight of the applied load. The release starts in any case from the dustbin and once the end, the cycle has been completed and it has not been successful. Therefore, we are ready to go back to the *Start_Stop* point, from which, depending on the control unit's commands, we can start again for an identical cycle to serve the customer not satisfied or we can conclude a cycle previously suspended in the area Wait before repeating the missing cycle. So after opening the claws in a similar way to the final positions, you go lower and then back to avoid contact: at this point on one side is commanded to open the door, with the consequent descent of the plastic cup on the bottom of the bin; on the other hand, the hand returns to the initial position, with movements necessary to avoid bump the arm against other parts of the system. The direction along which the arm moves during the retraction has been optimized to allow movement as long as possible without causing shocks, which tended to occur mainly between the backward elbow and the three cup-dispensers stored at the bottom. Instead, the situation is more complex to reach the dustbin offset point: the leak could be detected between any two points in which the test is carried out, thus since the glass starts to be filled and when it is released from the same. It was therefore decided to identify a collection point for each macro area, from which to then go to the OffesetPattumiera point. The different areas identified are: RubinettoSx (*RubinettoSx*), RubinettoDx (*SecondoColpoDx*), Wait1 (*Wait1Dx*), Wait2 (*Wait2*), Finale1, Finale2 and Finale3 (the relatives offset points). A point has been chosen for each area, such as to avoid collisions with other points in the system or with other cups temporarily stored in *Wait1* or *Finale3* positions (those near the bin) and in any case or almost directly accessible from the point of corresponding area in which the breakage of the plastic cup is detected; otherwise they must be reachable by moving to an adjacent point before arriving at the chosen one. The points specifically identified for these movements are indicated on RobotStudio with the following names:

OffsetPattumiera	Pattumiera	RibassoPattumiera	UscitaPattumiera	SvincoloPattumiera

As you can see in the image related to the worktop at the begin on the chapter, this floor has been slightly raised between the delivery stations and the customer, also to avoid inserting the column of the stapler on a base at a different height than the plan, as happens for example in the prototype system. The new part of the plan thus obtained, even if it has a fairly limited size, is much more homogeneous, at a height very close to the *Finale3* station and separates, at least ideally, the area of competence of the robot from that of the customer. By painting the two areas on one side with two different colors, I would further distort the perception of the robot from the client, on the other probably this effect would make the customer less able to interfere in the area where the movements of the YuMi occur.

Very important, now that the plan is defined, it will be the choice of the material that will constitute it: this choice must be weighted and meet the objectives both from an aesthetic point of view and similarity with a real bench, both hygiene and durability. Firstly, in order to facilitate cleaning, it is good practice for the surface to be smooth and not wrinkled. Using wood, even if it would increase the proximity to a real counter, could reduce its useful life if the plan was scratched or etched and the humidity or beer would come into contact with the wood not protected by a special layer of paint; even if this discourse must still be dealt with in detail, it seems a better solution to rely on a good quality metallic or plastic work plan

13.2 Tapping taps (not executed)

It was not possible to complete the tapping part of the real beer on the real system in the laboratory, because of the available time it would have been necessary to provide for the change of the stem of water with those of beer, which proved to be too narrow between the moment in which the cycle evolution part was completed and the date on which YuMi ABB had to be re-packed. The careful analysis of the cycle with water allowed, however, together with the knowledge of the behavior of the beer and its foam, to prevent various potentially harmful situations. Probably this will reduce the future phase to a simple adjustment of the time between the various strokes of the cycle, to verify that an excessive or deficient amount of foam is not formed for each phase. This operation will in any case be repeated or at least to be adjusted even if it is decided to change the type of beer to be tapped with respect to those estimated, to adapt from time to time to the different characteristics. After defining the opening for which the desired amount of foam will be obtained, the small adjustment lever will be locked. Further minor adjustments may also be necessary due to the fact that the claw will be slightly lighter than the test one due to the lack of the intake and vision module, with a minimum increase of the available torque, or for any change of future components concerning nipper, beer, glass or thorn. These adjustments on the tap will become more important if you decide to change the nippers or lighten the fingers.

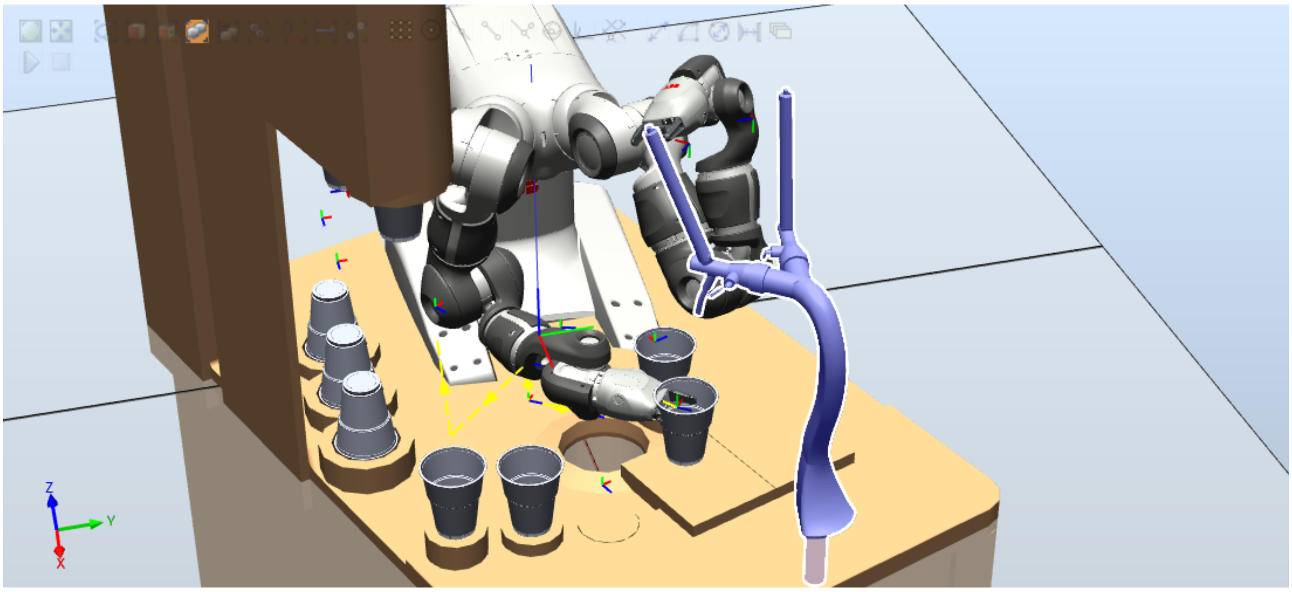


Figure 13.2: **A tapping phase on RobotStudio**

Chapter 14

POSSIBLE FUTURE DEVELOPMENT

14.1 Robot as smart object: app idea

As already indicated at the beginning of the development of this thesis, in order to make the system human-friendly towards potential clients it will be necessary to use not only aesthetic devices, such as characterization of the bartender, providing human and sympathetic connotations and dressing it appropriately through the tissues used to increase its IP rating. The task of using modern technology to engage the customer will be very important. In this regard, given the development time that had been set, it was thought in a first step will be integrated touch panel to acquire the different orders provided by the customer, at reasonable cost but at the same time of a size that can be comfortably used.

In the following phase, developing an APP through which communicating directly via smartphone would undoubtedly improve this aspect, on the model of what was seen with Makr-Shakr [Mak] in the analysis of market solutions. In this phase it will also be possible to create a more advanced graphic and environment, with the possibility of illustrating to the client some aspects of tapping and the peculiarities of the different techniques and beers, if his order is waiting or in preparation, and in what phase it stands. In this way, a non-malicious customer, but only distracted, would be less likely to take an order that was not yet complete. Furthermore, it would have the advantage of eliminating a component such as the touch panel which could be subject to breakage problems, fortuitous (on-site or during transport) or malicious, which would invalidate the operation of the entire station until the external intervention occurred.

