POLITECNICO DI TORINO

Master Course in Mechatronic Engineering

MASTER OF SCIENCE THESIS

Modelling and Control of Robots for Cooking

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A.Y. 2018/2019

CONTENTS

ABSTRACT

In war time science and technologies were mainly focused on the development and production of military offending and defending materials as well as war machines, i.e. tanks, missiles, fighter planes, U-boats, military ships, etc.

After the last world war, the stability of peace time and the growth of social wellness encouraged the progressive development of new technologies and the transition from handicraft production of low quantities of consumer goods towards large scale series production.

Therefore, a lot of humans repetitive or dangerous tasks have been replaced by automatic machines, the so-called robots.

The evolution of these machines allowed also to perform tasks that humans are unable to perform, for workspace size limitations or for extreme environment operation, such as outer space or bottom of the sea operations.

In the present work a practical application of robots for cooking activity is dealt with. In particular the study is focused on the design, modelling and control of a pizza maker robot to be introduced in a restaurant kitchen to replace all the human pizzaiolo activities related to pizza doughs roll out and condiments filling in order to reduce the customer waiting time between the incoming order and the prepared pizza ready to be cooked.

The initial idea has been to use a simple hybrid robot architecture (cart-like type) to be used both in single unit, with different tasks assigned, and in an assembled configuration of two units for the execution of high complexity tasks.

The final objective is the evaluation by simulation of the production times of ten pizzas of different tastes by different robot configurations, in order to identify the most performant one.

The robot identified in the feasibility study, according with a defined list of requirements, has resulted too big, occupying a large kitchen space. The result has not encouraged to carry out the performance simulation with this robot architecture, even if the forward and inverse kinematics equations have been derived. Therefore, the use of a commercial and collaborative manipulator arm of more complex design is investigated.

Accounting for the payload requirement identified in the feasibility study the selected manipulator is the UR10, by Universal Robots Company, also available in a wheeled cart version named Neobotix MMO-700. To complete the robot architecture the commercial gripper with a suitable force fit ROBOTIQ 2F-85 is adopted. The workstation and the kitchen lay out have been adapted to the selected commercial manipulator.

Three different configurations of two robots, using always the same type of manipulator arm, are investigated, upon the definition of a different list of tasks for each robot unit in each configuration.

MATLAB and **SIMULINK** models are derived to accomplish the performance analysis and to identify the most performant configuration.

Cooking and delivery times are taken outside of the performance analysis, as part of kitchen assistant work; however, a dedicated robot to these tasks is included in one configuration for future implementation of pizza cooking and delivery activities.

For the analysed configurations one robot is dedicated to the pizza dough roll out activity, called Robot 2, and another one to the pizza preparation activity (filling with condiments), called Robot 1.

A third robot, called Robot 3, is dedicated to the activities of pizza cooking and delivery at a desk; its tasks have been developed only for one configuration (Configuration nr. 3) but are excluded from the performance simulation.

The results of the simulation show that the configuration using two fixed manipulator arms (Configuration nr. 3) is the most effective. This is justified by the lower speed of the cart in comparison with the manipulator one (cart speed 0,9 m/s, manipulator speed 1 m/s).

The two robots operate with good coherence of task times, in fact the periods of not productive activity are acceptably small for all the three configurations, i.e. they are less than 20% for Robot 2 (pizza roll out activity) and about 10% for Robot 1 (pizza preparation activity).

The total time required to prepare the defined set of ten pizzas is in a range of 24 – 26 min, being Configuration nr. 3 the most performant one and Configuration nr. 1 the less performant. These times are well competitive with a human pizzaiolo performance times.

Final considerations are included in the conclusions.

ACRONYSMS AND SYMBOLS

a, **b**, **c**, **d**	Feasibility study hybrid robot dimensions
A1	Feasibility study hybrid robot revolution Joint 1 gap
cci	Condiment container i={1, …, 10}
cjpsti	Pizza storage table position i in Configuration j. i, j={ 1, 2, 3}
cpi	Cooked pizza position i on the delivery table. i={1, 2, 3}
cs	Condiments spreading tool
d or **D**	Also feasibility study hybrid robot CoG distance from cart CL
dpti	Pizza dough partition tray i={1, 2, 3}
dro	Pizza dough partition roll out area
h or **Hrcgz**	Feasibility study hybrid robot CoG height
CoG or **CG**	Centre of Gravity
CL	Centre Line
Cx	Feasibility study hybrid robot cart longitudinal dimension
CjRkTi-x	Performance study Task i of Robot k in Configuration j
	i={1, 2, 3,4,5,6}, j={1, 2, 3}, k={1, 2, 3}
	x = dpti (i={1, …, 10}) OR x = cipsti (i={1, 2, 3}) OR x = cci (i={1, …, 8}) OR x = gc OR x = oc OR x = ooc OR x = sc
C3R3T1-c3pstiov	Performance study Task 1 of Robot 3 in Config. 3, i={1, 2, 3}
C3R3T2-ovcpi	Performance study Task 2 of Robot 3 in Config. 3, i={1, 2, 3}
DH	Denavit-Hartenberg
DOF	Degrees Of Freedom
E	Eastwise direction
fc	Flour container
gc	Garlic container
G1, **G2**, **G3**	Feasibility study hybrid robot revolution Joints gap
GP	Manipulator Gripping Point
HMRR	Hybrid Modular Reconfigurable Robot
J1,.., **J4**	Feasibility study hybrid robot revolution Joints
L1, **L2**, **L3**	Feasibility study hybrid robot Links length
L1,.., **L30**	Optimised work station locations
M1,.., **M5**	Feasibility study hybrid robot masses

M6	Feasibility study hybrid robot workload
MDH	Modified Denavit-Hartenberg
MRR	Modular Reconfigurable Robot
Mt	Feasibility study hybrid robot total mass
N	Northwise direction
NE	North-Eastwise direction
NW	North-Westwise direction
oc	Origan container
ooc	Olive oil container
ov	Oven
pp	Pizza preparation area
pst	Pizza storage table position
P1	Closest operating point of the feasibility study hybrid robot
P2	More distant operating point of the feasibility study hybrid robot
qi	Joint coordinate i={1, 2, 3,4,5,6}
rp	Roll pin
R	Feasibility study hybrid robot cart wheels radius
$\mathbf{R^b_a}$	Rotation matrix of reference a represented in reference b
sc	Salt container
S	Southwise direction
Sc	Feasibility study hybrid robot Hrcgz longitudinal position
SE	South-Eastwise direction
SW	South-Westwise direction
tsl	Tomato sauce ladle
$\mathbf{t^b_a}$	Translation vector from reference **a** to reference **b**
$\mathbf{T^b_a}$	Reference **a** transformation matrix represented in reference **b**
W	Westwise direction
Wa	Feasibility study hybrid robot longitudinal overall dimension
Wb	Feasibility study hybrid robot cart wheelbase
WbCL	Feasibility study hybrid robot cart wheelbase centre line

DEVELOPED FILES AND SOFTWARE

1. ***Task paths.xlsx***, **EXCEL** file collecting robot task paths
2. **TRAJ**, software developed in **C++** code that generates the gripping point trajectories in terms of manipulator joints angles (uses library from [13])
3. ***Task trajectories Conf_1.xlsx***, **EXCEL** file collecting Conf. 1 task trajectories
4. ***Task trajectories Conf_2.xlsx***, **EXCEL** file collecting Conf. 2 task trajectories
5. ***Task trajectories Conf_3.xlsx***, **EXCEL** file collecting Conf. 3 task trajectories
6. ***SIM_Configuration_1.slx***, **SIMULINK** file developed for simulate Conf. 1 Mission
7. ***SIM_Configuration_2.slx***, **SIMULINK** file developed for simulate Conf. 2 Mission
8. ***SIM_Configuration_3.slx***, **SIMULINK** file developed for simulate Conf. 3 Mission
9. ***Single pizza production times.xlsx***, **EXCEL** file collecting Scenario 1 plots
10. ***Mission performance times.xlsx***, **EXCEL** file collecting Scenario 2 plots

These and further files are available at the link

http://bit.ly/GiuzioMT

or write at the following email address

giuzio.masterthesis@gmail.com

1 THESIS AIM AND OBJECTIVES

The aim of this thesis is to study how to introduce a robotic assistant inside a restaurant kitchen. The robot should replace all the human pizzaiolo activities related to pizza doughs roll out and condiments filling in order to reduce the customer waiting time between the incoming order and the prepared pizza ready to be cooked.

The initial objective is to perform a feasibility study for the design of a simple cart-like type robot to be used for a pizza maker application both as an independent robot unit and in an assembled configuration of two robots of the same type.

The final objective is the evaluation by simulation of the production times of ten pizzas of different tastes by different robot configurations, in order to identify the most performant one.

2 GENERAL ROBOTICS

The term ***robot*** identifies an electro-mechanical assembled machine capable to perform easy or complex actions and tasks automatically, mainly if programmable by a computer. Movements can be controlled either by an external device or by an embedded controller.

Robots can be autonomous or semi-autonomous and finalised for a wide range of applications: toys, patient's assistance, surgical operations, human prostheses, industrial manufacturing processes, inspection and operation in dangerous environments, car drivers, etc.

Robotics is the branch of technology that deals with robots’ design, construction, operation and application as well as computer systems for their control, sensors feedback and information processing.

Many of today's robots are inspired by human and animal nature and converge to the field of *bio-inspired robotics*.

Modular reconfigurable robots (MRRs) are complex autonomous kinematical machines realised through the assembly of independent modules. Each module is capable of independent movements and can be connected to other modules to allow the formation of different required configurations. Modification of kinematic and dynamic parameters of the system is essential to allow the assembled configurations to perform specific tasks.

MRRs are developed through the adoption of traditional robotics technologies by serial or parallel assembly of units. They are widely used in industry field for a variety of applications, for example automation, welding, screwing, packaging, pick-and-place operations, but also for medical assistance like surgical operations, for recreational applications like flight simulators or for 3D printers.

2.1 STATE OF ART FOR COOKING ROBOTS

Nowadays a lot of humans repetitive or dangerous tasks have been replaced by automatic machines, the so-called robots.

The evolution of these machines allowed also to reproduce, sometime by self-learning procedures, the human movements for specific tasks.

In the cooking field different applications can be found as reported in the references, whose details are described in the following.

The video in [1] shows a pizzaiolo robot designed by French start-up Ekim. This robot can spread tomato sauce on the pizza base, put the pizza in the oven, take a cardboard box, put the pizza inside, cut the pizza and put oil and pepper on top. The pizza preparation with taste condiments is demanded to human work.
The robot is able to perform several tasks at once and is composed by three commercial and collaborative arms (UR10 plus Robotiq gripper).

The video in [2] shows the Zume robotic pizza factory. Here there is a robotic line were humans and robots work together sharing a list of tasks. Humans are demanded to roll out the doughs and put them on a conveyor belt where a tomato sauce-dispensing robot, nicknamed Pepe, and a sauce-spreading robot, nicknamed Marta, add tomato sauce on the rolled out doughs. Then humans are also involved in pizza filling with proper taste condiments, whilst a six-axis robot, nicknamed Bruno, picks up pizzas at the end of the conveyor line and put them into the oven. After the pizza comes out of the oven, it is boxed by humans in specialty pizza boxes that alleviate the effects of steam on the crispness of the pizza crust.

The video in [3] shows the robot, nicknamed Rodyman, developed and manufactured by the Prisma Lab of Federico II Naples University by a team of international researchers based in Naples and managed by the Professor Bruno Siciliano. The robot, provided with two arms with five fingers hands, can roll out a pizza dough partition after having self-learned the movements of a skilled pizzaiolo through the signals generated by the sensors of a suit dressed by the human pizza maker.

The video in [4] shows the robot barista, nicknamed Toni, developed in Turin in 2018 and presented in Milan on July 2019. Toni takes cocktails orders from an app and is featured with two 6-axis robotics arms. One arm picks up all the ingredients from the bar counter, mixes or shakes them and pours the cocktail in a glass taken by the other robotic arm that deliver it to the customer. Toni can tear off the mint leaves, cut lemon slices, crush the ice, pick up bottle of cocktail ingredients, pour all in a shaker and shake them like a human barista. It is declared the preparation of up to 80 drinks an hour.

The video in [5] shows the Bubble Lab, based in Beijing, China, Robot barista showed at CES 2017. The robot can prepare a cappuccino in 3 min reproducing the human barista movements. Actually, the machine cleaning is still demanded to human intervention, but next generation could be self-cleaning. The robot is formed by two UR3 manipulator arms each one equipped with a Robotiq gripper.

The video in [6] shows the first robotic barista in U.S., nicknamed Gordon, developed and manufactured by Café-X Technologies, San Francisco. It is featured like a robotic arm that can serves up to 120 customized coffee orders an hour.

The video in [7] shows the first collaborative robot, nicknamed NEPO, created from an idea of Franco Filippi of EPF, an industrial automation company based in Carrù (CN) Italy, to draw beer reproducing human movements. It is an innovative project for a new generation automatic dispenser to serve draft beer in locations were the human presence is not available.

The [8] and [9] journal articles present biologically inspired actuators that utilize pneumatic muscles actuators (PMAs) and pneumatic bellows actuators (PBAs) both able to realize only contractive or extractive motions. It is possible to interconnect several of such modules forming a high redundant snake-like robotic structure for industrial applications.

In the conference [10] there is a description of a hybrid robot that has been developed for a robotic competition known as Robocon. This robot can handle and transport some objects such as balls. It is composed by three parts: the main frame with locomotion ability, a scoop with a ball guide and a ball shooter that is used to drop the balls in a fuel disk.

2.2 HYBRID ROBOTICS

A new generation of MRRs named modular self-reconfigurable robots (MSRRs) is currently of high interest for investigation and development due to their unique advantage despite the traditional robots of reconfigurability, reusability and easy manufacturing and maintenance.

Those classified as ***hybrid***, due to their mixed structural design that can include also wheels for locomotion, respond to the current growing demands in different domain of applications.

A good example of hybrid reconfigurable robot is the Ijspeert salamander. In [11] the author presents his robot that can both swim and walk, alternating the two motions depending on the terrain it needs to cross. The robot design is inspired by the salamander movements, whose locomotion performed study is also showed. In detail the paper explains how the spinal cord model was used as the key implementation of the robot. In particular it walks by means of four limbs and “produces lateral undulations of the spine with six actuated hinge joints”.

Figures 2.2-1 and **2.2-2** report shape and model characteristics of the Ijspeert salamander.