14.2 Schunk manipulators

As we have seen during the whole thesis, the big constraints in the development and reliability of the system are given by the mechanical constraints imposed by our YuMi ABB, by the weights it can bear and by the forces it can impose. We cannot of course go to intervene on the robot's engines or bypass some procedures to ensure the security and provide the system's collaborativity, but to the already defined real system we have come to know a new component that could improve the properties of our system in a future real application. The Schunk in its cooperative branch *Co-Act* develops a good variety of grippers, including two designed specifically for the YuMi ABB robot. This in itself is a considerable advantage because the connection between the gripper and the robot arm is correct, without the loss of time, costs and the increase in weight downstream of the caliper given by the adapter which would move the load center of gravity away, decreasing the useful one again. Even without the presence of this adapter, these are the two pivotal points on which to focus when we analyze the characteristics of the Schunk grippers: the weight of the gripper and the distance of the load from the attachment of the claw to the robotic arm. This is because both the increase in weight of the this gripper and the distance of the center of gravity of the load contribute to the resulting moment, with an increase in torque that the YuMi must subtract from that destined for the load. From the feedback we received from the system implemented in the laboratory, we have thus a third parameter that proved to be lacking in our case, that is, the maximum grip strength provided by the claws; the strength we currently have risks of not being enough, regardless of any knurling or a possible insert of different material to increase friction. In some ways this problem can be solved, for example with regard to the sliding of the plastic cup downwards, as it is filled, also due to the forces which tend to open the two nippers due to the taper of the cup. The solution could be to reproduce the corresponding part of the negative in the plastic cup on the finger grip area, where there is a change in its taper: this would have a real support for the cup, safer, without the sliding that has the correction of the coordinates for the waiting areas and final delivery in the cycle was necessary. After seeing the real finish of the prototype hands we can say that such a solution could be proposed again using the same 3D printer material directly. Moreover, the replicated shape of the plastic cup would allow a much more precise reciprocal position between the claw and the plastic cup, with different advantages:

- a reduction of a couple of millimeters of the center of gravity of the load-claw compared to the average of the grips in our tests, given by the decrease in diameter in the grip area

- a continuation of the arc over half of the circumference, as envisaged in the test finger even if then filed to allow withdrawal and release from the beaker, it could be made to a lesser extent (thus projecting less) but thanks to the precision of coupling and support, however, provide a reaction to a force that for some reason tried to push the plastic cup out of the claws

This solution, however, has no weight in the sampling phases of the cups: the available torque, very limited despite the sheath designed to increase friction, also has the function of withdrawing the glass and dragging it out of the cup-dispenser. We have not yet tested the cup-dispenser in practice, but since the robot was not able to take the plastic cup already only if pressed with too much force against the previous increasing friction, it is presumable that even the resistance offered by the rubber sheath at the dispenser outlet can greatly reduce the reliability of the system. This is why this aspect needs to be improved. This shaping of the fingers would not change the retraction procedure seen during the programming phase, which would always remain valid.
For the sake of clarity, let's briefly return to the force that the clamp is able to supply to the clamp currently. As can be seen from the image below, the maximum gripping force is 20 N up to a maximum of 40 mm, to then decrease.

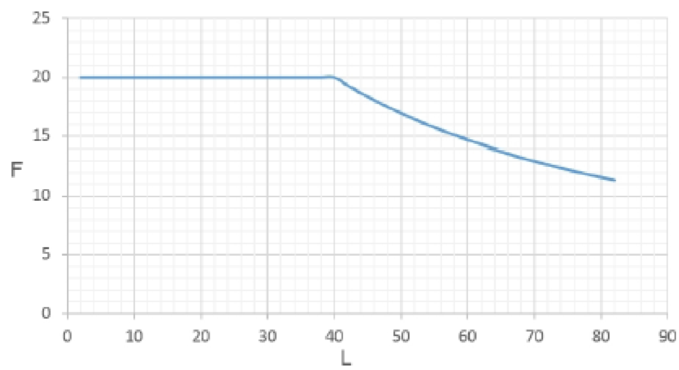


Figure 14.1: **The gripping force applicable by the YuMi depending on the center of gravity distance from the end of the gripper**

Furthermore, moving away from the upper edge of the plastic cup, I could have another advantage. For the posts at the bottom, the hands to pick up a cup in positions 5 and 6, each time he came to a position very close to the previous taking positions: if, as it should be, the plastic cup was pushed up to the edge of the collar, both that is at the beginning or end of the column, I have no additional problems. If, instead, as the cup-dispenser is emptied, the spring is not able to bring the various glasses exactly in the same position, with the passing of the cycles I could erode the narrow margin between the gripper in the previous station, now empty, and the collar. Since the diameter of the plastic cup in the intended grip area is about 38 mm and the overhang given by the base compared to its housing is equal to 14 mm, it is not possible to fit accurately into this parameter even recovering a couple of millimeters making "re-enter" the cup. The graph will then drop to about 17 N, a value that does not change in substance even if another pair of mm is recovered for the new diameter provided in case the housing is made. The possible solutions provided by Schunk are essentially two, the first pneumatics and the second, its electrical evolution, even more recent. For the pneumatic gripper, with the model name MPG plus 32 [MPG17], the power supply is not the one that the YuMi can provide internally, which has a very low power (payload indicated of only 150 g [YuM]). At the base of the gripper there are two standard connections for pneumatic supply which internally go directly to control the valve that contains an elliptical piston, as you can see in the **??**

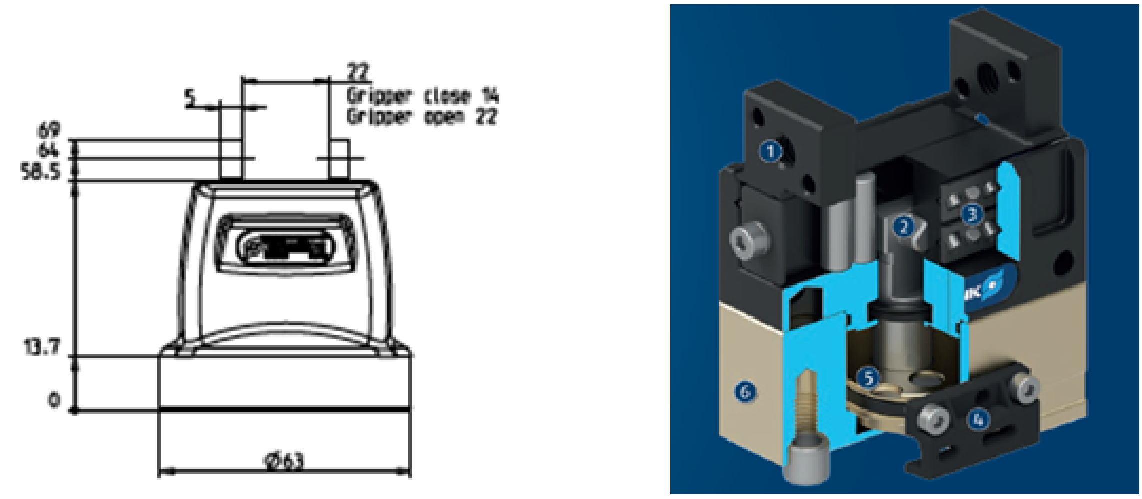


Figure 14.2: **MPG plus 32 dimensions and a 3D section of the element**

On the left there is the front view of the caliper, in which the circular part with a diameter of 63 mm serves as a link between the actual gripper and the arm of the YuMi. Compared to the standard gripper, it has some advantages among the listed critical characteristics. The total weight of the claw decreases in a non-substantial way compared to the current situation (remember that between the clamp, fingers and full plastic cup it reaches about a weight of 640 grams): from the data on the CAD drawing the total weight is 207 grams, compared to 215 of the standard clamp without filters and suction modules, vision [MPG]. Of these 100 grams are due to the MPG-plus 32 module sectioned on the right, the rest to the casing-adapter assembly and to the quick-connect connections for power supply. Very interesting, however, is the reduction of the overall thickness of the gripper: in the standard solution the base of the fingers was housed at 84 mm from the clamps, here the share drops a lot and is 58.5 mm, 64 mm considering the final hole appendix. This means breaking down the bending moment at the base of the gripper, with less effort on the part of the robot. This effort already remains within the limits for the right arm, as it is no longer necessary to cut the accelerations, but it can be very useful when handling the knobs, as the amount of torque needed to balance the weight of the gripper will decrease. The pipes of the external power supply will start from the base of the gripper and will go towards a small external compressor (which will need to be evaluated if it can be the same that provides to blow the CO_2 into the barrel); from an aesthetic point of view these could immediately be inserted into the fabric that will be necessary to increase the IP rating of the system.

Very different is the attack of the fingers to the claw, in which the stroke of each individual finger/s changes first. This stroke is greatly reduced, with a difference of only 4 mm per part (8 total, compared to the previous 50) between opening and closing, with a distance between the two appendages coming out of the caliper that varies between 14 and 22 mm. This opening, however, is the one that has been used in laboratory tests to take plastic cups and therefore can be considered sufficient, it being understood that this must be taken into account in the design of the part between the TCP and the fingertips of the new claws. If these grippers will be used, the connection between the fingers and their housing should be completely re-established, which as seen in the **??** is now on a different plane. It will take about 80 mm in the opening configuration, starting from 32 of the open configuration: this higher excursion should not increase the weight of the first part of the new fingers, because given the plan they would be fixed on, it is no longer necessary to spend material to advance the base, moving the load center of gravity away, before earning at the opening. Moreover, to reduce the weight, as mechanical efforts on the fingers did not seem a critical parameter for the type of 3D printer material used, one could consider the option of creating a monoblock of this material (with a specific weight slightly higher than the unit per dm^3) without going to use the heavier aluminum. Alternatively, the thickness of the material may be slightly reduced at some points, especially due to the thickness of the material beyond the area where the plastic cup is taken, the function of which is purely aesthetic and does not support the load. Again, if you wrap your hand with a glove similar to that of disposable gloves, you could puncture the fingers along different directions, removing material. The idea is to recover from the fingers about another ten grams of weight, and about 5 mm as a decrease in the distance between the center of gravity of the plastic cup and housings (2 of which due to the reduction of the radius at the point of grip), compared to the current ones.

Going to see the technical characteristics of the product we observe that the maximum load to be applied to the clamp, equal in our case to the glass more fingers, is equal to 430 grams, parameters in which we return while exploiting it almost fully. To improve also in this case it is the IP degree, which at the beginning is equal to that of the YuMi (30) while though not so important the opening speed of the nippers is improved, which passes from about 0.3 s (for the closure foreseen in the tests of laboratory) at 0.02 s; on the contrary, it will be necessary to verify that the increase in speed does not lead to excessive violent impacts. It also improves the maximum temperature at which the clamp can operate, going from a maximum temperature of 35° to a maximum of 100 (it is important that it covers the entire range provided for the YuMi): it is therefore more than safe for high temperatures, while we must continue to consider the minimum temperature of the environments in which it will be inserted to avoid surprises. Returning to the last fundamental point, that of the force in opening and closing, we comment on the following graph:

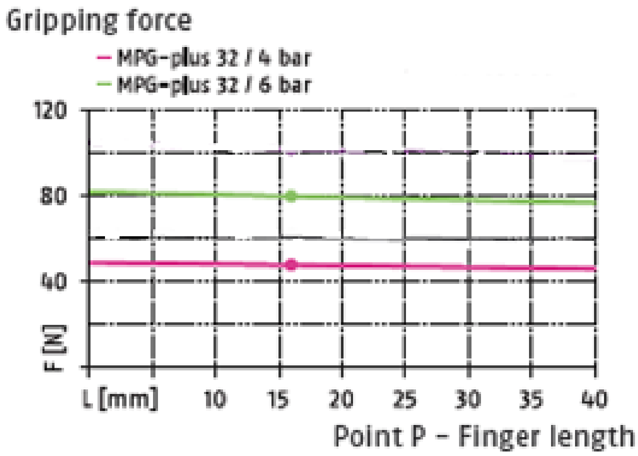


Figure 14.3: **Gripping available force-gripping point distance with the new claws**

Initially we note that the graph indicates a maximum distance from the beginning of the appendices of 40 mm, given that even if not a little we will respect, considering the 11 mm thickness of the appendices and the new grasping range of about 37 mm. Up to this value we can see how the closing force of the claws is kept constant and almost four times higher than the current value. Moreover, this limit value is the same in which the base gripper showed a flex in the maximum force; beyond this value began to decline. With a correct configuration of the attachment to the housing of the fingers it will be possible to recover a couple of millimeters, attesting however to around 45-48 mm from the housings. Also in this case we find ourselves at the technological limit of the element, but considering that we hardly limit the maximum limit and the big gain compared to the standard solution, even for a slope that increases by the straight line in the 14.3 we will get a very high gain in terms of performance and we will become able to overcome the problem in overexposed outlet, even if it is not possible to quantify it in a precise manner. The 6 bar pressure line was considered, which the MPG-plus 32 technical manual considers as the nominal pressure [MPG17]. This solution is therefore to be taken seriously into consideration.

The electrical evolution of the Schunk clamp presents the internal EPG-25 module. We do not have any information on the weight on this clamp, even if the internal module has EPG-25 weighs 110 grams

[Sch17]. 10 more than the MPG-plus 32 module. However, we do not need power supply couplings external of the element, we can think that the element has a total weight (EPG-25 plus external casing including adapter with the YuMi attack) very similar to the previous solution. From an aesthetic and cost point of view, having this component could therefore be an advantage, but a big problem arises by analyzing the dimensions: unlike the MPG-plus 32, the distance between the housing of the fingers and the end of the gripper is measured in 107 mm against the 69 of the previous solution [EGP17], moving the load even further away from the housing (slightly higher even than the basic solution). Furthermore, as we can see in image below, also the maximum force is only the half of the other module. Therefore, despite the other parameters being advantageous, the resulting moments on the wrist would be too high for the application developed, risking to compromise the functionality of the system or in any case not giving it any real improvement.

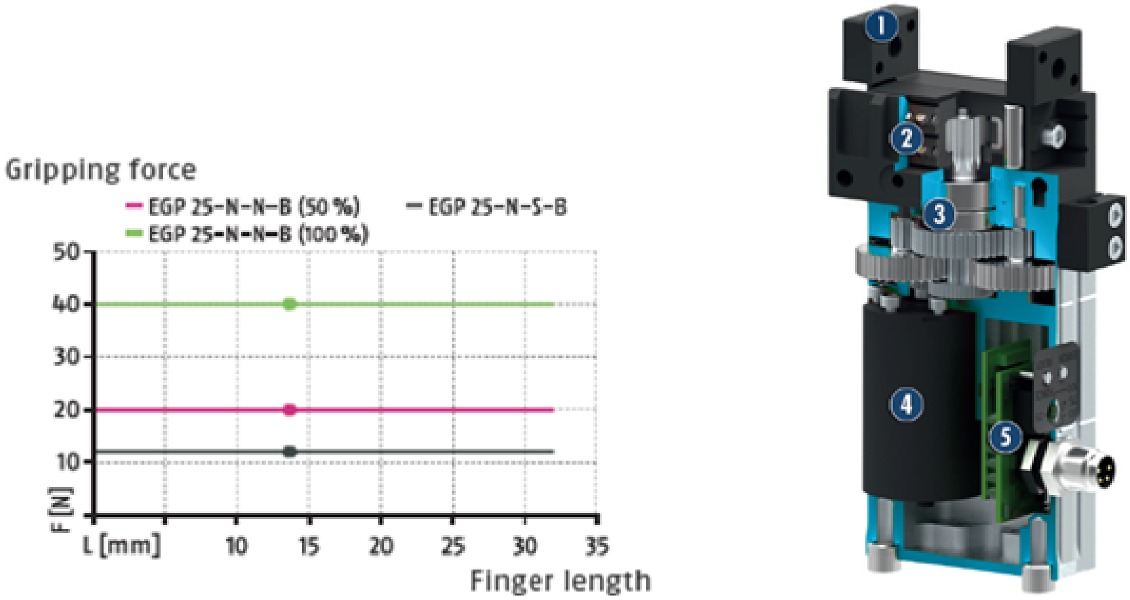


Figure 14.4: **Gripping available force-gripping point distance on EPG-25 and 3D section of the element**

14.3 Safety considerations and safety idea

Among the various accessory applications initially conceived for the system, two main ones were identified: the possibility for the customer to take a selfie hugged with the robot and the robot's ability to perform a rotation of the glass very quickly by drawing a circle, so that the centrifugal force keeps the beer against the bottom of the glass even when it is in an inverted position. The idea of these ancillary movements also came from observing the various videos in the initial phase of research of similar solutions on the market, especially those related to the ”cocktail-maker” robot [Qua], [Har], which dances when not used.

Proceeding with the development we realized that both ideas were to be set aside, as not achievable in the case in question, while other ideas, such as that to achieve different positions of rest for the left arm when not engaged with the knobs, positions selected in a random way, cycle after cycle, they are certainly of minor impact but easily implementable. The main point to be observed is compliance with safety regulations [Arr] also for problems that may occur during these accessory movements; other ideas that may arise later will be evaluated first of all in the light of this parameter. Let us first analyze the second case listed: here the problems are multiform, starting from the maximum rotation speed of the joint 3 (that of the elbow around which rotation would be easier), of 180°/s and a possible variation of the angle of that joint less than 360°, to the fact that as already seen for lateral displacements the maximum linear velocities are often strongly reduced due to the combination of the movements required to the various joints in a hardly analyzable way. The rotation could hardly take place at a suitable speed and in the available volume that is limited by the other stations, the plastic cups in them and the carter of the picking stations but, even if that were the case, it would not be possible to move safely. In fact, it would be enough to have an unwanted contact with one of the two arms by the customer to stop the movement, with sudden spilling of the liquid everywhere and splashes. In addition, given the current strength of the claws in the grip and not yet proven in practical cases that of Schunk grippers, if you stop the plastic cup inverted lacking the force of centrifugal force could even drop the glass together with its contents. The behavior of the robot according to UNI EN ISO 13850 also makes impossible to take the selfie with the robot: as soon as you make a contact with the person the robot would be blocked (it would not be a big problem if you expect the YuMi is already in place), but when power is removed from the engines you could watch the fall of the hands or in any case to restart of the power after a few seconds, new contacts, new consequent stops. All this would not be pleasant for the client and would end up highlighting the difference from the man instead of trying to bridge the distance and appear more human-friendly. The selfie would then also be hindered by the orientation chosen for the YuMi in the station, facing the center of the table and by arms excellent in dimensions for the requirements of compactness required but not to ”hug” a person.