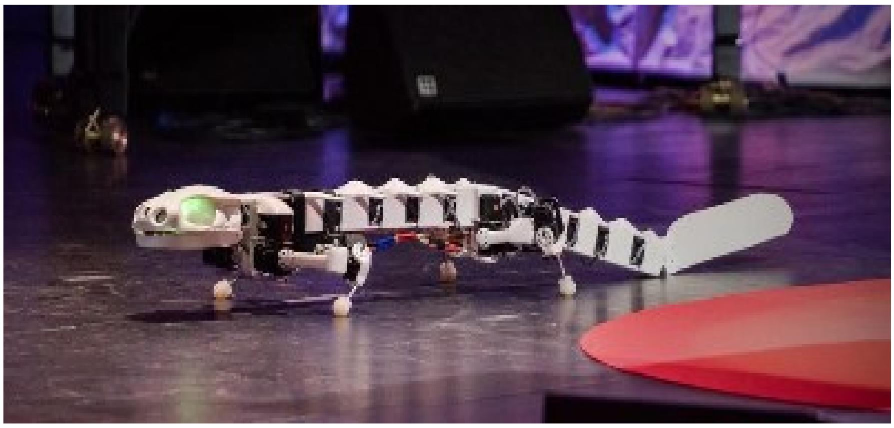


Figure 2.2-1 - Ijspeert salamander hybrid reconfigurable robot.

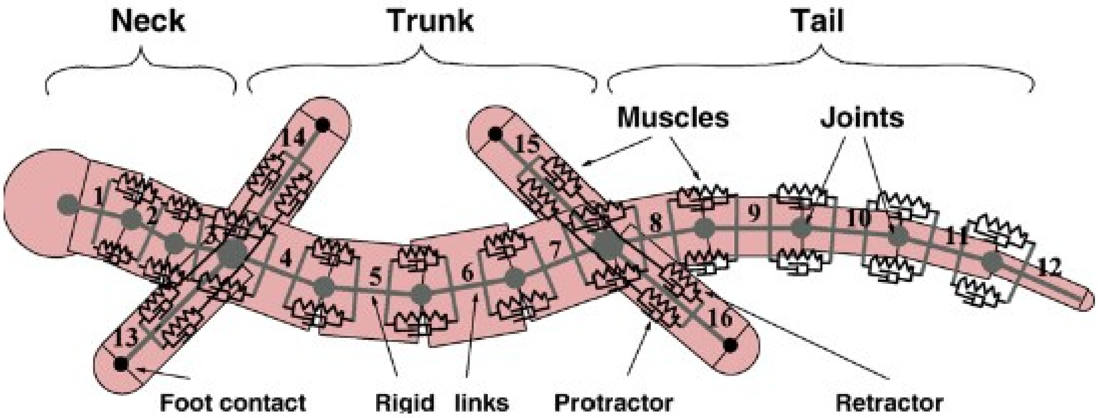


Figure 2.2-2 – Two dimensional biomechnical simulation of the salamander body modified by Ijspeert.

3 PROBLEM STATEMENT

As declared in Section 1 the aim of this thesis is to design a robotic assistant to be introduced inside a restaurant kitchen to replace the human pizzaiolo activities related to pizza doughs roll out and condiments filling in order to reduce the customer waiting time between the incoming order and the prepared pizza ready to be cooked.

To achieve this, the following steps are identified:

1. Definition of a working table suitable for the dimensions of a kitchen.
2. Carry out a feasibility study for the design of a possible simple cart-like robot architecture, hybrid and reconfigurable, composed by a cart and a manipulator arm.
3. Consider the operational feature of two simple cart-like robots to be assembled for the execution of a high complexity task, identified in the roll out operation of pizza dough partitions using a roll pin.
4. After disassembly consider each robot to proceed in parallel for the preparation of its own pizza in an independent way.

In this section a brief description of the workstation definition, the robot design feasibility study and the obtained results are reported, whilst all the design feasibility study details, including robot kinematics, are given in **Appendix A**.

3.1 WORKSTATION LAYOUT

The basic idea is to reproduce as much as possible the way of working of a human pizzaiolo. Consequently, the pizza maker workstation is provided with all tools for pizza doughs roll out and duplicated tools for pizza preparation, i.e. filling it with condiments.

Due to the robot simple architecture, a rotating roll pin (i.e. featured with an internal shaft allowing the rotation of the external wooden part) jointly with an automatic rotating mechanism of the roll out area are identified as necessary to allow the roll out of the pizza dough in all directions to produce an almost circular pizza.

A table for placing the already prepared pizzas is foreseen on the rear of the robots. The oven is assumed to stay on the right side of the workstation.

In **Figure 3.1-1** there is a representation of the workstation and its dimensions, which are 2100 mm length, 1000 mm depth, 750 mm height.

Figure 3.1–1 - Workstation and work environment layout realized with SKETCH UP.

The pizza maker robot carts are placed at a convenient distance from the workstation to preserve easy transit to any assistant personnel during the workstation preparation phase. This distance is contained to the value of 550 mm to limit the robot Links extension.

3.2 ARCHITECTURE DESIGN

Once the definition of the table is done the next step is to carry out the feasibility study for the design of a non-complex self-reconfigurable robot.

The leading idea is to start from a set of two similar simple robot units of cart-like form. They are composed by a cart with wheels that permit the robot motion on a plane in one direction only, then on top of it there is a robotic arm composed by four revolute joints attached to links of different lengths and finally there is an end effector, i.e. a gripper, at the end of the chain (**Figure 3.2-1**).

The simple cart-like robots are then characterized by 5 degrees of freedom (DOF).

The definition of each robot unit geometry and the design of the overall work environment arrangement requires a sort of loop, because of the different requirements to be satisfied all together. The adopted list of requirements includes:

- constrains on the cart dimensions, which have influence on the workstation dimensions and roll pin length;
- proper length of the links to pick up all the tools available on the

workstation;

- free from overturning;
- no interference of links when closest tools are to be collected and used, which means that the robot cannot stay too close to the workstation;
- a free corridor between the robots and the workstation to allow human personnel assistance in the preparation of the workstation, as mentioned above.

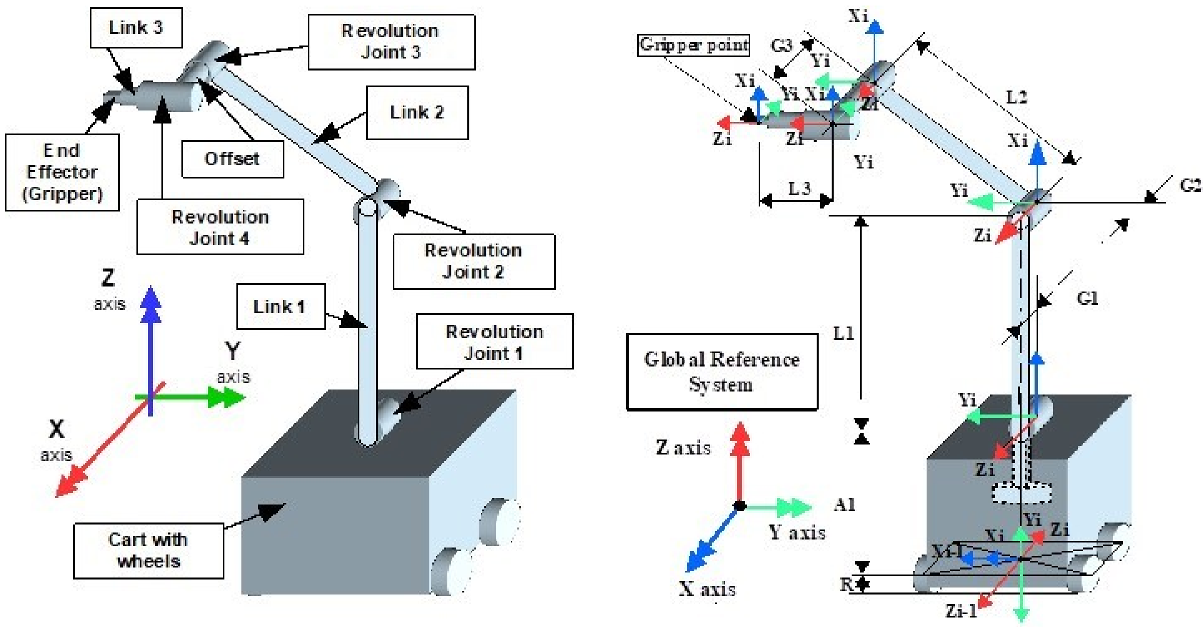


Figure 3.2–1 - Simple cart-like robot sketch.

3.2.1 LONGITUDINAL DESIGN

The overall longitudinal size of the robot unit is imposed by the length of the cart, which is equivalent to the minimum distance between the end effectors gripping points of two robots when assembled and, therefore, equivalent to the extension of the roll pin.

This dimension is also relevant for the overall workstation extension, to avoid interferences between the two robots in specific cases of pizza preparation. On the contrary the cart depth dimension is important for the design against overturning during operation. Here the cart length is defined to be 550 mm.

3.2.2 LINKS LENGTH

Accounting for the distance of the robot from the workstation and from the rear storage table and considering also the position of the most distant and closest tool, the resulting lengths of the three links are: Link 1=1200 mm, Link 2=980 mm, Link 3=300 mm. The cart depth is fixed to be 700 mm.

Figure 3.2.2-1 gives a sketch of the overall arrangement and robot movements to store the prepared pizza.

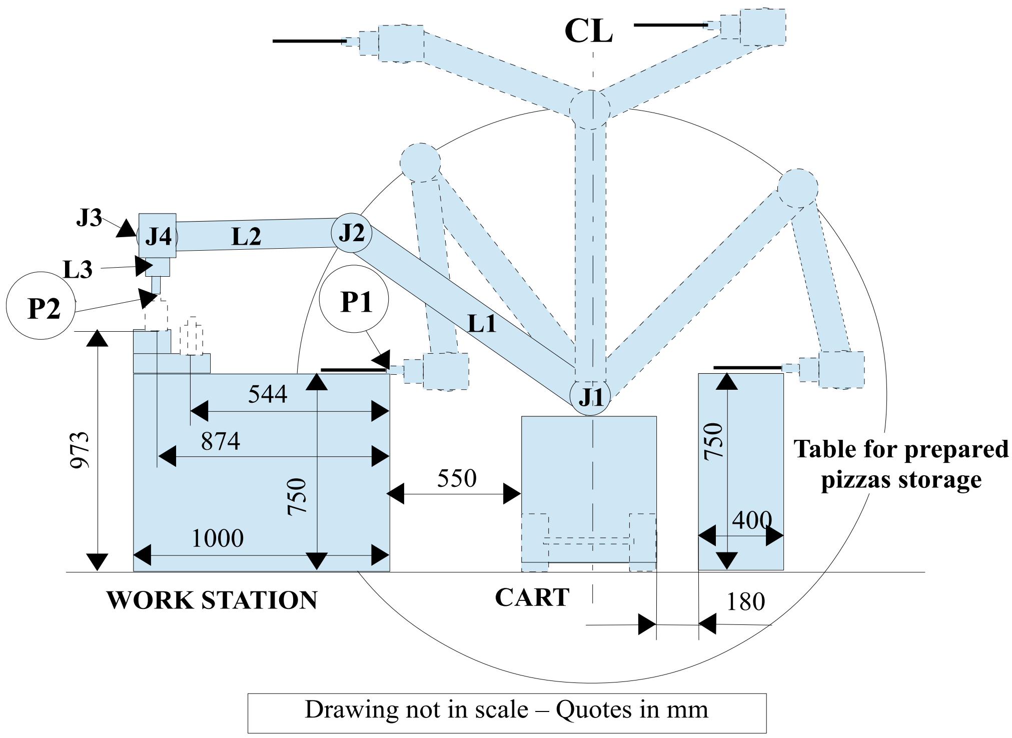


Figure 3.2.2-1 - Schematic view of the work environment arrangement and robotic arm movements.

3.2.3 STABILITY CONSIDERATIONS

The design geometry is completed by verifying that the robot architecture is free from overturning during its operation.

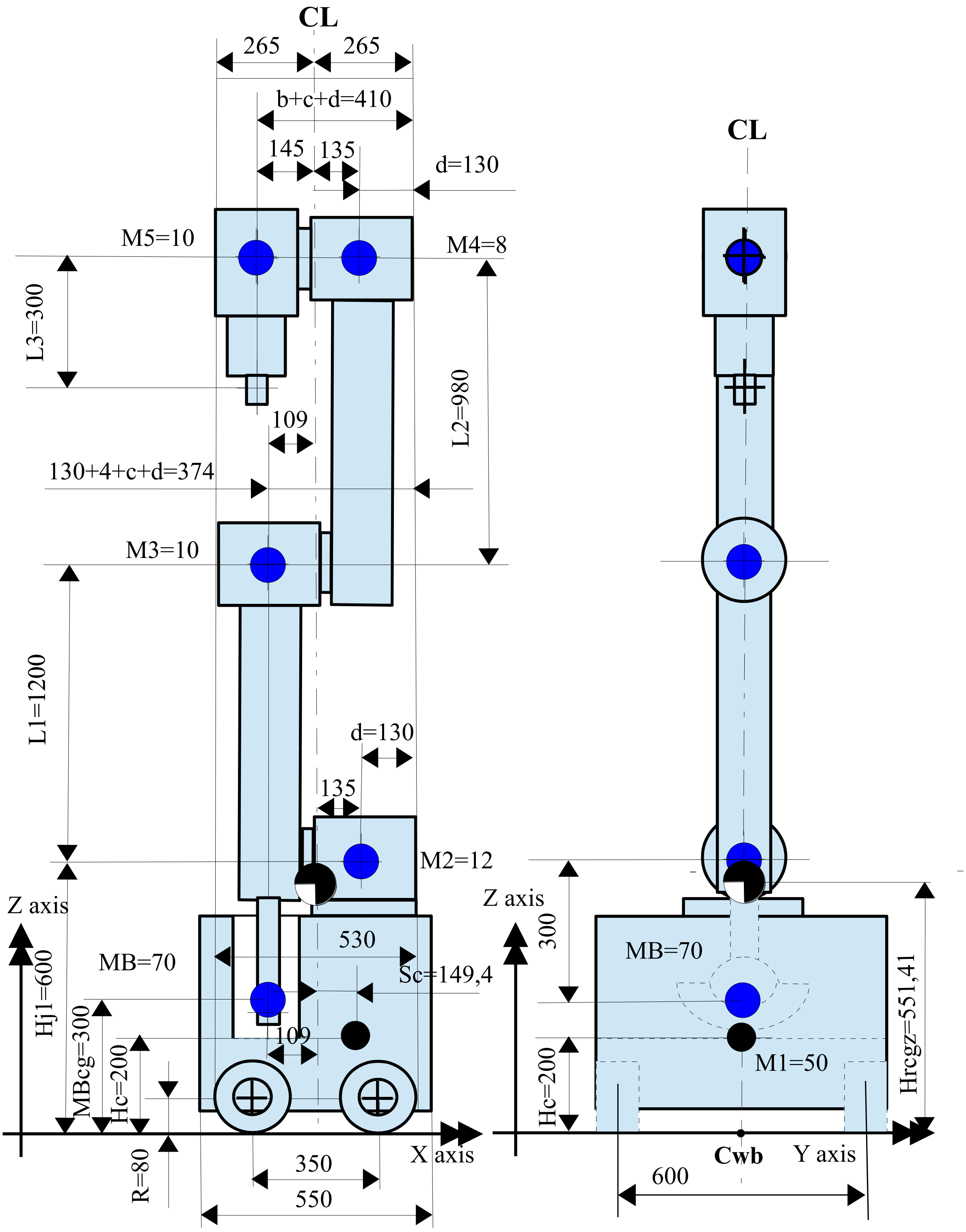
Once estimated the robot masses, assumed to be concentrated in the middle of each joint including half mass of any link concurring to that joint, the need of a balance mass is evident.