14.4 Possible development of the system

In addition to the step is also very interesting the gripping system present in the videos analyzed previously in the single Kuka robot station [Kuka], reconstructed for clarity via CAD below 14.5.

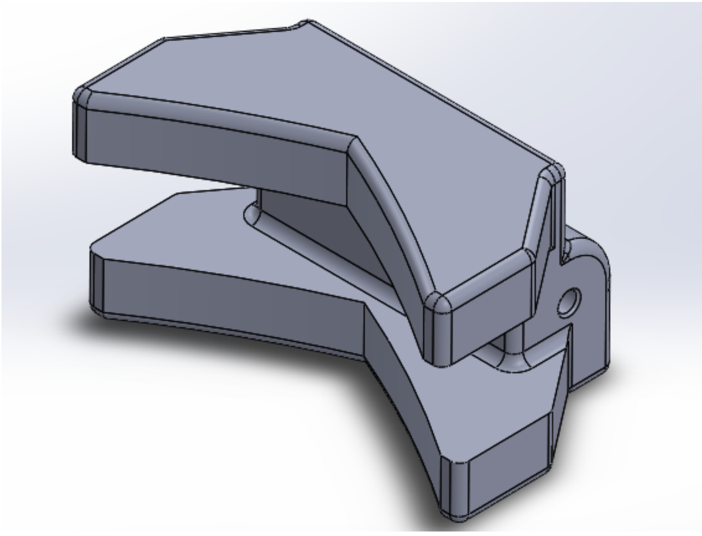


Figure 14.5: **Rotational free handling element**

The basic plastic component had two gripping elements at the top and bottom, which as you can see are not perfectly aligned, but with the upper element slightly higher than the bottom one (or vice versa if it is rotated by 180°). This is to be able to have a better grip on the plastic cup by using the taper of the cup itself or any other object. The fact that thanks to the hole we can see in the center can rotate around a pin also makes it possible to use different tapers and diameters by creating four points or small areas of different contact on the same element. The element can also make self-corrections during pick-up and release, stopping only in a position where the friction has reached a certain value. For this reason it could be a useful element to consider whether to insert or not in our hand, weighing on one side the advantages in grip and the minimum dimensions that should have and on the other the weakening of the rest of the structure of the hand that would derive from it, the weight of the element itself and its cost.

An improvement will also be that of developing special output movements in the event of contacts in delicate points of the program, so that the resumption of movements from a random point would very easily lead to repeated contacts without being able to resume proper movement, on the model of how much expected for the waiting positions of the left hand during the Wait phase. Posts that are difficult to exit may be those around the most backward taking positions (*Presa1, 2* and *4*) and the case where the pincer is pushed against the table top: if it was moving backwards from the X

axis, as in the phases of release from the end positions and return to the *Start_Stop* point, to raise the TCP backwards the robot will rotate around the wrist, thus lowering the tip of the fingers and easily creating new contacts and sliding on the table surface. As for the waiting stations, a good idea to make the system more human-friendly could be to predict different positions and then let the robot choose randomly on which to send the left arm in the time interval between a tapped and the next. The stations will be appropriately defined in the future to avoid excessive times for reaching them or contacts to return to the correct position after an emergency stop. An immediate example would be to insert the lowered position also for the left knob with respect to the *PresaChelaOFF* point, resting on the tap.

A development that can be implemented following the system from the point of view of programming will be that of the design in the beer foam, now completely tapped and with the foam in a stable condition (without large bubbles that are still breaking), before delivering it to the customer. This procedure must be carried out with great care, but the repeatability and precision characteristics of the YuMi, better than those of the UR3 [YuM], [UR3], for example, can allow it. To this end, the compactness and creaminess of the beer that is being tapped are to be considered: in fact these designs are typical of stout beers, such as Guinness, but they could hardly be made for other beers like the British, with a low CO_2 content. Therefore, the Baladin beers available in the kegs will be considered and for which of these it is possible to adopt the procedure. In any case the movements will be carried out in a single movement but at a very reduced speed and without sinking the spout in the foam to an excessive high, to avoid destroying the layer protecting the newly formed product or, worse, to pour part of the beer. In 14.6 you can observe the movements of the traditional Irish design, the clover, even if pursued other drawings can be realized:

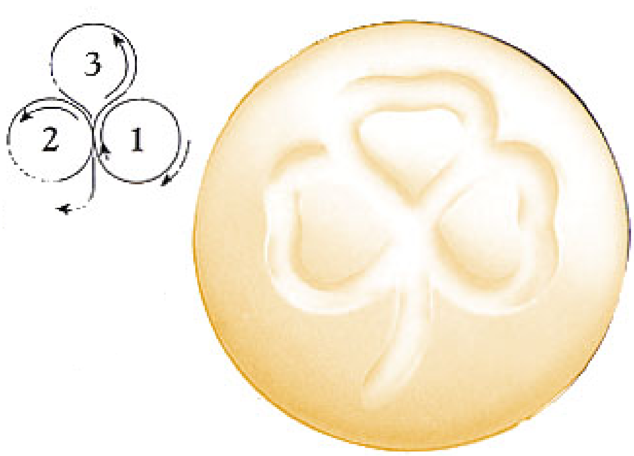


Figure 14.6: **The sketch on the beer foam**

In the little image on the left you can see how the mouth of the tap will have to move on the surface of the foam to get the design. However, since the plug will be still and the plastic cup will move, the directions programmed for the movement of the arm must be opposite to those indicated above. Also here we must consider the usual problem of the stop of category 0 [Arr]. To make this "habit" possible, we must make sure that interruptions during these movements do not produce loss of product, also verifying that during all the movements for decoration the joint 5 is found at a correct angle to the plane. Surely, however, if this arrest happened, the correct outcome of the design could not be guaranteed.

Since the majority of the population is right-handed, in order to facilitate the taking of glasses in the public's delivery station, one could also think of an identical position, but speculate with respect to the one developed in the case in question, where the right-handed was considered robot. This would not entail particular problems, also because by completely reversing the tasks of the arms the situation would not change, given the same task-space and dexterity (and identical singularities, problems) between the right and left arms [YuM]. You should only pay attention even during the programming phase, inverting the sign of each Y coordinate for each inserted target and the change of configuration, given that, of course, the reference system of the right arm is right-handed, while for the left it is left-handed. If you had a lot of space available, you could then insert an island with the presence of the two robots, a mirror to the other: a further attention to consider in this case will be to put the islands at a distance that the two arms that move the knobs never collide, providing a connection between the two tables to make the station a whole, without too much discontinuity.

Chapter 15

CONCLUSIONS

Although the degree thesis concerns the system of the draft beer robot, considering the expected time for development, it was not conceivable to develop the system up to an ultimately conclusion, with a system already finished in every detail and ready for marketing. The main objective was to tackle an unknown problem starting from scratch, to analyze it from every point of view, searching information, identifying all the various problems associated and trying to solve them laying the solid and certain bases on which to realize the final version in concrete of the draft beer robot station. This station was obliged to respond to certain needs, which are listed again below:

- Collaboration and security
- Repeatability and reliability
- Easy handling of the system
- Human-Friendly
- Reduced maintenance
- Protection against external agents by choosing an appropriate IP rating

From the point of view of collaboration, the robot has been chosen with the best characteristics among the cobots analyzed in detail, with limited weights of moving parts, padded prominent parts with respect to the structure to facilitate contact with them, able to absorb part of the energy. With regard to the third point, it was decided to break down the system into two different modules: one containing the volume at controlled temperature with the various kegs and the automatic exchange system when the current keg was almost empty, the other module with the work under which the system was present and probably also the PLC to monitor the cycle, while above are the robot and the other components listed several times. The chosen structure has allowed us to maintain the standard dimensions of the Europallet 800x1200 mm, considered more convenient for the land transport than the large version (1000x1200) and allowed a margin if the initially considered system dimensions would not have been in any case hosted by the Europallet. The YuMi, for intrinsic characteristics, is the collaborative robot that is more human friendly.

Moreover, many other considerations have been made, from the development of the nippers, to the fabric that must be inserted to comply with the IP degree, fabric that can be colored and attractive as if it were a dress, while ornaments and headpieces can also be inserted various if deemed appropriate. The human-friendly aspect was then also considered thanks to the touch panel or the development of an app in the future in order to interact directly with the robot by reducing the reciprocal distances, in the idea of reproducing a design on the foam, in the programming whose movements were made as similar as possible to the human ones and also the waiting points for left hand have been inserted between two successive taps. The maintenance has been analyzed in the various interventions necessary for a classic system so as to be able to understand what the needs were. The situation has already improved by analyzing the recent technological improvements and the different variations thanks to Baladin's knowledge, choosing the components for our system in order to respond to maintenance needs and to have a volume compatible with what you will have under the working plan and capable of producing minimum waste in the system. We have also tried to make different maintenance interventions coincide, in order to minimize the remote requests that will have to take place. The adequate IP protection, not present for example for the YuMi, will have to be realized in the future by covering the cobot with a suitable and tailor-made fabric, while to date no final choice has been made on the fingers and therefore it is a premature speech. After having identified the IP degree necessary for our application, we have already thought about how to isolate the area below the worktop from the top (with an appropriate table design, without holes down) and the plant will be raised from the ground, to defend itself better from infiltration from below. We have been informed about the particular fabrics to cover the YuMi, learning that it is possible to achieve the IP protection level identified without reducing the speed or the possibility of movement of the robot.

Regarding safety, repeatability and reliability, we need to consider not only individual measures taken but to consider the system and the cycles developed on it. For example, the reliability and repeatability of the San-Jamar cup dispensers will still have to be considered, valued by the catalog as the best for our needs but not yet tested in practice. It will also be necessary to check the tapping times and the quantities of foam that will really be tapping the beer, even if here the uncertainties seem minor and the corrections to be adopted possibly more immediate. As stressed several times during the development of the thesis, while placing us in the best possible situation from the point of view in the choice of the collaborative robot, some problems were also detected during the real tests. There are two problems reduced, but not eliminated: the poor mechanical properties of the cobot and the behavior given by the controller for arrests of type 0. Facing them has constituted a large part of the thesis work.

The YuMi is a robot created primarily for pick & place operations in collaboration with human labor. These operations are carried out in a very precise way, for precision assemblies, but normally very small pieces are moved, which partly justify the low payload supplied. A slightly higher payload would still be useful and reasonable, but probably this robot pays duty on this parameter to be able to keep low the energy level exchanged in case of collisions and therefore maintain excellent standards of collaboration. In fact, this robot can reach high speeds, even 1500 mm/s, but also for linear movements and not so close to the shoulder you can immediately see from the practical tests as these speeds are not even remotely reached, even if they are considered to limit the entity of the various shocks. We can expect an evolution over the years so that, at a maximum speed equal to the current one, the controller is able to better manage the various movements in order to make them occur at higher speeds in order to reduce the times, or to have similar movements speed with a higher associated payload and lower maximum ideal accelerations, to solve some of our problems. The other parameter that from the mechanical point of view is very limiting is given by the insufficient force that the nippers of the YuMi are able to exercise. From this point of view it is very easy to expect future developments, since one of the main applications of this robot can also be that of inserting screws to screw different components together and a greater ability to support the efforts on the nippers to maintain tightened the screw that is inserted can prove to be really important, while now it is not enough to insert materials that create a greater friction to obtain sufficient forces in the grip. In any case we have already tried, with the analysis of Schunk claws, to overcome this problem with regard to our specific application. The behavior of the YuMi under type 0 arrest conditions has instead been specifically studied by the manufacturer to avoid potentially dangerous situations, and it is therefore more difficult to think that in the later versions we can see a change in this characteristic. At most, another cobot may appear on the market, with similar structural features and collaborations, which does not provide for this procedure. However, the problem has been remedied by bringing us back to a situation that is not ideal but more than acceptable and some improvement, even if slight, it will probably be possible to optimize even more finely some positions of the cycle, so as to obtain for the whole stretch of interest (the one in which the plastic cup is at least partially full) angles of the axis of joint 4 with respect to the plane even closer to 90°, so as to reduce the possibility of rotation.

Surely the fact that we suffer more is not to have, at the state of the art, alternatives of dimensions and characteristics comparable with our choice and of having to forcefully respect some constraints that are not likely. The YuMi was in fact the only two-armed cobot of a size compatible with human ones and a level of collaborativity necessary to be able to leave it safely in a place without continuous external supervision. Probably, waiting for a subsequent generation of collaborative robots would have made possible a system more compliant with those that were our reactivity requirements for some movements and especially torque developed by the motor upstream of the joint 5 (which determines the payload) and setting from the claws. As already considered during the development of the thesis, precisely because technology allows us to consider all the problems of the case arriving at a solution, often satisfactory, this is the ideal time to acquire a detailed knowledge of the problem, the system and the technology present of the parts that make it up.

However, we can say that it was possible to find a robot that would respond to the characteristics we were looking for and that could be the center of our system. Even if some modifications have to be made on prototypes, moreover, the evolution of some components of the tapping system compared to the classic one has allowed to have considerable improvements, partly also able to compensate the instability of the treated beverage compared to the others. The elements were then defined and distributed in the best way in accordance with the capabilities of the chosen robot, on a bench of suitable size, trying to conform the plan also in order to not have more unwanted intrusions than necessary by a distracted customer, that would increase the probability of problems. With the development of the various types of cycles, the various issues listed before have been deleted or reduced within acceptable limits, implementing also a subsequent phase in which the various movements have been optimized, made more fluid and safe and the cycles times were reduced to times comparable with those of a bartender, even if longer due to the speed with which the various trips took place. At last, again with a view to amortizing time, some conditions have been devised to alternate the phases of the different cycles with each other, developing, for each of the two arms, the movements and the necessary new points. If the new type of grippers treated or another type of grippers not yet considered will be able to provide us with the extra safety to be able to easily overcome small frictions that may occur for example between two stacked plastic cups, we could say to have a reliable system.

We can therefore say that, even with some small reservations and considering that several steps must still be taken to bring this sort of embryo to a finite and marketable system, the goal we had set ourselves for the degree thesis has been reached.

Appendix A

Appendix. RAPID programs examples

Following there are some examples of the movements of the various cycles developed through the RAPID programming language, both for the right arm and for the left arm, already commented during the development of the central chapters of the work.

A.1 LEFT ARM

In each of the following cycles all the elements presented above are present. For example, the cut on accelerations, which is still present because the cycles on the left arm are however faster than the relative on the right arm, and this cut increased the torque available to the arm to move the knobs. There are also signals to wait for the Set/Reset signals of the various Digital Outputs on the other arm, which will be immediately reset as soon as they are no longer necessary, the instructions *g_...*, created to give instructions precise to the grippers of the YuMi, the delays thanks to the *WaitTime* signal. The various movements, for an immediate reading, are tabulated with respect to these instructions. In the case of MoveC, the *CirPathMode* \PathFrame in the previous line is necessary to keep the TCP of the hand always in the same position with respect to the circle it is describing. Each procedure, being the only one for that specific type of cycle, is named with main in order to be read by the YuMi controller, while these stakes were not intended to give the name to the module.

A.1.1 Left legal draft

Since it is a legal spill, you can see the four movements that make it up, two opening and two closing the left knob. In the simplified cycle, we can see the absence of the waiting position: for this reason we can see that the only linear movements are those of approach and release from the *PresaSx* point, where the deviation from the linear trajectory could cause a collision between the fingers and the knob.

```
MODULE Module1
Coordinate of the various points

  PROC main()
    AccSet 50, 100;
      MoveJ StartStopSx,v800,z10,Servo\WObj:=ManopolaSx;
    WaitTime 12;
    g_Calibrate;
      MoveJ Interp1Sx,v800,z10,Servo\WObj:=ManopolaSx;
    g_GripOut;
      MoveJ Interp2Sx,v800,z20,Servo\WObj:=ManopolaSx;
      MoveJ OffPresaSx,v800,fine,Servo\WObj:=ManopolaSx;
      MoveL PresaSx,v150,fine,Servo\WObj:=ManopolaSx;
    WaitTime\InPos,0;
    WaitDO custom_DO_1, 1;
    CirPathMode \PathFrame;
      MoveC IntRotSx,PresaSxON,v500,fine,Servo\WObj:=ManopolaSx;
    WaitTime 6;
    CirPathMode \PathFrame;
      MoveC IntRotSx,PresaSx,v500,fine,Servo\WObj:=ManopolaSx;
    WaitTime\InPos,0;
    g_GripIn;
    WaitDO custom_DO_1, 1;
    CirPathMode \PathFrame;
      MoveC IntRotSx2,PresaSxON2,v150,fine,Servo\WObj:=ManopolaSx;
    WaitTime 3;
    CirPathMode \PathFrame;
      MoveC IntRotSx2,PresaSx,v500,fine,Servo\WObj:=ManopolaSx;
    WaitTime\InPos,0;
    g_GripOut;
      MoveL OffPresaSx,v200,fine,Servo\WObj:=ManopolaSx;
      MoveJ Interp2Sx,v800,z10,Servo\WObj:=ManopolaSx;
```

```
        MoveJ Interp1Sx,v800,z20,Servo\WObj:=ManopolaSx;
        MoveJ StartStopSx,v800,z10,Servo\WObj:=ManopolaSx;
  ENDPROC
ENDMODULE
```