Considering an aluminium and plastic structure, the following (probably underestimated) masses have are for the analysis:

M1 (Cart) = 50 kg
M2 (Base + Joint 1 + half Link 1) = 12 kg
M3 (Joint 2 + half Link 1 + half Link 2) = 10 kg
M4 (Joint 3 + half Link 2 + half Link 3) = 8 kg
M5 (Gripper + half Link 3) = 10 kg
M6 (maximum workload) = 6 kg

The calculated balance mass is 70 kg and is attached on the opposite side of Link 1 at a distance from Joint 1 of 300 mm. Therefore, the overall robot unit mass **Mt** is 160 kg.

Figure 3.2.3-1 gives a sketch of the final robot architecture.



Dawing not in scale – Hybrid robot in non-work position – Masses in kg - Quotes in mm

Figure 3.2.3-1 - Schematic representation of final feasibility study robot architecture.

3.3 ROBOT MODEL

The dynamic model is made starting from the study of the kinematics motion of a single cart. The model used for this is a three massless links composing a robot with the Denavit-Hartenberg (DH) parameters in **Table 3.3-1**.

From given DH parameters the homogeneous transformation matrix representing the end effector movements in the base coordinate system is calculated.

However, because the study must be carried out with respect to a global reference frame, coinciding with the bottom right and rear corner of the workstation, the homogeneous transformation matrix is transformed in the global reference frame.

θ (rad)	d (m)	a (m)	α (rad)
0	q_1	0	π
$\pi/2$	q_2	A1	π
q_3	-G1	L1	0
q_4	G2	L2	0
q_5	G3	0	$-\pi/2$
q_6	L3	0	0

Table 3.3-1 - DH parameters obtained from the robotic model.

INVERSE KINEMATICS

The study of the inverse kinematics is carried out by examining rotations and translations separately from the homogeneous transformation matrix obtained from DH parameters and successive transformation.

The joint angle values depend as follows:

- **q6** from rotations only
- **q3** and **q4** from translations and rotations
- **q5** from a combination between **q3** and **q4**
- **q1** and **q2** from translations only

The robot is redundant with respect to joint **q4,** i.e. the fact that the robot can reach a given point both in elbow-up and elbow-down configuration.

4 DESIGN OPTIMIZATION OF THE COOKING ROBOT

The performed feasibility study shows that for the application under analysis the identified simple cart-like robot (5 Degrees of Freedom), based on the assumed requirements, results too big occupying a lot of the restaurant kitchen space.

In fact, the total height of the robot, with the arm fully extended and including the cart, is more than 3 m. Therefore, a very big kitchen would be necessary to accommodate the two robots and to allow their operation, mainly for the pizza transfer phase on the storage table.

In synthesis the big dimensions of the designed hybrid robot are related to:

- the requirement to use a simple cart-like type of robot configuration, with monodirectional cart and no manipulator arm rotation around the vertical axis, which implies a large arm movement through the upper side to put the prepared pizza on the rear table;
- the requirement to perform a complex task by having two robots working in assembled configuration, which implies a large workstation;
- the requirement to have two robots working in parallel to perform simultaneously the same pizza preparation tasks without interferences and, therefore, the need to have a big workstation to accommodate the duplicated tools.

Therefore, as an alternative, different solutions are investigated considering the use of a commercial and collaborative robotic arm and cart, giving priority to characteristics of small size, light weight, compatibility with the workstation and safe for human interaction.

Among a list of products available on the market (see **Section 4.1**), the UR10 manipulator manufactured by the Universal Robots Company is chosen for its dimensions and compliance with the payload requirement. Moreover, it is very useful for the pizza maker application the availability on the market of a mobile version of this manipulator known as MMO-700, which is composed by the mobile platform MPO-700 and the robotic arm UR10 installed on the top.

Similarly, among different types of commercially available grippers, the selected one that guarantees a payload very close to the one identified in the preliminary study in terms of force fit (or gripping force) is the ROBOTIQ 2F-85 gripper.

The selected commercial UR10 manipulator is a 6 DOF robotic manipulator of light weight, high speed movements, easy to program, flexible and safe for human interaction. Its reduced dimensions allow an adaptation of the workstation, with a slight reduction of its quotes. Moreover, the limit value of 5 kg force fit for the selected gripper requires also a small resizing of the condiment containers. As a further optimization step, a more functional distribution of tools and an increment of the number of pizza dough partitions to be allocated, i.e. up to 10, is done.

The use of a commercial collaborative robot removes the initial requirement of robots assembly for the execution of a complex task, therefore the roll pin length is reduced to the minimum necessary. In addition, the smaller workstation dimensions allow its preparation and containers refilling from the lateral sides, eliminating the need of a free corridor between the robot and the workstation. Finally, the availability of the rotational movement of the manipulator arm around the vertical axis allows to remove the complex pizza dough roll out rotating mechanism.

4.1 SELECTED COLLABORATIVE HYBRID MANIPULATOR

As mentioned, the cooking robot optimization design is now oriented to the investigation of existing commercial collaborative robots suitable for our application.

The operational range and the payload characteristics of a variety of commercial products are reported in the following **Table 4.1-1**, jointly with manufacturer name and web site.

Among all the market available products the Universal Robots Company UR10 Manipulator is selected.

The UR10 is the bigger robotic arm of the commercial and collaborative manipulator series UR3, UR5 and UR10.

It is a lightweight, fast, easy to program, flexible and safe robotic arm with 6-axis and 6 degrees of freedom featured with six rotating joints named Base, Shoulder, Elbow, Wrist 1, Wrist 2 and Wrist 3.

The main UR10 technical data, which are of interest for the present study, are reported in the following **Table 4.1-2**, whilst **Figure 4.1-1** reports same UR10 geometric data available on the web.

A picture of the UR10 manipulator is given in **Figure 4.1-2**.

Manufacturer Web site	***Model type Web site***	***Reached distance***	***Payload***
Universal Robot https://www.universal-robots.com/it/	UR3 https://www.universal-robots.com/it/prodotti/robot-ur3/	500 mm	3 Kg
	UR3e https://www.universal-robots.com/it/prodotti/robot-ur3/	500 mm	3 Kg
	UR5 https://www.universal-robots.com/it/prodotti/robot-ur5/	850 mm	5 kg
	UR5e https://www.universal-robots.com/it/prodotti/robot-ur5/	850 mm	5 kg
	UR10 https://www.universal-robots.com/it/prodotti/robot-ur10/	1300 mm	10 kg
	UR10 https://www.universal-robots.com/it/prodotti/robot-ur10/	1300 mm	10 kg
Fanuc https://www.fanuc.eu/it/it/robot/robot-filter-page/robot-collaborativi	CR-4iA https://www.fanuc.eu/it/it/robot/robot-filter-page/robot-collaborativi/collaborative-cr4ia	550 mm	4 Kg
https://www.fanuc.co.jp/en/product/robot/f_r_collabo.html	CR-7iA https://www.fanuc.eu/it/it/robot/robot-filter-page/robot-collaborativi/collaborative-cr7ial	717 mm	7 Kg
http://www.technifutur.be/downloads/cobotique/11-fanuc.pdf	CR-7iA/L https://www.fanuc.eu/it/it/robot/robot-filter-page/robot-collaborativi/collaborative-cr7ial	911 mm	7 Kg
	CR-15iA https://www.fanuc.eu/it/it/robot/robot-filter-page/robot-collaborativi/collaborative-cr15ia	1441 mm	15 kg
	CR-35iA https://www.fanuc.eu/it/it/robot/robot-filter-page/robot-collaborativi/collaborative-cr35ia	1813 mm	35 kg
Rethink Robotics https://www.rethinkrobotics.com/	Sawyer https://www.rethinkrobotics.com/sawyer/	1260 mm	4 kg

Table 4.1-1 – A list of commercially available manipulator arms (**part 1**).

Manufacturer Web site	***Model type Web site***	***Reached distance***	***Payload***
ABB	Yumi https://new.abb.com/products/robotics/industrial-robots/irb-14000-yumi https://new.abb.com/products/robotics/industrial-robots/irb-14050-single-arm-yumi https://new.abb.com/products/robotics/industrial-robots/irb-14050-single-arm-yumi https://new.abb.com/products/robotics/industrial-robots/irb-14050-single-arm-yumi https://new.abb.com/news/detail/13774/abbs-yumi-collaborative-robot-named-2016-best-industrial-robot https://new.abb.com/products/robotics/industrial-robots/irb-14000-yumi/irb-14000-yumi-data https://new.abb.com/products/robotics/case-studies/abb-elektro-praga-czech-republic https://new.abb.com/products/robotics/case-studies/deonet-netherlands	559 mm	0,5 kg
Siasun Robot & Automation Co., Ltd. http://www.siasun-in.com/plus/list.php?tid=69	https://www.youtube.com/watch?v=GjGbogLv_jw http://www.siasun-in.com/en/ http://www.siasun-in.com/en/Press_Center/Company_News/20180523/469.html		
	SIASUN DUCO Hybrid Cobot HCR20 http://www.siasun-in.com/en/Robotic_World/SIASUN_Flexible_7_Axis_Robot/20180926/570.html	Natural Navigation and 20 kg payload Cobot technology	Cobot Payload up to 20 kg, Load Tolerance 100 kg
	SIASUN DUCO GCR20-1100 http://www.siasun-in.com/en/Robotic_World/SIASUN_Flexible_7_Axis_Robot/20180926/571.html	1100 mm	20 kg Body Weight 50 kg
	SIASUN DUCO GCR14-1400 http://www.siasun-in.com/en/Robotic_World/SIASUN_Flexible_7_Axis_Robot/20190201/611.html	1400 mm	14 kg

Table 4.1-1 – A list of commercially available manipulator arms (**part 2**).

Manufacturer Web site	***Model type Web site***	***Reached distance***	***Payload***
	SIASUN DUCO Cobot SCR5 http://www.siasun-in.com/plus/view.php?aid=289	800 mm	5 kg
	SCR3 http://www.siasun-in.com/plus/view.php?aid=479	600 mm	3 kg
	HSCR5 http://www.siasun-in.com/plus/view.php?aid=480		Grasping load 5kg
ST Robotics http://strobotics.com/	r12 collaborative robot arm R12-5 Low cost 5-axis 500mm jointed (articulated) robot arm. Fast and quiet, amazing performance for the price. Wide range of grippers, end effectors and accessories. Optional tool changer and mountings for tools. Safe collaborative robots. Optional sensors and safety devices. Optional linear track. R12-six Low cost 6-axis 500 mm jointed (articulated) robot arm.	R12-5 http://strobotics.com/small-articulated-robot.htm 500 mm	http://strobotics.com/endarm2.htm 0,5 kg
https://www.franka.de/	https://www.franka.de/technology	855 mm	3 kg

Table 4.1-1 – A list of commercially available manipulator arms (**part 3**).

Weight	*28,9 kg*
Payload	*10 kg*
Working area	*1300 mm for +/-360°*
Operational speed	*Base and Shoulder = 120 °/s* *Elbow and Wrists 1,2,3 = 180 °/s* *End effector = 1 m/s*
Base footprint	*ϕ190 mm*
Materials	*Aluminum and plastic*
Temperature	*Working range 0-50 °C*
Base centre height	*128 mm*
Base vs. Shoulder gap	*176 mm*
Link 1 length	*612 mm - contributing to the operational range*
Link 1 vs. Link 2 gap	*128 mm*
Link 2 length	*572 mm - contributing to the operational range*
Wrist 1 vs. Wrist 2 gap	*116 mm*
Wrist 2 vs. Wrist 3 gap	*116 mm - contributing to the operational range*
Wrist 3 vs. End effector length	*92 mm*

Table 4.1-2 – UR10 main technical data.

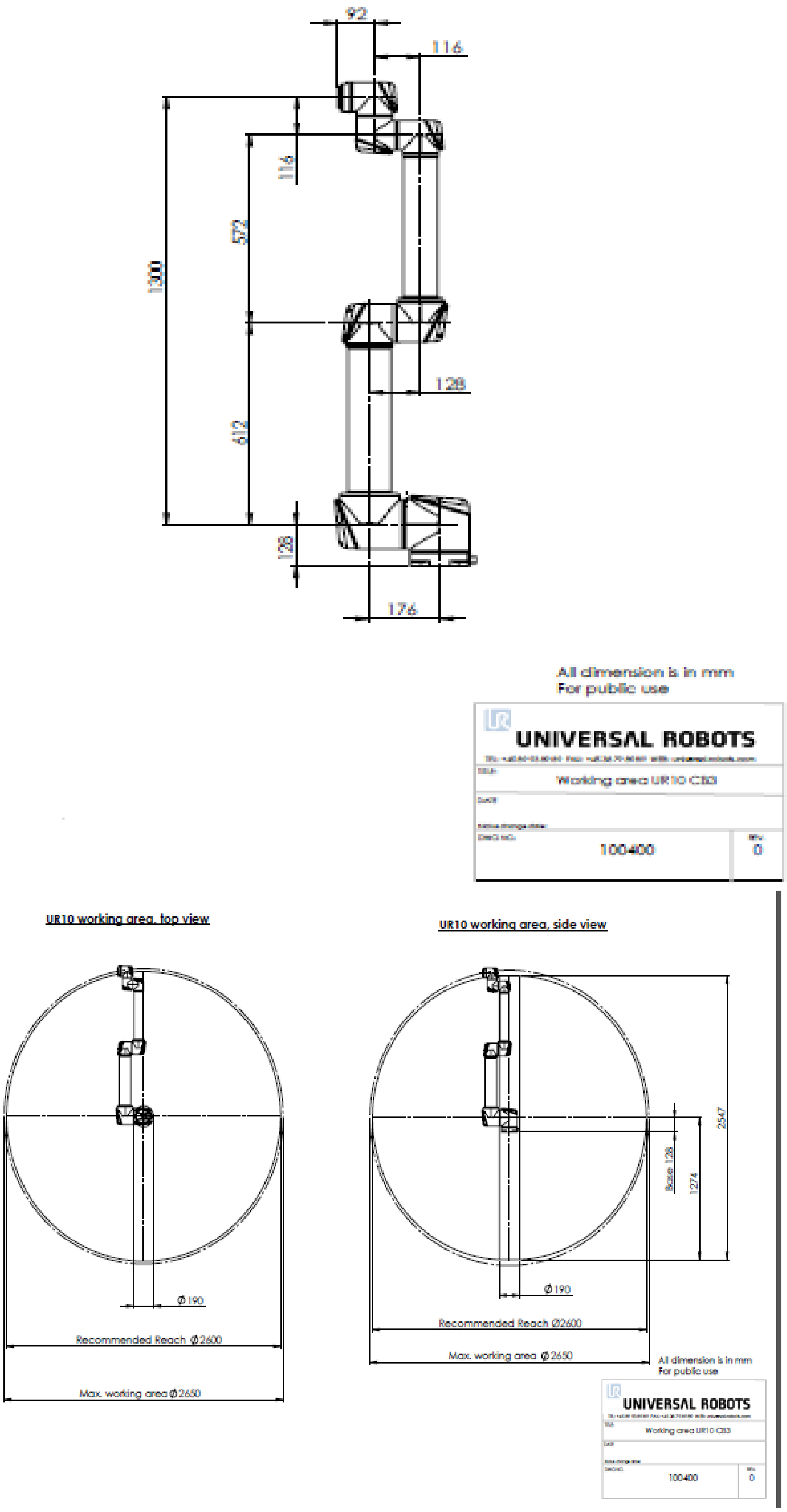


Figure 4.1-1 – Geometric UR10 data for public use.

Figure 4.1-2 – UR10 manipulator.

4.2 MOBILE MANIPULATOR NEOBOTIX MMO-700 WITH UR10

Very attractive for our application is the mobile manipulator Neobotix MMO-700, which combines the omnidirectional mobile platform MPO-700 with the UR10 manipulator.

The mobile manipulator Neobotix MMO-700 main technical data, which are of interest for the present study, are reported in the following **Table 4.2-1**, whilst geometric data available on the web are given in **Figure 4.2-1**.

Some images of the MMO-700 with UR10 are given in **Figure 4.2-2**.

Weight	*120 kg*
Payload	*400 kg*
Operational speed	*Less than 1 m/s, omnidirectional*
Number of wheels	*4*
Wheel pitch	*480 mm*
Wheel gauge	*480 mm*
Base dimensions	*Length = 821 mm* *Width = 521 mm* *Heigth = 767 mm*
Position of the manipulator arm base	*Middle of the width, i.e. 260,5 mm* *148 mm in length from the cart centre (calculated)* *Heigth = 767 mm*
Sensors	*Laser scanner Sick S300*

Table 4.2-1 – MMO-700 main technical data.

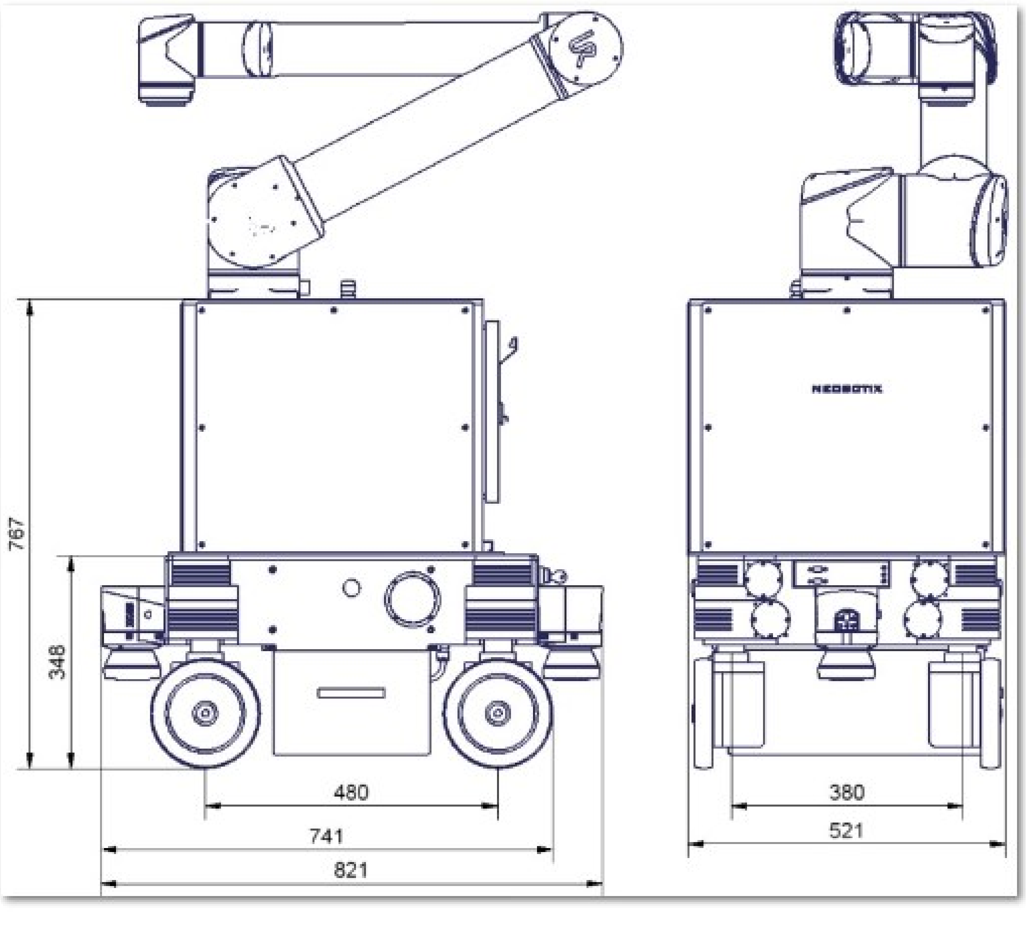


Figure 4.2-1 – MMO-700 with UR10 geometric data.

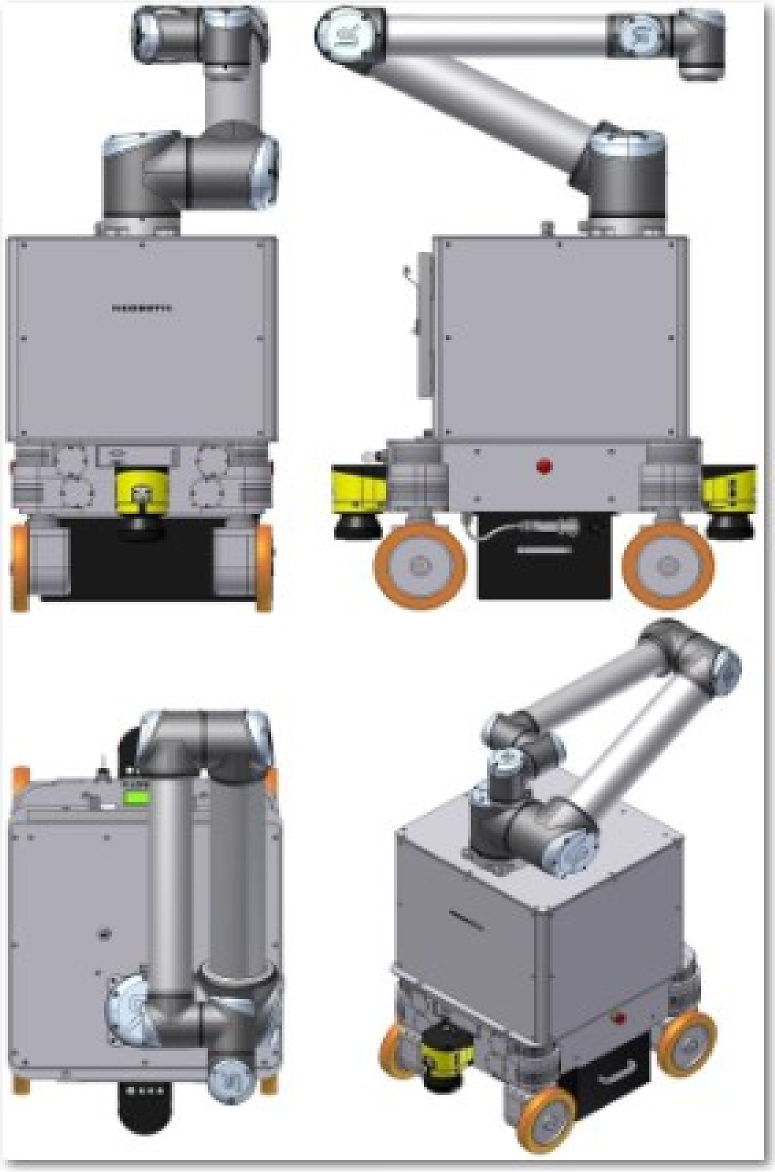


Figure 4.2-2 – MMO-700 with UR10.

4.3 ROBOTIQ 2F-85 GRIPPER FOR UR10

As far as the end effector is concerned the 2 fingers ROBOTIQ 2F-85 gripper, compatible with the UR10 (plug and play), is used. This is a low weight and small dimensions gripper offering a grip payload compatible with the weight of all the tools to be manipulated in the pizza maker application.

The two fingers ROBOTIQ 2F-85 gripper technical data of interest for the present study are reported in the following **Table 4.3-1**, whilst the gripper geometric data are represented in **Figure 4.3-1**.

An image of the Robotiq 2F-85 gripper is shown in **Figure 4.3-2**.

Weight	*0,9 kg*
Form fit	*5 kg*
Force fit (grip payload)	*5 kg with silicon covered fingertips*
Grip force	*20 to 235 N*
Stroke	*85 mm*
Finger speed	*20 to 150 mm/s at steps of 0,4 mm (max value used here)*
Gripper dimensions	*Length fully open = 149,3 mm* *Length fully closed = 162,8 mm* *Width fully open = 152,7 mm* *Width fully closed = 126,9 mm*
Fingertip	*Length = 38 mm* *Thickness = 6,5 mm (each finger)* *Depth = 22 mm* *Contact area = 22 x 38 mm*
Interface with UR10	*ϕ75 mm*

Table 4.3-1 – ROBOTIQ 2F-85 gripper main technical data.

From the **Table 4.3-1** data come out that the gripping area moves forward during the fingers closure. Assuming the gripping point to be in the middle of the finger length, the manipulator control is done assuming a gripper length of (162,8 – 19) = 143,8 mm. Considering the thickness of tools to be gripped the closed length results a little bit less than 162,8 mm. Therefore, in this study the assumed gripper length is 143 mm after the UR10 interface.

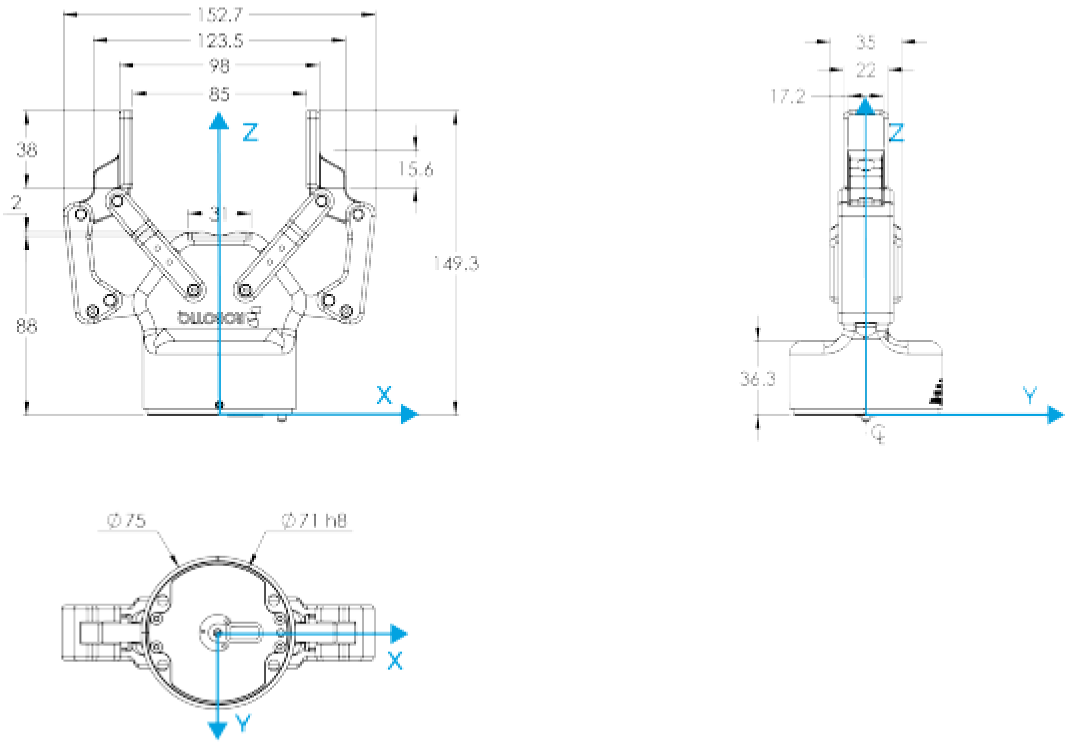


Figure 4.3-1 – Geometric data of Robotiq 2F-85 gripper.

Figure 4.3-2 – Robotiq 2F-85 gripper in open position.

4.4 MMO-700 TOTAL MASS AND STABILITY CHECK

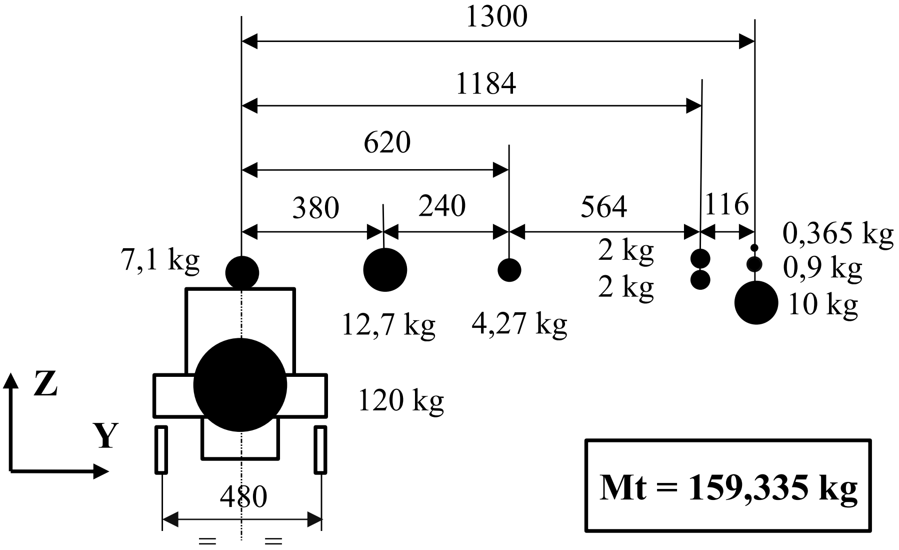
It is sure that the MMO-700 with UR10 manipulator and the maximum prescribed payload of 10 kg is stable in the whole manufacturer recommended working range of 1300 mm. However, a simple check has been performed using the following mass and geometric data available on the web.

- UR10 Base mass = 7,1 kg
- UR10 Shoulder plus part of Link 1 mass = 12,7 kg at 380 mm from the Base axis
- UR10 Elbow mass plus part of Link 1 and Link 2 masses = 4,7 kg at 240+380=620 mm from the Base axis
- UR10 Wrist 1 mass = 2 kg at 612+572=1184 mm from the Base axis
- UR10 Wrist 2 mass = 2 kg at 612+572=1184 mm from the Base axis
- UR10 Wrist 3 mass = 0,365 kg at 612+572+116=1300 mm from the Base axis
- UR10 Payload = 10 kg at 612+572+116=1300 mm from the Base axis
- Robotiq 2F-85 gripper mass = 0.9 kg at 612+572+116=1300 mm from the Base axis
- MMO-700 cart mass = 120 kg assumed centered on the wheelbase
- MMO-700 wheel pitch = 480 mm
- MMO-700 wheel gauge = 480 mm
- UR10 Base on MMO-700 lateral position = 260,5 mm (middle of cart width)
- UR10 Base on MMO-700 longitudinal position = 148 mm from the cart center
- UR10 Base on MMO-700 height position = 767 mm

The stability check, which is positive, is reported in **Figure 4.4-1** for the lateral operation and in **Figure 4.4-2** and **Figure 4.4-3** for the longitudinal operation. In all cases the resulting center of gravity remains inside the wheelbase.