A.1.2 Right mixed cycles

In the following cycle you can instead see a mixed cycle, that is a cycle in which the orders of two glasses are executed, with the first stroke of the second order tapping that goes between the two of the first glass of beer. Here, too, it is a legal draft for both plastic cups, with a total of four strokes and eight circular movements, among which you can however see the waiting position, also reached with linear movement to avoid accidental contacts between hand and knob. From the stand-by position, two DOs are present before opening the beer flow again: the first signal commands the return from the standby position, the second the knob switching. By comparing the signals with the previous cycle, one can also notice how the signals for the plastic cups are divided according to the type of tapping used, for greater clarity. As previously mentioned, since only one tank of CO_2 was available that had to blow the air out of the beer from the keg, both glasses of the mixed cycle were directed to the same tap.

```
MODULE Module1
Coordinate of the various points

  PROC main()
    AccSet 50, 100;
        MoveJ StartStopDx,v800,z10,Servo\WObj:=ManopolaDx;
    WaitDO custom_DO_4, 1;
    g_Calibrate;
    g_MoveTo 10;
        MoveJ Interp1Dx,v1500,z20,Servo\WObj:=ManopolaDx;
        MoveJ OffPresaDx,v1500,z50,Servo\WObj:=ManopolaDx;
        MoveJ PresaDx,v150,z1,Servo\WObj:=ManopolaDx;
    g_GripOut;
    WaitTime\InPos,0;
    WaitDO custom_DO_2, 1;
    CirPathMode \PathFrame;
```

```
    MoveC IntRotDx,PresaDxON,v500,fine,Servo\WObj:=ManopolaDx;
WaitTime 6;
CirPathMode \PathFrame;
    MoveC IntRotDx,PresaDx,v500,fine,Servo\WObj:=ManopolaDx;
WaitTime\InPos,0;
    MoveL AttesaNuovaSpillataDx,v1500,z5,Servo\WObj:=ManopolaDx;
WaitDO custom_DO_4, 1;
    MoveL PresaDx,v150,z1,Servo\WObj:=ManopolaDx;
WaitDO custom_DO_2, 1;
CirPathMode \PathFrame;
    MoveC IntRotDx,PresaDxON,v150,z1,Servo\WObj:=ManopolaDx;
WaitTime 6;
CirPathMode \PathFrame;
    MoveC IntRotDx,PresaDx,v500,z1,Servo\WObj:=ManopolaDx;
WaitTime\InPos,0;
    MoveL AttesaNuovaSpillataDx,v1500,z5,Servo\WObj:=ManopolaDx;
WaitDO custom_DO_4, 1;
    MoveL PresaDx,v150,z1,Servo\WObj:=ManopolaDx;
WaitDO custom_DO_2, 1;
CirPathMode \PathFrame;
    MoveC IntRotDx,PresaDxON,v150,z1,Servo\WObj:=ManopolaDx;
WaitTime 3;
CirPathMode \PathFrame;
    MoveC IntRotDx,PresaDx,v500,z1,Servo\WObj:=ManopolaDx;
WaitTime\InPos,0;
    MoveL AttesaNuovaSpillataDx,v1500,z5,Servo\WObj:=ManopolaDx;
WaitDO custom_DO_4, 1;
    MoveL PresaDx,v150,z1,Servo\WObj:=ManopolaDx;
WaitDO custom_DO_2, 1;
CirPathMode \PathFrame;
    MoveC IntRotDx,PresaDxON,v150,z1,Servo\WObj:=ManopolaDx;
WaitTime 3;
CirPathMode \PathFrame;
```

```
        MoveC IntRotDx,PresaDx,v500,z1,Servo\WObj:=ManopolaDx;
    WaitTime\InPos,0;
        MoveL OffPresaDx,v200,z50,Servo\WObj:=ManopolaDx;
    g_GripIn;
        MoveJ Interp1Dx,v1500,z20,Servo\WObj:=ManopolaDx;
        MoveJ StartStopDx,v1500,z10,Servo\WObj:=ManopolaDx;
  ENDPROC
ENDMODULE
```

A.1.3 Left-right knob change

In this last cycle relating to the left hand, instead, the change of knob is shown in the case where two plastic cups, whose cycles would overlap each other, are not tapped at the same draft. As already specified, no new points have been developed for this knob change. To obtain the change from the right-hand knob to the left, simply reverse the relative movements.

```
MODULE Module1
Coordinate of the various points

  PROC main()
        MoveJ StartStopSx,v800,z10,Servo\WObj:=ManopolaSx;
    g_Calibrate;
    g_MoveTo 10;
        MoveJ Interp1Sx,v1500,z20,Servo\WObj:=ManopolaSx;
        MoveJ Interp2Sx,v1500,z20,Servo\WObj:=ManopolaSx;
        MoveJ OffPresaSx,v1500,z5,Servo\WObj:=ManopolaSx;
    g_GripOut;
        MoveL PresaSx,v150,fine,Servo\WObj:=ManopolaSx;
        MoveL OffPresaSx,v200,z5,Servo\WObj:=ManopolaSx;
        MoveJ Interp1Dx,v1500,z10,Servo\WObj:=ManopolaDx;
        MoveJ OffPresaDx,v1500,z50,Servo\WObj:=ManopolaDx;
    g_MoveTo 10;
        MoveL PresaDx,v150,z1,Servo\WObj:=ManopolaDx;
    g_GripOut;
```

```
        MoveJ OffPresaDx,v200,z50,Servo\WObj:=ManopolaDx;
    g_GripIn;
        MoveL Interp1Dx,v1500,z20,Servo\WObj:=ManopolaDx;
        MoveJ StartStopDx,v800,z10,Servo\WObj:=ManopolaDx;
        MoveJ StartStopSx,v800,z10,Servo\WObj:=ManopolaSx;
  ENDPROC
ENDMODULE
```

A.2 RIGHT ARM

A.2.1 Right legal cycle

In the cycle below, a single legal draft cycle is presented starting from the lower and closest to the client taking position, the number 6. You can see how, after the last changes explained in section 12.1, the lines related to the acceleration reduction are have been canceled, because fortunately they are no longer necessary. The only cut still present is where the plastic cup is completely full, to avoid pouring beer with changes of speed and direction too violent.

```
MODULE Module1
Coordinate of the various points

  PROC main ()
    Reset custom_DO_2;
    Reset custom_DO_4;
        MoveJ Start_stop,v500,z10,Servo\WObj:=Bicchiere1;
    g_Calibrate;
        MoveJ Interp6,v1500,z20,Servo\WObj:=Bicchiere1;
        MoveJ ApproccioP6,v1500,z10,Servo\WObj:=Bicchiere1;
    g_GripIn;
        MoveJ Presa6,v100,fine,Servo\WObj:=Bicchiere1;
    g_MoveTo 4.4;
        MoveL SvincoloP6,v100,z1,Servo\WObj:=Bicchiere1;
    Set custom_DO_4;
    Reset custom_DO_4;
```

```
    MoveJ VersoSpillatore,v1500,z200,Servo\WObj:=Bicchiere1;
    MoveJ InizSpillDx,v1500,fine,Servo\WObj:=Bicchiere1;
!AccSet 50, 100;
Set custom_DO_2;
WaitTime 4;
CirPathMode \PathFrame;
    MoveC InterpDx,RubinettoDx,v30,fine,Servo\WObj:=Bicchiere1;
Reset custom_DO_2;
WaitTime 2;
    MoveL OffsetWait1Dx,v500,z20,Servo\WObj:=Bicchiere1;
    MoveJ Wait1,v80,fine,Servo\WObj:=Bicchiere1;
WaitTime 60;
Set custom_DO_4;
Reset custom_DO_4;
    MoveL OffsetWait1Dx,v500,z20,Servo\WObj:=Bicchiere1;
    MoveL SecondoColpoDx,v500,fine,Servo\WObj:=Bicchiere1;
AccSet 70, 100;
Set custom_DO_2;
WaitTime 3;
Reset custom_DO_2;
WaitTime 2;
    MoveL Uscita1e2,v200,z20,Servo\WObj:=Bicchiere1;
    MoveL IntConsegna,v200,z10,Servo\WObj:=Bicchiere1;
SingArea \Wrist;
    MoveL OffsetFinale2,v200,z10,Servo\WObj:=Bicchiere1;
SingArea\Off;
    MoveL Finale2,v50,fine,Servo\WObj:=Bicchiere1;
WaitTime \InPos, 0;
g_GripIn;
    MoveL RibassoFinale2,v50,fine,Servo\WObj:=Bicchiere1;
    MoveL SvincoloFinale2,v150,z10,Servo\WObj:=Bicchiere1;
AccSet 100, 100;
    MoveJ Start_stop,v1500,z10,Servo\WObj:=Bicchiere1;
```

```
        g_GripOut;
    ENDPROC
ENDMODULE
```