Anticipating here the use of the same cart MMO-700 with the installation of two UR10 manipulators, by means of a steel plate interface of dimensions 260 x 1100 x 20 mm and weighing about 45 kg (steel specific weight = 7,85 kg/dm^3), it is of more interest the lateral stability check for this configuration.

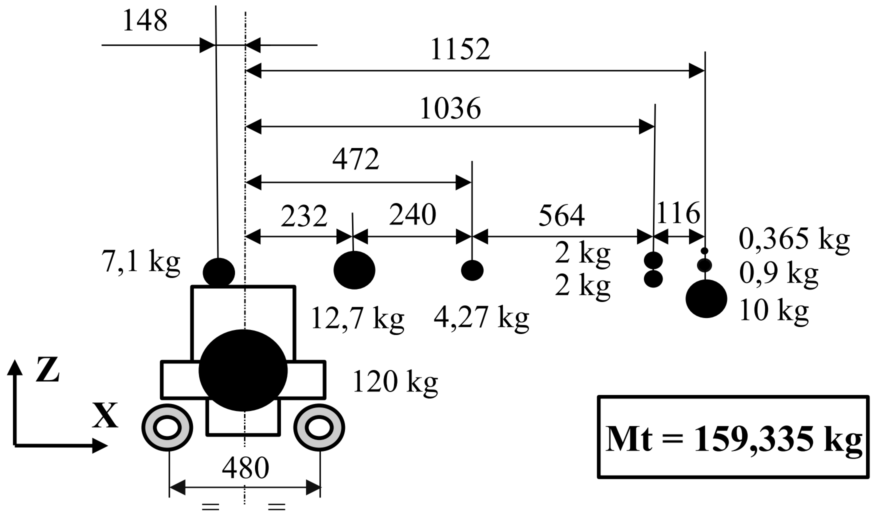
In longitudinal operations one manipulator acts like a balance mass for the other one. Therefore, the stability check is not necessary for this case. As far as the lateral stability is concerned, the check shows that even considering the limit operating conditions and the maximum payload for both manipulators, which is a condition never occurring in the present application, the resulting center of gravity remains inside the wheelbase (see **Figure 4.4-4**).



$$12{,}7 * 380 + 4{,}27 * 620 + 4 * 1184 + 11{,}265 * 1300 = 159{,}335 * d$$

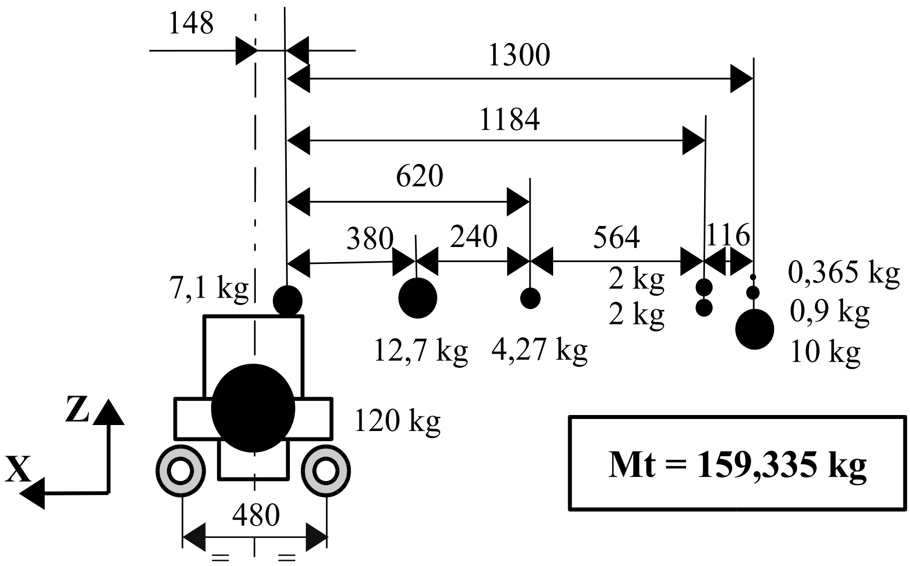
$$d = \mathbf{168{,}54} \text{ mm} < 240 \text{ mm}$$

Figure 4.4-1 - Stability check of MMO-700 with UR10 manipulator and Robotiq 2F-85 gripper for lateral operation.



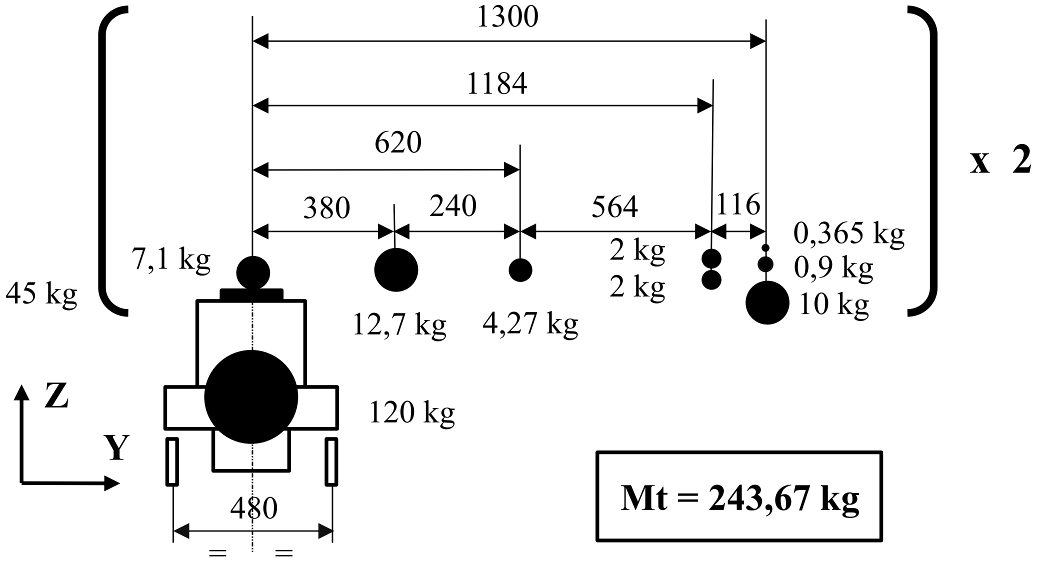
7,1 * (-148) + 12,7 * 232 + 4,27 * 472 + 4 * 1036 + 11,265 * 1152 = 159,335 * d
d = **132,00** mm < 240 mm

Figure 4.4-2 - Stability check for MMO-700 with UR10 manipulator and Robotiq 2F-85 gripper for longitudinal operation (one side).



7,1 * 148 + 12,7 * 528 + 4,27 * 768 + 4 * 1332 + 11,265 * 1448 = 159,335 * d
d = **205,07** mm < 240 mm

Figure 4.4-3 – Stability check for MMO-700 with UR10 manipulator and Robotiq 2F-85 gripper for longitudinal operation (other side).



(12,7 * 380 + 4,27 * 620 + 4 * 1184 + 11,265 * 1300) * 2 = 243,67 * d

d = **220,41** mm < 240 mm

Figure 4.4-4 - Stability check for MMO-700 with two UR10 manipulators and Robotiq 2F-85 grippers for lateral operation.

4.5 GRIPPING POINT COORDINATES AT REST RESPECT UR10 BASE

Figure 4.5-1 gives a sketch of the UR10 manipulator plus the gripper with the relevant quotes at rest position. From this sketch the coordinates of the gripping point (**GP**) or control point with respect to the manipulator Base center are derived.

X_{GP} = 545 – 572 -116 = **-143** mm or Y_{GP} if the manipulator is turned 90°

Y_{GP} = 176 – 128 +116 = **164** mm or X_{GP} if the manipulator is turned 90°

Z_{GP} = 128 + 278 – 92 – 143 = **171** mm

However, in the following performance study, the **GP** coordinates at rest are derived case by case in the global reference system.

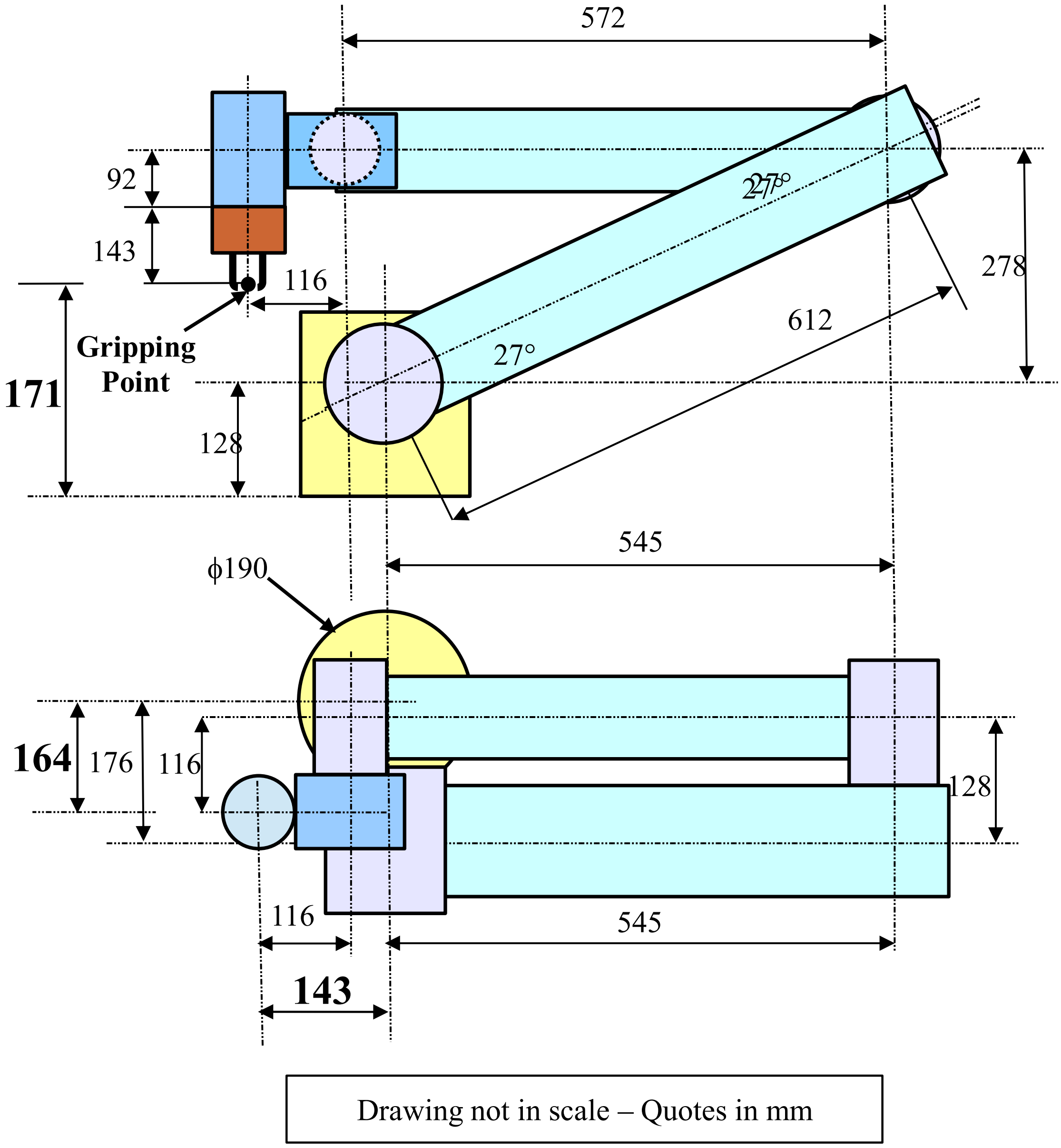


Figure 4.5-1 - UR10 manipulator geometric data at rest position for gripping point coordinates derivation referred to the Base.

4.6 OPTIMISED WORKSTATION AND KITCHEN LAYOUT

The new and optimised workstation is defined with a modular concept. In detail there is a module dedicated to the activity of pizza dough roll out and another one dedicated to the pizza preparation (filling with condiments).

On the pizza roll out module there are the roll pin, the flour container, nr. 10 pizza doughs partitions above the relative trays, and a shovel.

On the pizza preparation module there are nr. 8 containers for nr. 8 different condiment types, the condiments spreading tool, the tomato sauce ladle with an automatic sauce dispenser and the relevant accommodation, a shovel, the origan container, the salt container, the garlic container, and the olive oil container.

Condiments, allowing the preparation of nr. 6 basic pizza tastes are the same foreseen for the workstation designed in the feasibility study. They are listed below reporting in parenthesis the workstation location and the container code, which are introduced later:

- mozzarella cheese (**L3**, **cc1**),
- aubergines (**L4**, **cc2**),
- zucchini (**L5**, **cc3**),
- peppers (**L6**, **cc4**),
- wurstels (**L7**, **cc5**),
- sausages (**L8**, **cc6**),
- mushrooms (**L9**, **cc7**), and
- ham (**L10**, **cc8**).

The pizzas taste that can be prepared are:

1. marinara (tomato sauce, salt, origan, garlic, and olive oil)
2. margherita (tomato sauce, salt, mozzarella cheese and olive oil)
3. ortolana (tomato sauce, salt, mozzarella cheese, aubergines, zucchini, peppers, origan and olive oil)
4. wurstel (tomato sauce, salt, mozzarella cheese, wurstel and olive oil)
5. salsiccia (tomato sauce, salt, mozzarella cheese, sausages and olive oil)
6. prosciutto e funghi (tomato source, salt, mozzarella cheese, ham, mushrooms and olive oil)

The set of containers must be filled with condiments cut in small pieces in order to be sure of their falling down on the pizza once the container has been overturned and shaken. A grid on the top is introduced to provide a sort of dosage adjustment of the condiment. Differentiated grids are considered for flour, taste condiments, salt, origan and garlic.

The use of containers is preferred to the dispensers because these are normally used for dry food or fully liquid food. There is a high probability that wet food could be compacted inside the dispenser not falling down when requested.

4.6.1 WORKSTATION GEOMETRY AND LAYOUT

The two workstation modules are placed against a wall and side by side, with the pizza preparation module on the right. From now on the pizza preparation module will be called Module 1 and the pizza roll out module will be called Module 2.

Similarly, Robot 1 will be the robot unit performing tasks on the Module 1, whilst Robot 2 will be the robot unit performing tasks on the Module 2.

The pizza shovel is a duplicated tool and will be differentiated with numbers 1 (on Module 1) and 2 (on Module 2). There is also a third shovel of slightly different design for oven use, but it will be introduced later jointly with Robot 3.

The sequence of robot tasks, reproducing the way of working of a human pizzaiolo, are listed in the following.