A.2.2 Right mixed cycle

In the following mixed cycle, for example, there are two legal cycles (to obtain a German tap, simply return to the Wait area after the second stroke and, after the necessary time, make the third shot before heading to the delivery area). As in almost all cases, two consecutive plastic cups will be taken from the same cup-dispenser, in both cases we are directed to the station 2 (ex-station 1). In the cycle below is also included the list of movements necessary for the change of plastic cup, if so decided by the controller. The *Start_Stop* point is present in the first and last statement for practicality issues during the tests, in fact if it was in a different point this was a point easily reached without shocks and from which you could connect directly to the Wait stations. In addition to the points indicated in the previous chapters, it should be noted that the request for precision in movement has also made us incline here for linear movements, in order to avoid contact and sliding between fingers and plastic cup.

```
MODULE Module1
Coordinate of the various points

    PROC main ()
        Reset custom_DO_1;!P2W1F1
            MoveJ Start_stop,v500,z10,Servo\WObj:=Bicchiere1;
        g_Calibrate;
            MoveL InterpD,v1500,z10,Servo\WObj:=Bicchiere1;
            MoveL Interp1,v1500,z100,Servo\WObj:=Bicchiere1;
            MoveL ApproccioP2,v1500,fine,Servo\WObj:=Bicchiere1;
        g_GripIn;
            MoveL Presa2,v100,fine,Servo\WObj:=Bicchiere1;
        WaitTime\InPos,0;
        g_MoveTo 4.4;
            MoveL SvincoloP2,v100,z1,Servo\WObj:=Bicchiere1;
            MoveL Interp1,v1500,z50,Servo\WObj:=Bicchiere1;
            MoveJ InterpVS,v1500,z100,Servo\WObj:=Bicchiere1;
```

```
Set custom_DO_3;
Reset custom_DO_3;
    MoveJ VersoSpillatore,v1500,z100,Servo\WObj:=Bicchiere1;
    MoveJ InizSpillSx,v1500,fine,Servo\WObj:=Bicchiere1;
!AccSet 50, 100;
Set custom_DO_1;
WaitTime 4;
CirPathMode \PathFrame;
Reset custom_DO_1;
    MoveC InterpSx,RubinettoSx,v30,fine,Servo\WObj:=Bicchiere1;
WaitTime 2;
    MoveL OffsetWait1Sx,v500,z20,Servo\WObj:=Bicchiere1;
    MoveJ Wait1,v80,fine,Servo\WObj:=Bicchiere1;
WaitTime \InPos,0;
g_GripIn;
    MoveL RibassoW1,v50,fine,Servo\WObj:=Bicchiere1;
    MoveL ApproccioPW1,v150,z10,Servo\WObj:=Bicchiere1;
    MoveJ Start_stop,v500,z10,Servo\WObj:=Bicchiere1;
g_Calibrate;
    MoveL InterpD,v1500,z10,Servo\WObj:=Bicchiere1;
    MoveL Interp1,v1500,z100,Servo\WObj:=Bicchiere1;
    MoveL ApproccioP2,v1500,fine,Servo\WObj:=Bicchiere1;
g_GripIn;
    MoveL Presa2,v100,fine,Servo\WObj:=Bicchiere1;
WaitTime\InPos,0;
g_MoveTo 4.4;
    MoveL SvincoloP2,v100,z1,Servo\WObj:=Bicchiere1;
    MoveL Interp1,v1500,z50,Servo\WObj:=Bicchiere1;
    MoveJ InterpVS,v1500,z100,Servo\WObj:=Bicchiere1;
    MoveJ VersoSpillatore,v1500,z100,Servo\WObj:=Bicchiere1;
Set custom_DO_3;
Reset custom_DO_3;
    MoveJ InizSpillSx,v1500,fine,Servo\WObj:=Bicchiere1;
```

```
!AccSet 60, 100;
Set custom_DO_1;
WaitTime 4;
CirPathMode \PathFrame;
Reset custom_DO_1;
    MoveC InterpSx,RubinettoSx,v30,fine,Servo\WObj:=Bicchiere1;
WaitTime 2;
    MoveL OffsetWait2,v500,z20,Servo\WObj:=Bicchiere1;
    MoveJ Wait2,v80,fine,Servo\WObj:=Bicchiere1;
WaitTime\InPos,0;
g_GripIn;
    MoveJ RibassoW2,v50,fine,Servo\WObj:=Bicchiere1;
    MoveJ ApproccioPW2,v150,z10,Servo\WObj:=Bicchiere1;
    MoveJ ApproccioPW1,v1500,z10,Servo\WObj:=Bicchiere1;
    MoveL RibassoW1,v150,z10,Servo\WObj:=Bicchiere1;
    MoveL Wait1Carico,v50,fine,Servo\WObj:=Bicchiere1;
Set custom_DO_3;
Reset custom_DO_3;
WaitTime 0.2;
g_MoveTo 4.4;
    MoveL OffsetWait1Sx,v200,z20,Servo\WObj:=Bicchiere1;
    MoveL SecondoColpoSx,v500,fine,Servo\WObj:=Bicchiere1;
Set custom_DO_1;
WaitTime 3;
Reset custom_DO_1;
WaitTime 2;
AccSet 70, 100;
    MoveL Uscita1e2,v200,z20,Servo\WObj:=Bicchiere1;
    MoveL IntConsegna,v200,z10,Servo\WObj:=Bicchiere1;
SingArea \Wrist;
    MoveL OffsetFinale1,v200,z10,Servo\WObj:=Bicchiere1;
SingArea \Off;
    MoveL Finale1,v50,fine,Servo\WObj:=Bicchiere1;
```

```
WaitTime \InPos, 0;
g_GripIn;
    MoveL RibassoFinale1,v50,fine,Servo\WObj:=Bicchiere1;
    MoveJ SvincoloFinale1,v150,z10,Servo\WObj:=Bicchiere1;
AccSet 100, 100;
    MoveJ Start_stop,v500,z10,Servo\WObj:=Bicchiere1;
    MoveJ OffsetWait2,v500,z20,Servo\WObj:=Bicchiere1;
    MoveJ ApproccioPW2,v1500,z10,Servo\WObj:=Bicchiere1;
    MoveJ RibassoW2,v150,z10,Servo\WObj:=Bicchiere1;
    MoveJ Wait2Carico,v50,fine,Servo\WObj:=Bicchiere1;
Set custom_DO_3;
Reset custom_DO_3;
WaitTime 0.2;
g_MoveTo 4.4;
    MoveL OffsetWait2,v200,z20,Servo\WObj:=Bicchiere1;
    MoveL RubinettoSx,v500,z100,Servo\WObj:=Bicchiere1;
    MoveL SecondoColpoSx,v500,fine,Servo\WObj:=Bicchiere1;
AccSet 70, 100;
Set custom_DO_1;
WaitTime 3;
Reset custom_DO_1;
WaitTime 2;
    MoveL Uscita1e2,v200,z20,Servo\WObj:=Bicchiere1;
    MoveL IntConsegna,v200,z10,Servo\WObj:=Bicchiere1;
SingArea \Wrist;
    MoveL OffsetFinale2,v200,z10,Servo\WObj:=Bicchiere1;
SingArea \Off;
    MoveL Finale2,v50,fine,Servo\WObj:=Bicchiere1;
WaitTime \InPos, 0;
g_GripIn;
    MoveL RibassoFinale2,v50,fine,Servo\WObj:=Bicchiere1;
    MoveL SvincoloFinale2,v150,z10,Servo\WObj:=Bicchiere1;
AccSet 100, 100;
```

```
        MoveJ Start_stop,v500,z10,Servo\WObj:=Bicchiere1;
    g_GripOut;
  ENDPROC
ENDMODULE
```