Robot 2

- flour spreading on the pizza roll out area;
- pick up and drop on the pizza roll out area one pizza dough partition;
- pick up the roll pin and roll out the pizza dough partition;
- pick up the pizza shovel and transfer the rolled pizza dough on the pizza preparation area.

Robot 1

- fill the ladle with tomato sauce and spread it on the rolled pizza dough;
- pick up the salt container and distribute it on the pizza;
- pick up in sequence the condiments containers required by the pizza taste to be prepared and distribute them on the pizza;
- pick up the condiments spreading tool and distribute uniformly them on the pizza;
- pick up the olive oil container and distribute it on the pizza;
- pick up the origan and garlic containers and distribute them on the pizza, when required;

- pick up the pizza shovel and transfer the prepared pizza on the rear storage table.

Robot 3 (introduced later)

- pick up the prepared pizza from the storage table and put it in the oven for cooking;
- pick up the cooked pizza from the oven and put it on the delivery table.

The global reference system has its origin at the bottom right and rear corner of the workstation Module 1 (see **Figure 4.6.1-1**).

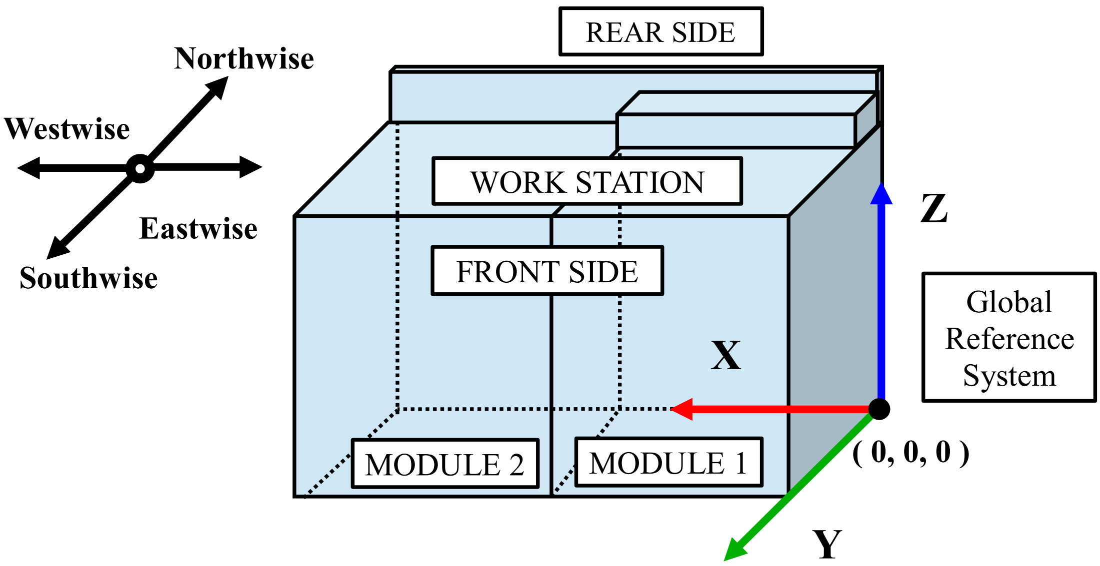


Figure 4.6.1-1 – Workstation and Global Reference System.

The location of any tool on the work station is realized with a recess of 2 mm in depth with respect to the work station surface, enlarged by 2 mm in diameter and provided with an indentation to accommodate the special featured handle of tools to avoid human wrong positioning of them during the work station preparation. The indentation is not foreseen for final condiments origan, salt, garlic and olive oil because of the slim diameter of these containers, which allows the gripper to directly pick up them. A deeper recess is foreseen for the condiments spreading tool and a particular special feature is arranged for the tomato sauce ladle and tomato sauce dispenser.

The overall dimensions of the workstation result 1600 mm length, 920 mm depth and 750 mm height. On the Module 1 there is an area raised by 100 mm, as explained later.

Special attention has been given to the pizza dough roll out area. In fact, unlike the feasibility study solution, now the availability of the omnidirectional cart and the feature of 360° rotational manipulator arm allows to eliminate the automatic rotating mechanism, even if its absence introduces some complexity in the robot movements control.

First of all sufficient space is required to move the roll pin not only in the fore and aft directions, which will be called 0° direction or North/Southwise directions, but also in the alternate movements at +/- 45° (NE/SW) and +/-90° (E/W) directions.

Looking at **Figure 4.6.1-2** the space to reserve to the pizza dough roll out operation must be at least 470 mm for a roll pin having a total length of 342 mm, including the special handle and considering a stroke of 320 mm. The designed roll out area is higher than 470 x 470 mm.

On the rear side of the robots is placed a table for the storage of three prepared pizzas, i.e. pizzas which are ready for cooking. The kitchen assistant (or Robot 3) picks up these pizzas for their cooking and final delivery at desk.

In the **Appendix B** there is a brief description of any tool of each Module and the geometric coordinates of the relevant allocation and of the pick-up point of the tools in the global reference system. A simplified layout of the workstation is showed in **Figure 4.6.1-3**.

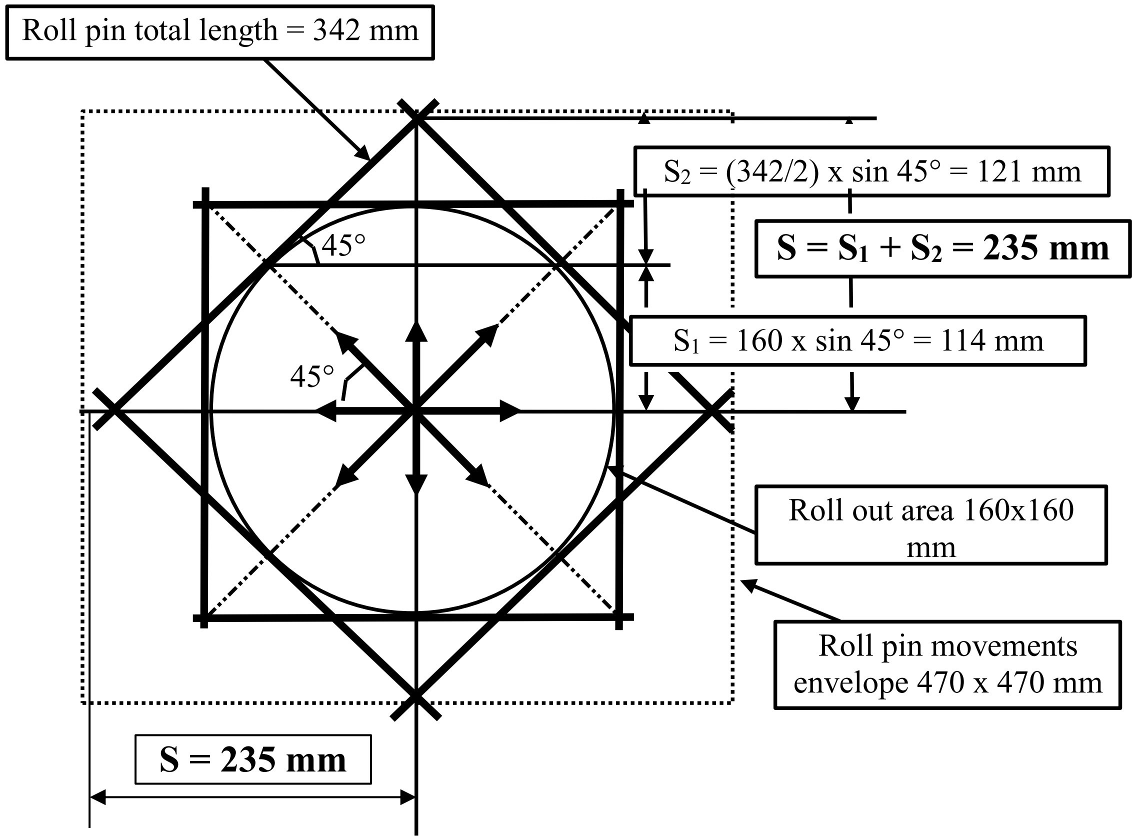


Figure 4.6.1-2 – Area to be reserved for the roll pin movements.

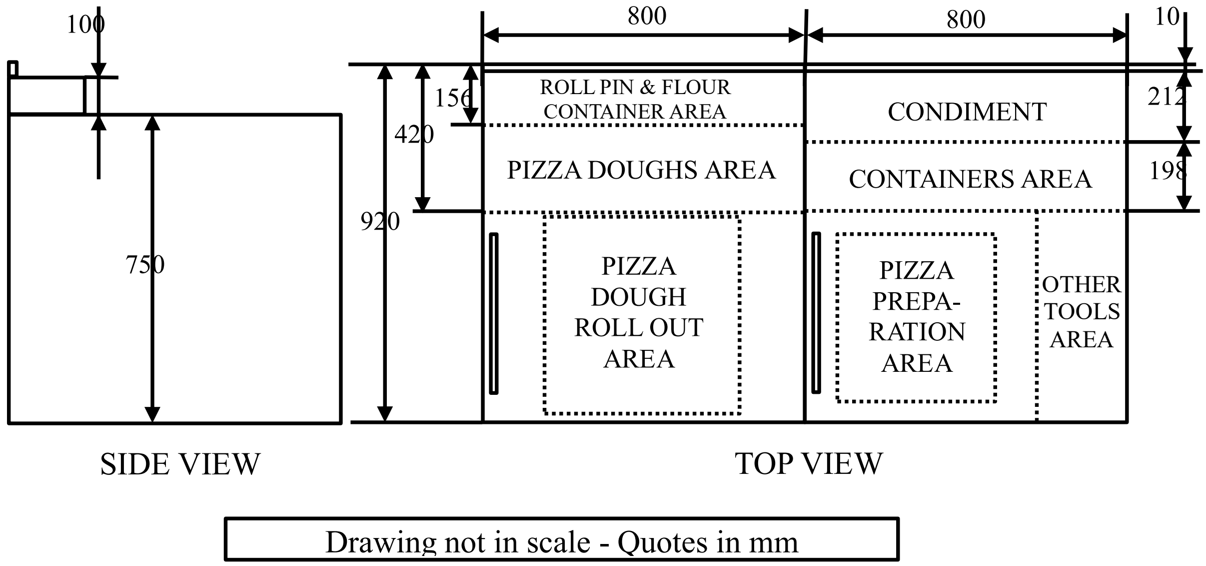
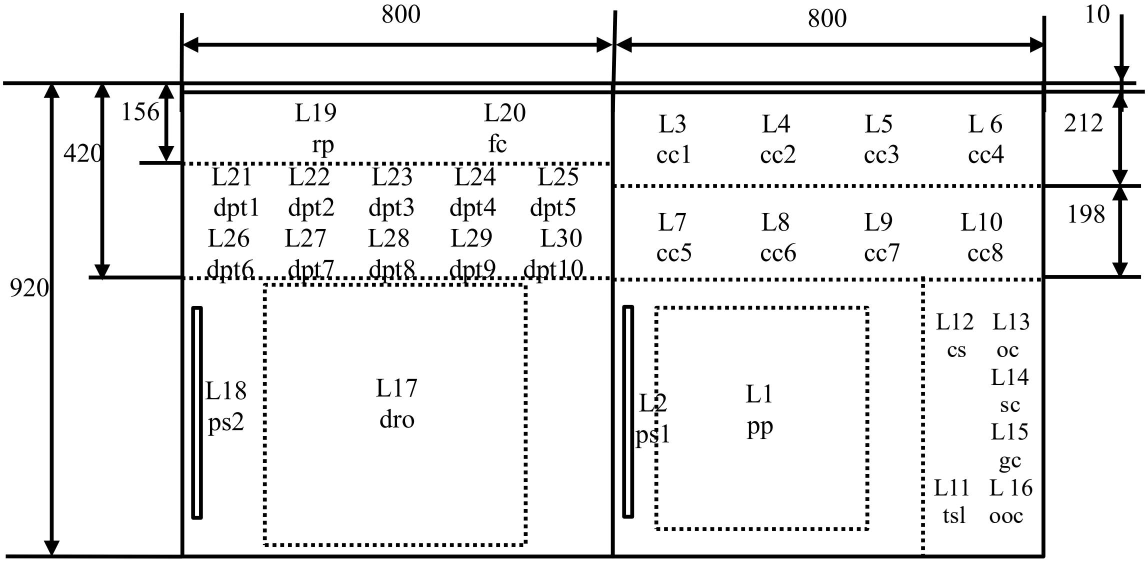


Figure 4.6.1-3 – Workstation simplified lay out.

Despite the considerations done in the feasibility study, the reduced dimensions of the workstation allow to put the mobile manipulator as close as possible to the work table, having the possibility to refill the table with any kind of condiments from the lateral side. By the other hand having focused this study on the comparative production times of nr. 10 pizzas of various tastes, from the available menu list, the foreseen capacity of the containers is considered fully compliant with the production of these number of pizzas.

Figure 4.6.1-4 gives a sketch of the workstation with the indication of the location number and tools code.

Finally, the reduced dimensions of the workstation allow the use of a fixed manipulator as an alternative to the mobile version. For this reason, this option is included inside the configurations identified for the performance study.



TOP VIEW - Drawing not in scale - Quotes in mm

Figure 4.6.1-4 – Workstation sketch with locations number and tools code.

The position of the manipulators varies as function of the configuration type. Similarly, the table where the already prepared pizzas will be stored for the further phase of cooking is situated in front of the workstation and behind the pizza maker robots at a position depending from the selected configuration of the manipulators, mobile or fixed.

The overall dimensions for the pizza storage table, considering a continuous cooking activity, are reduced to 1200 mm **X** axis length, 400 mm **Y** axis depth and 750 mm **Z** axis height, which allow to store three pizzas at the same time. The personnel or the mobile robot dedicated to the pizzas cooking operates on the other side of this table.

The oven is placed on the right side in front of the workstation. Finally, there is a desk at the exit of the oven for the final delivery of the cooked pizzas to the customer.

The schematic arrangement of the workstation is given in **Figure 4.6.1-5**, realized with the tool SKETCH UP.