A.3 DUSTBIN

A.3.1 Approach of the dustbin from OffsetFinale3

Finally, an example of what could be a cycle related to the elimination of broken glasses, which lose the beer they contain, is presented. It has been hypothesized that this is a point relative to the junction in the *Finale3* position, without knowing whether it is the collection point of that area (*OffsetFinal3*) or not. If you are already there, the first movement will be read but will have no effect, because the controller will notice that it has already reached the arrival point, proceeding then to execute the next line. It is also possible to observe how a new specific DO signal has been inserted for this procedure.

```
MODULE Module1
Coordinate of the various points

  PROC main()
    Reset custom_DO_5;
        MoveJ OffsetFinale3,v500,z10,Servo\WObj:=Bicchiere1;
        MoveJ OffsetPattumiera,v500,z10,Servo\WObj:=Bicchiere1;
        MoveL Pattumiera,v500,fine,Servo\WObj:=Bicchiere1;
    WaitTime\InPos,0;
    g_GripIn;
        MoveL RibassoPattumiera,v100,fine,Servo\WObj:=Bicchiere1;
        MoveL UscitaPattumiera,v500,z10,Servo\WObj:=Bicchiere1;
        MoveJ SvincoloPattumiera,v500,z10,Servo\WObj:=Bicchiere1;
    Set custom_DO_5;
        MoveJ SvincoloFinale1,v500,z100,Servo\WObj:=Bicchiere1;
        MoveJ Start_stop,v500,z10,Servo\WObj:=Bicchiere1;
    g_GripOut;
    Reset custom_DO_5;
  ENDPROC
```

ENDMODULE

Appendix B

Appendix. Basic notions on robotics

The YuMi ABB is a robot that has inside it a fairly high level of robotics and electronics. During the presentation of the thesis and in particular of the YuMi and the UR3 of the Universal Robots, we tried to list some basic features. The aim of the thesis is not to dwell on the theory of present robotics, with the only risk of being boring and incomplete. Below, however, it seemed useful to list some basic notions and definitions [Bas], ([**?**]), which can be useful for understanding what was previously developed.

The **end-effector**, often called hand or gripper during the previous pages, identify the structure at the end of the last link that is able to perform the required task.

The **pose** of a rigid body and then of end-effector's TCP is the set of parameters that uniquely define its position and its orientations in space. The **TCP (Tool Center Point)**, word very used during this work, is an ideal point on the end-effector that the robot software moves through space.

The **task-space** is a subset of the Cartesian/Euclidean space that can be reached by the TCP. The **dexterous space** is a subset of the task-space, not only reachable but in which the robot can also work.

A **joint** is the articulation of a robot. Each joint, moreover, can be of a **revolute** or **prismatic** type: the prismatic joint allow only the translation of the two elements it links, like the fingers we have in the two hands. All the other joints of the YuMi robots are revolute ones, because allow a rotations between the collected links. Each of these joints provide one degree of freedom: other type of joints like the cylindrical, the planar or the spherical ones, can provide also two or three dof to the structure, but usually they are more for industrial robot and applications.

A **link** is the element that collect two adjacent joints.

The value of each angle between the set of angle that the joint itself can present, is called **joint space**.

The set of all the joints and links compose the so-called **kinematic chains**. A kinematic chain is called **redundant** if it has more dof with respect to the ones strictly necessary to reach a point in the task-space. This is the case of our robot, that distinguishes the way with which reaches a given pose with the configurations, so according to the position of the different axis.

The **path** is the geometrical description of the set of desired points in the task-space. The robot controller has to maintain on it the TCP of the proper arm. The **trajectory** is the path and the time law required to follow it, from starting to endpoint.

The **trajectory planner** is a software that, given desired path, the kinematic and dynamic constraints (above all maximum accelerations and torques), computes each time the joint values to follow the given path. The trajectory depends also the configurations we have in the starting and in the ending point of this segment of the cycle. We can impose the **configuration** on each point, otherwise the trajectory planner provide itself to give a configuration to it, on the basis of the fluency of the resulting path we will have with the configuration chosen for the previous points.

A **singular configuration** is a point in which can be reach in theoretically infinite different ways, for instance for the alignment of two joints. These points are to avoid because approaching a singularity the speed of same joints can increase in a uncontrollable way also for small speed of the TCP.

The **inverse kinematics** is a problem in which from a given pose, the controller have to find the values of the angles of all its joints to reach that position. In this task the YuMi controller is aided from the quaternions, which reduce the heaviness of the problem from the computational point of view with respect to the other conventions.

The trajectory planning is defined by more **tasks**. A task is a set of operations, like for instance the withdrawal of the plastic cup. A task, in turn, is formed by movements.

Bibliography

[ABc] AB covers.

[Aca] Quality Beer Academy. Spillatura alla tedesca e alla belga, Quality Beer Academy.

[Acc] Accura ® Xtreme ™ White 200.

[Ann16] Annual report. 2016.

[Ant] Le misure acustiche. page 140.

[ARD] WHAT IS ARDUINO?

[Arr] Arresto di emergenza delle macchine: la norma UNI EN ISO 13850: 2015.

[Aum] Aumento della pressione per altezza geodetica.

[Bas] Basilio Bona. "Robotics", slides 2014-2015.

[Bas12] Pannelli operatore Basic Panel. pages 1–164, 2012.

[Bee16] Global Beer Consumption by Country in 2015, 2016.

[Bira] La Camera approva la definizione di birra artigianale.

[Birb] PERFETTA.

[CCID] Salvatore Cavalieri, Università Catania, Facoltà Ingegneria, and Viale A Doria. Bus di Campo IEC 61158 : Caratteristiche Principali. pages 1–12.

[Coo13] Coolers 2013. 2013.

[EGP17] EGP 25 drawing. 2017.

[Fus] Fusto Polykeg.

[Har] Harmony of the Seas - Bionic Bar.

[HEIa] HEINEKEN Italia. Videocorso di cultura birraria, lez.4.

[HEIb] HEINEKEN Italia. Videocorso di cultura birraria, lez.5.

[HEIc] HEINEKEN Italia. Videocorso di cultura birraria, lez.6.

[HEId] HEINEKEN Italia. Videocorso di cultura birraria, lez.7.

[InS] In-Sight 5000 Series Vision System ®.

[InS00] IN-SIGHT 2000 SERIES VISION SENSORS. pages 1–3, 2000.

[IPR] IP grade not certified estimation for the Robotiq gripper.

[Kuka] Kuka bartender single robot.

[KUKb] KUKA Robot pours a beer at Hannover Messe 2017.

[Lel] Sergio Lelli. L'impianto di spillatura.

[Mak] Makr-Shakr, how it works.

[Man] Manuale di istruzioni fusto monouso polykeg. pages 1–8.

[Mas] Master di Spillatura HEINEKEN 2013.

[Mat] Björn Matthias. Collaborative Robots â Power and Force Limiting. *International Collaborative Robots Workshop.*

[MPG] More powerful . Faster . Longer fingers . MPG-plus gripper for small components.

[MPG17] MPG plus 32 catalogue chapter. 2017.

[Org] Proprietá organolettiche.

[Pat00] Autore Alberto Patron. La Direttiva n . 29 / 2000 / CE e la regolamentazione internazionale dei pallet commerciali. pages 1–8, 2000.

[Pes] Qual è Peso specifico della birra?

[PHM] GUIDA SULLA MANUTENZIONE DEL MISURATORE PHMETRO.

[Qua] Bionic Bar! Robotic Bartenders Mix Drinks on Quantum of the Seas.

[RAP15] Technical reference manual, RAPID Instructions, Functions and Data types. page 1546, 2015.

[Ric04] Richard W. Unger. *Beer in the Middle Ages and the Renaissance*. 2004.

[Ris15] Risk Assessment for Human-Robot Collaborative Applications Risk Assessment for HRC Applications Overview. (October), 2015.

[Roba] Robotic bartender.

[Robb] Robotic bartender, RS TECH's RoboKiosk®,.

[Rob16a] Robotiq 2-Finger Adaptive Gripper. 2016.

[Rob16b] Robotiq Price List. pages 1–2, 2016.

[Sch17] Schunk GmbH & Co. KG. Assembly and operating manual - EGP. 2017.

[Stoa] La Storia della Birra.

[stob] Un pò di storia...

[Tog] N B Togliere. IMPIANTI DI SPILLATURA : PROBLEMI E RIMEDI Problemi derivanti da guasti al gruppo frigorifero. pages 5–7.

[UnO] Very unOfficial Travel Guides.

[UR3] Manuale dell' utente.

[YuM] Dati tecnici del prodotto.