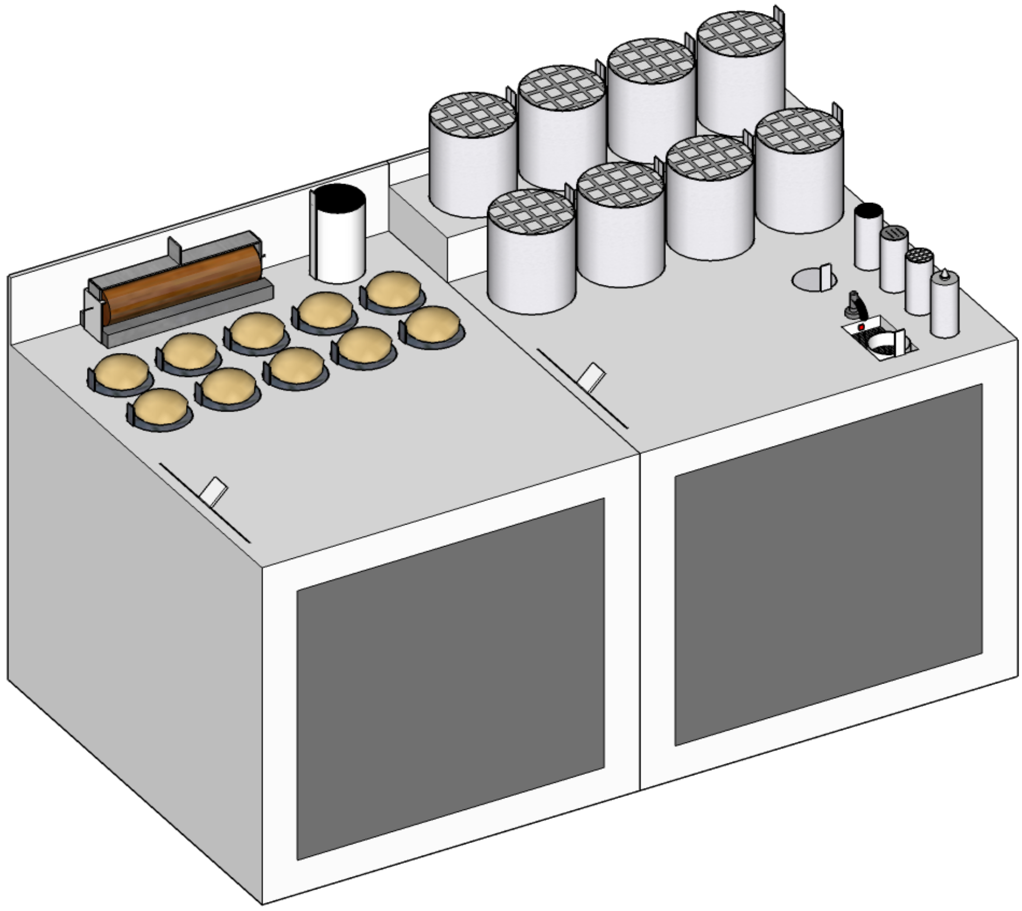


Figure 4.6.1-5 – Workstation overall lay out realized with the tool SKETCH UP.

4.7 PROPOSED SOLUTIONS FOR ROBOT CONFIGURATIONS

Three different robot configurations, for the evaluation of the time spent for the preparation of ten pizzas, are considered and detailed in the following:

1. two identical mobile robots (MMO-700 cart with UR10 manipulator), performing different tasks;

2. one cart MMO-700 with two identical UR10 manipulators, performing different tasks;
3. two fixed and identical UR10 manipulators, performing different tasks, plus one mobile robot, using the same types of cart and manipulator, performing the cooking phase of the pizza production process till its delivery at customer desk.

The second configuration has the disadvantage that when one manipulator requires the use of the cart the other manipulator must stop its activities. However, as the not moving cart corresponds to Configuration nr. 3, for the Configuration nr. 2 the cart use is limited to a minimum.

5 TASK LIST AND CONFIUGURATIONS LAYOUT

In this Section are detailed all the tasks foreseen for each Robot. The tasks are described in a general way and are applicable to any configuration. Small differences are in the use or not use of the robot mobility and/or in specific adaptations due to the different disposal of the manipulators and prepared pizza storage table, as required by the configuration.

It is useful to remember the declared identification of Robot 1 as the robot localized in front of work station Module 1 and dedicated to the pizza preparation activity, and of Robot 2 as the robot localized in front of work station Module 2 and dedicated to the roll out activity of the pizza dough partitions. Robot 3 is the robot identified in Configuration nr. 3 for pizza cooking and final delivery at desk.

5.1 CONFIGURATION NR. 1 TASKS AND LAYOUT

For this configuration the mobility of the robots is used as much as possible.

First, the position of the two Robots is specified. Considering the cart dimensions given in **Sections 4.2** and **4.5** the two carts cannot be placed side-by-side, otherwise the cart movements of one robot will interfere with the activities of the other robot.

However, there are two big advantages: one is that the cart has omnidirectional movements and the other one is that the manipulator can operate at 360°. Because the Robot 2 mobility is foreseen for pizza dough roll out activity and for pizza transfer from the roll out location to the preparation location, the two carts are placed sufficiently spaced to allow the needed movements.

To better understand the adopted orientation and position of the two carts, the roll out sequence is here clarified.

In the feasibility study the nature of the monodirectional cart-like manipulator and its reduced degrees of freedom suggested the need to install an automatic mechanism to rotate the pizza dough during the roll out. In fact, in order to produce a pizza with an almost circular shape the dough must be rolled in all directions. Now the rotational degree of freedom of the manipulator around the vertical axis allows to eliminate the automatic rotating mechanism.

Following the observation of the movements done by a human pizzaiolo in using the roll pin, the following procedure has been implemented upon the assumptions of an initial height of 50 mm for the pizza dough partitions, a final pizza thickness of 4 mm and a roll out stroke of 320 mm.

To avoid that the pizza dough may remain attached to the table surface, some flour is distributed over the roll out area before putting there the dough partition.

1. Put the roll pin external surface at a height of 40 mm from the table top level and at the center of the roll out area (location L17), i.e. roll pin pick up point at coordinates X = 1200 mm, Y = 670 mm, Z = 901 mm.
2. Move the roll pin Northwise for a stroke of 80 mm while moving progressively down up to 4 mm (roll pin external bottom surface gap to the table top level at the end of the 80 mm stroke = 36 mm).
3. Move the roll pin Southwise for a stroke of 160 mm maintaining the

same distance from the table top level.

4. Move the roll pin Northwise back to the center of the roll out area maintaining the same distance from the table top level.
5. Rotate clockwise the roll pin by 90°.
6. Move the roll pin Eastwise for a stroke of 80 mm while moving progressively down by 4 mm (gap to table top level at the end of the stroke = 32 mm).
7. Move the roll pin Westwise for a stroke of 160 mm maintaining the same distance from the table top level.
8. Move the roll pin Eastwise back to the center of the roll out area maintaining the same distance from the table top level.
9. Rotate counterclockwise the roll pin by 45°.
10. Move the roll pin North-Eastwise for a stroke of 120 mm while moving progressively down by 4 mm (gap to table top level at the end of the stroke = 28 mm).
11. Move the roll pin South-Westwise for a stroke of 240 mm maintaining the same distance from the table top level.
12. Move the roll pin North-Eastwise back to the center of the roll out area maintaining the same distance from the table top level.
13. Rotate counterclockwise the roll pin by 90°.
14. Move the roll pin North-Westwise for a stroke of 120 mm while moving progressively down by 4 mm (gap to table top level at the end of the stroke = 24 mm).
15. Move the roll pin South-Eastwise for a stroke of 240 mm maintaining the same distance from the table top level.
16. Move the roll pin North-Westwise back to the center of the roll out area maintaining the same distance from the table top level.
17. Rotate clockwise the roll pin by 45°.

18. Move the roll pin Northwise for a stroke of 160 mm while moving progressively down by 4 mm (gap to table top level at the end of the stroke = 20 mm).
19. Move the roll pin Southwise for a stroke of 320 mm maintaining the same distance from the table top level.
20. Move the roll pin Northwise back to the center of the roll out area maintaining the same distance from the table top level.
21. Rotate clockwise the roll pin by 90°.
22. Move the roll pin Eastwise for a stroke of 160 mm while moving progressively down by 4 mm (gap to table top level at the end of the stroke = 16 mm).
23. Move the roll pin Westwise for a stroke of 320 mm maintaining the same distance from the table top level.
24. Move the roll pin Eastwise back to the center of the roll out area maintaining the same distance from the table top level.
25. Rotate counterclockwise the roll pin by 45°.
26. Move the roll pin North-Eastwise for a stroke of 160 mm while moving progressively down by 4 mm (gap to table top level at the end of the stroke = 12 mm).
27. Move the roll pin South-Westwise for a stroke of 320 mm maintaining the same distance from the table top level.
28. Move the roll pin North-Eastwise back to the center of the roll out area maintaining the same distance from the table top level.
29. Rotate counterclockwise the roll pin by 90°.
30. Move the roll pin North-Westwise for a stroke of 160 mm while moving progressively down by 4 mm (gap to table top level at the end of the stroke = 8 mm).
31. Move the roll pin South-Eastwise for a stroke of 320 mm maintaining the

same distance from the table top level.

32. Move the roll pin North-Westwise back to the center of the roll out area maintaining the same distance from the table top level.
33. Rotate clockwise the roll pin by 45°.
34. Move the roll pin Northwise for a stroke of 160 mm while moving progressively down by 1 mm (gap to table top level at the end of the stroke = 7 mm).
35. Move the roll pin Southwise for a stroke of 320 mm maintaining the same distance from the table top level.
36. Move the roll pin Northwise back to the center of the roll out area maintaining the same distance from the table top level.
37. Rotate clockwise the roll pin by 90°.
38. Move the roll pin Eastwise for a stroke of 160 mm while moving progressively down by 1 mm (gap to table top level at the end of the stroke = 6 mm).
39. Move the roll pin Westwise for a stroke of 320 mm maintaining the same distance from the table top level.
40. Move the roll pin Eastwise back to the center of the roll out area maintaining the same distance from the table top level.
41. Rotate counterclockwise the roll pin by 45°.
42. Move the roll pin North-Eastwise for a stroke of 160 mm while moving progressively down by 1 mm (gap to table top level at the end of the stroke = 5 mm).
43. Move the roll pin South-Westwise for a stroke of 320 mm maintaining the same distance from the table top level.
44. Move the roll pin North-Eastwise back to the center of the roll out area maintaining the same distance from the table top level.
45. Rotate counterclockwise the roll pin by 90°.

46. Move the roll pin North-Westwise for a stroke of 160 mm while moving progressively down by 1 mm (gap to table top level at the end of the stroke = 4 mm).
47. Move the roll pin South-Eastwise for a stroke of 320 mm maintaining the same distance from the table top level.
48. Move the roll pin North-Westwise back to the center of the roll out area maintaining the same distance from the table top level.
49. Rotate clockwise the roll pin by 45°.
50. Stop

Now it is clear that during the application of this procedure the cart of Robot 2 moves fore and aft, right to left and in diagonal +/-45°. Therefore, the two carts are initially spaced as per **Figure 5.1-1** with respect to the workstation. Robot 1 will move Westwise by 800 mm to reach the working position, whilst the Base of Robot 1 at rest position is 1600 mm Eastwise of Robot 2 Base.

In **Figure 5.1-1** it is also showed the position of the prepared pizzas stored table.

Figure 5.1-2 shows the overall kitchen lay out realized with the tool **SKETCHUP**. In detail the cart of Robot 1 is placed parallel to the Module 1 with the Base of manipulator at coordinates:

$X_{C1R1} = -400$ mm
$Y_{C1R1} = 1220$ mm
$Z_{C1R1} = 767$ mm

The Robot 1 gripping point coordinates at rest position in the global reference system are:

X_{C1GP1} = -400 + 143 = -257 mm

Y_{C1GP1} = 1220 + 164 = 1384 mm

Z_{C1GP1} = 767 + 171 = 938 mm

The cart of Robot 1 when moved at the working position is parallel to the Module 1 with the Base of manipulator at coordinates:

X_{C1R1} = 400 mm

Y_{C1R1} = 1220 mm

Z_{C1R1} = 767 mm

The Robot 1 gripping point coordinates at working position in the global reference system are:

X_{C1GP1} = 400 + 143 = 543 mm

Y_{C1GP1} = 1220 + 164 = 1384 mm

Z_{C1GP1} = 767 + 171 = 938 mm

The cart of Robot 2 is placed parallel to the Module 2 with the Base of manipulator at coordinates:

X_{C1R2} = 1200 mm

Y_{C1R2} = 1220 mm

Z_{C1R2} = 767 mm

The Robot 2 gripping point coordinates at rest position in the global reference system are:

$X_{C1GP2} = 1200 - 143 = 1057$ mm

$Y_{C1GP2} = 1220 – 164 = 1056$ mm

$Z_{C1GP2} = 767 + 171 = 938$ mm

The coordinates of prepared pizza locations on the storage table are:

$X_{C1PST1} = 500$ mm	$X_{C1PST2} = 100$ mm	$X_{C1PST3} = -300$ mm
$Y_{C1PST1} = 1920$ mm	$Y_{C1PST2} = 1920$ mm	$Y_{C1PST3} = 1920$ mm
$Z_{C1PST1} = 750$ mm	$Z_{C1PST2} = 750$ mm	$Z_{C1PST3} = 750$ mm

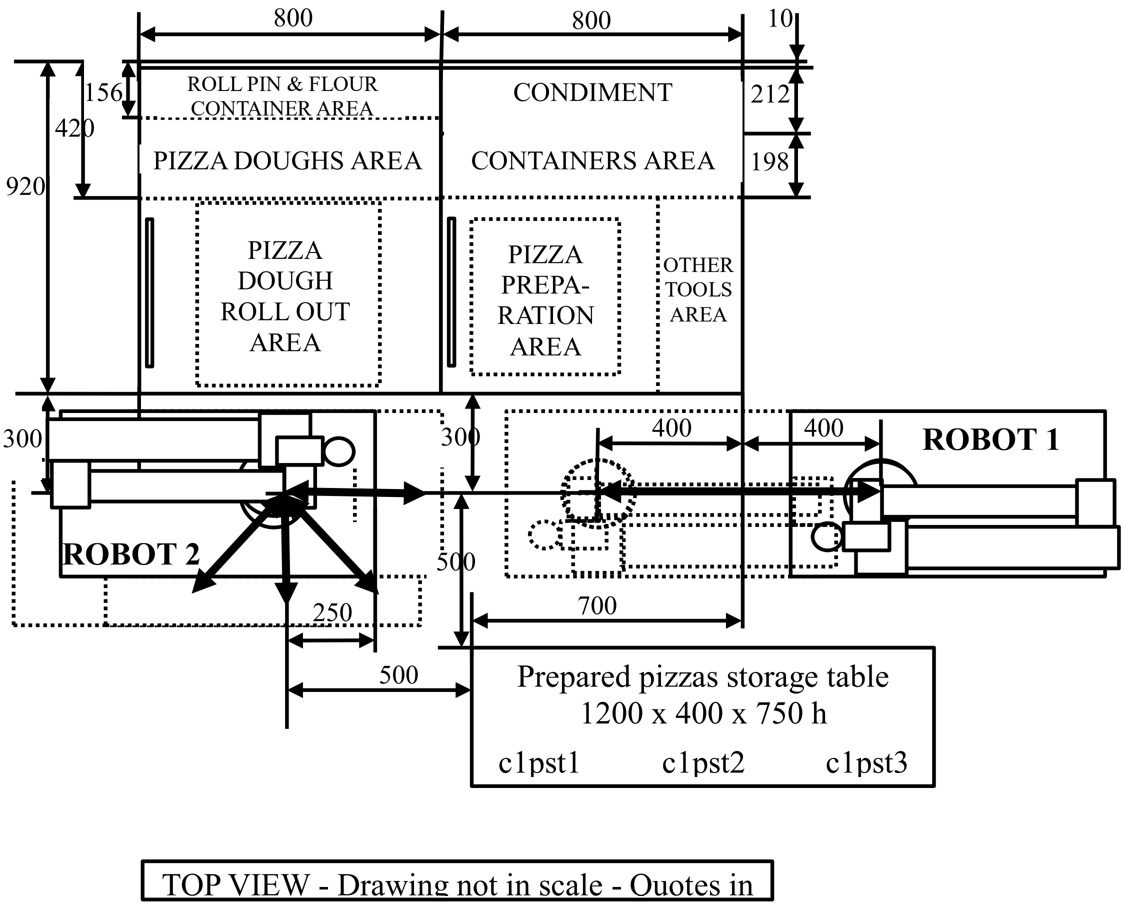


Figure 5.1-1 – Kitchen lay out for Configuration nr. 1.

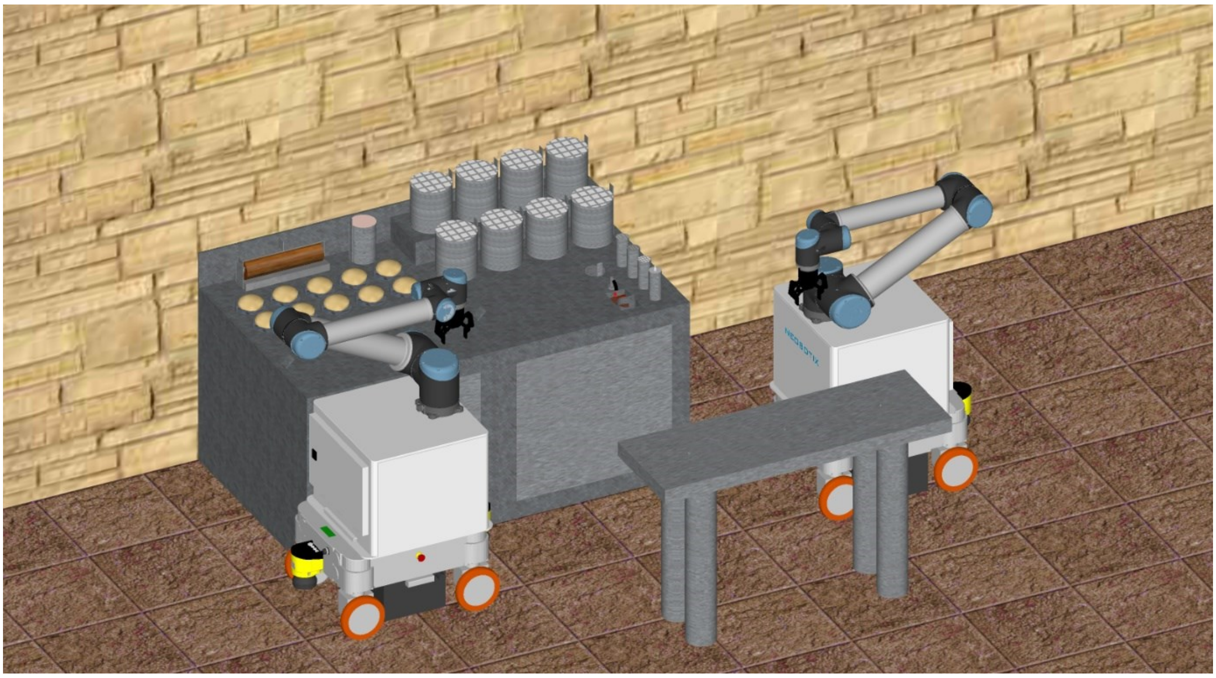


Figure 5.1-2 – Configuration nr. 1 kitchen lay out realized with the tool **SKETCHUP**.

5.1.1 ROBOT 2 AND 1 TASKS IN CONFIGURATION NR. 1

In the following it is described the sequence of tasks once the two. When the robot mobility is required the words “CART USE” are specified. Robot 1 moves from the rest position to the working position before to start its tasks sequence. Normally the two robot units operate in an independent way, with two exceptions.

Exception 1: When Robot 2 has completed the pizza dough roll out task it needs to transfer the rolled out pizza on the preparation location in front of Robot 1. For this action Robot 2 must check if the transfer is allowed by Robot 1, who has to remain in stand-by at rest. If transfer is not yet allowed, Robot 2 will remain in stand-by (pizza cannot be transferred until the pizza preparation area is free); on the contrary, if the transfer is allowed the rolled out pizza will be transferred at the pizza preparation area by the use of the pizza shovel 2; Robot 2 will send to Robot 1 the information of completed transfer once the pizza shovel 2 has been placed in its location **L18**.

Exception 2: When Robot 1 must transfer the prepared pizza on the pizza storage table. For this action Robot 1 must check if the transfer is allowed by Robot 2, who stays in stand-by at rest. If the transfer is not yet allowed, Robot 1 will remain in stand-by but not at rest; on the contrary, if the transfer is allowed the prepared pizza is transferred on the pizza storage table by the use of the pizza shovel 1; Robot 1 will send to Robot 2 the information of transfer completed once the pizza shovel 1 has been placed in its location **L2** and Robot 1 has put itself in stand-by at rest (Robot 1 can work only if the preparation area is occupied). In parallel Robot 1 will inform the kitchen assistant that a pizza is ready for cooking on the pizza storage table.

The logic of task accomplishment is better explained in the **Section 6.3**. However globally speaking Robot 1 starts its tasks from the rest position and proceeds till the last task of pizza transfer on the storage table, through the execution of each task starting from the position reached in the previous task and waiting in the position reached in the last task until the pizza transfer consent from Robot 2 is received. After the pizza transfer on the storage table Robot 1 puts itself at rest, informs Robot 2 and the kitchen assistant for transfer completed and waits for a new pizza to be prepared.

Similarly, Robot 2 starts from the rest position and continues its tasks till the transfer of the rolled-out pizza at the pizza preparation location upon the consent from Robot 1. Nevertheless Robot 2 will complete the performing task and will put at rest if Robot 1 sends the request for pizza transfer on the storage table.

5.1.1.1 C1 Robot 2 tasks

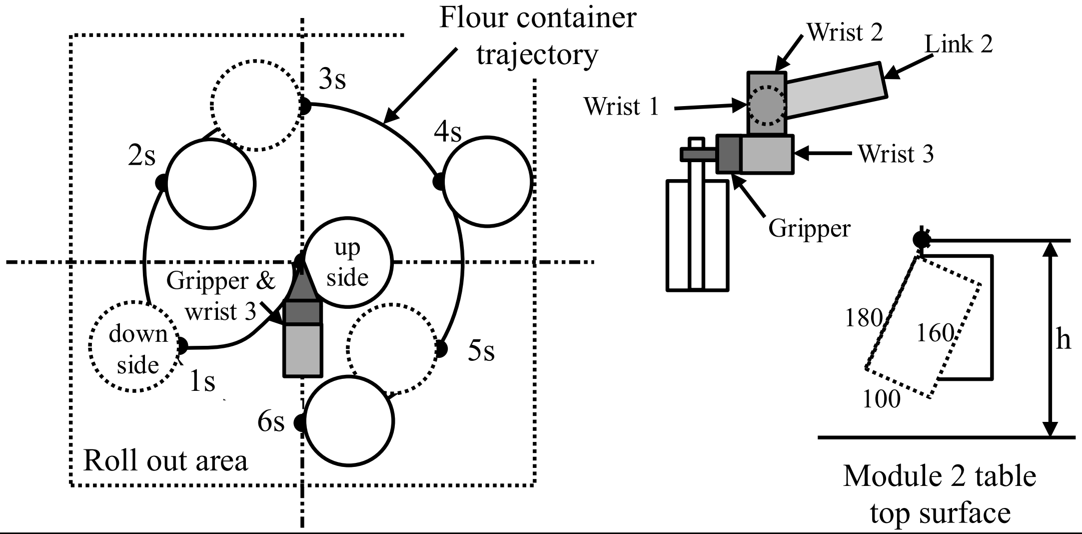
All the actions are referred to the gripping point **GP**, unless otherwise specified. Tasks are listed following the chronological sequence of execution and may be summarized as follows:

- flour container use: i.e. distribute flour on the roll out area to avoid pizza dough adhesion;
- dough partition tray use: i.e. pick up the tray and revers the pizza dough partition on the roll out area;
- pizza dough roll out by the use of the roll pin;
- transfer the rolled-out pizza at pizza preparation location.

C1R2T1 *- Flour container use (see also* ***Figure 5.1.1.1-1****)*

1. move with the gripper open by 10 mm, fingers with rest orientation (W3=0°) and robot terminal part horizontal and perpendicular to the front wall, to position **fc** at location **L20**;
2. close the gripper, pick up the flour container and raise up by 100 mm;
3. move at a position 210 mm above location **L17** maintaining robot terminal part horizontal; 210 mm is a value greater than the distance of the container bottom corner, opposite to the pick-up point [in this case $210 > (180^2 + 100^2)^{1/2}$], to allow free overturning;
4. rotate clockwise Wrist 3 in 6 seconds at 180°/s while moving at a speed of 100 mm/s with a sort of spiral trajectory in a plan parallel to the Module 2 table top surface;

5. move back at 100 mm above position **fc** at location **L20**, move down by 100 mm, open the gripper for 10 mm and raise up by 100 mm.



Flour container trajectory referring to Loc 17 centre																		
X	[mm]	0	20	42	87	100	87	71	50	0	-50	-71	-87	-100	-87	-71	-50	0
Y	[mm]	0	35	42	50	0	-50	-71	-87	-100	-87	-71	-50	0	50	71	87	100
W3	[deg]	0	60	120	180	270	360	60	120	180	240	300	360	90	180	240	300	360
T	[sec]				1		2			3			4		5			6

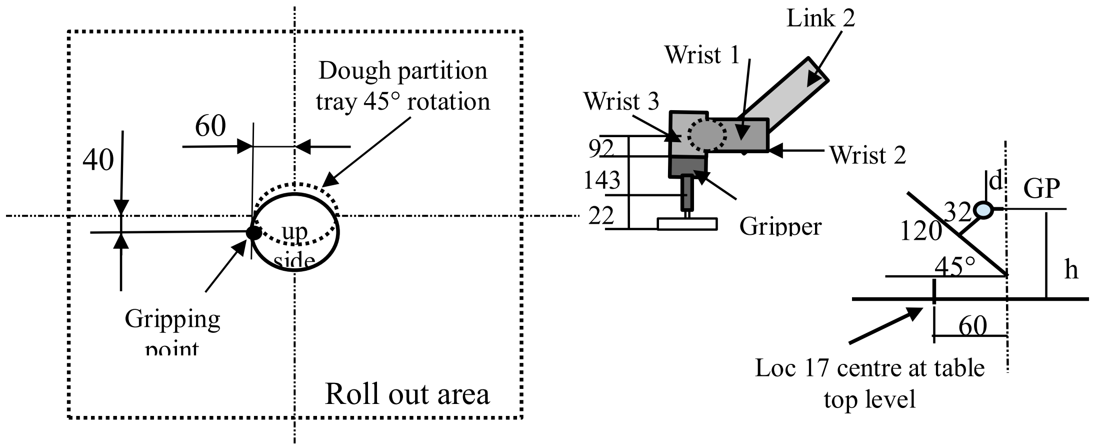
Figure 5.1.1.1-1 – Flour container trajectory above the roll out area.

C1R2T2 *- Typical dough partition tray use (see also* ***Figure 5.1.1.1-2****)*

1. move the gripper open by 10 mm, fingers with rest orientation (0°) and robot terminal part vertical, to position **dpt1** at location **L21**;
2. close the gripper, pick up the pizza dough partition, raise up by 100 mm;
3. move at a position 70 mm above the center of location **L17** and shifted Southwise by 40 mm and Westwise by 60 mm, maintaining robot terminal part vertical;
4. rotate counterclockwise Wrist 2 by 45° at 180°/s;
5. move up by 20 mm and suddenly down by 20 mm;
6. move Northwise by 100 mm, then raise up by 60 mm and rotate

clockwise Wrist 2 by 45° at 180°/s;

7. move back at 100 mm above position **dpt1** at location **L21**, maintaining robot terminal part vertical, move down vertically by 100 mm, open the gripper for 10 mm and raise up by 100 mm.



To leave the dough partition at the centre of the roll out area the tray extremity must be 60 mm beyond the roll out location centre. Therefore, the gripping point **GP**) will stay 60 mm Westside of the location centre, according to the tray handle position, and:

40 mm (60-20) beyond of location centre (Southwise) [d = 60 * cos45° - 32 * sin45° = 20 mm]
65 mm, at least, above the table top level [h = 60 * sin45° + 32 * cos45° = 65 mm]

Figure 5.1.1.1-2 – Dough partition tray rotation above the roll out area.

For the other trays the task is the same. Only the position code and location number will change from code **dpt2** to code **dpt10** and from location **L21** to location **L30**. The task name will change from **C1R2T1-dpt1** to **C1R2T1-dpt10**.

C1R2T3 *- Pizza dough roll out using the roll pin (see also* ***Figure 5.1.1.1-3****)*

1. move the gripper open by 10 mm, fingers with rest orientation (0°) and robot terminal part vertical, to position **rp** at location **L19**;
2. close the gripper, pick up the roll pin, move rightwise by 15 mm and raise up by 100 mm;

3. move to 40 mm above the center of location **L17** maintaining robot terminal part vertical;
4. apply the roll pin operational procedure (see **Section 5.1**) by rotating step by step Wrist 3 clockwise from 0° to 90° and counterclockwise to 45° and to -45° at 180°/s – CART USE;
5. move back at 100 mm above position **rp** at location **L19**, maintaining robot terminal part vertical, move down vertically by 100 mm, then 15 mm leftwise, open the gripper for 10 mm and raise up by 100 mm.

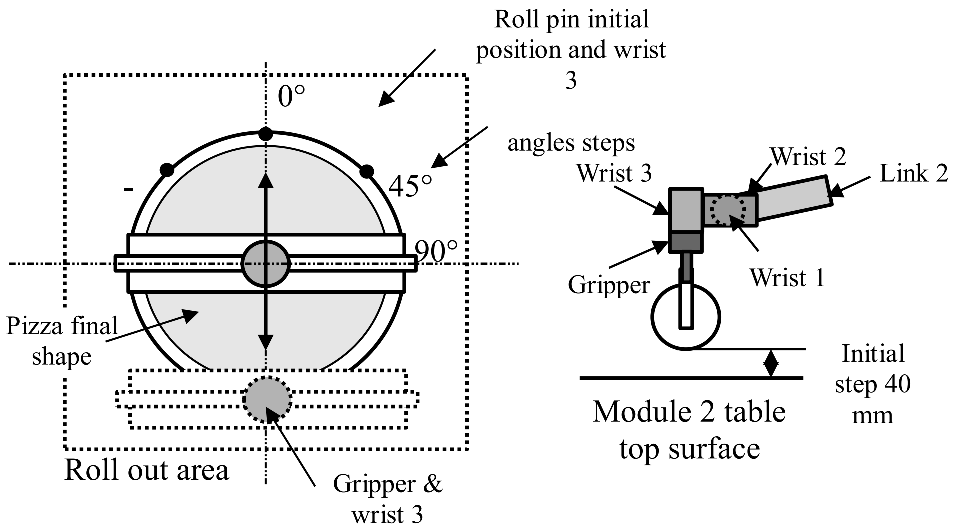
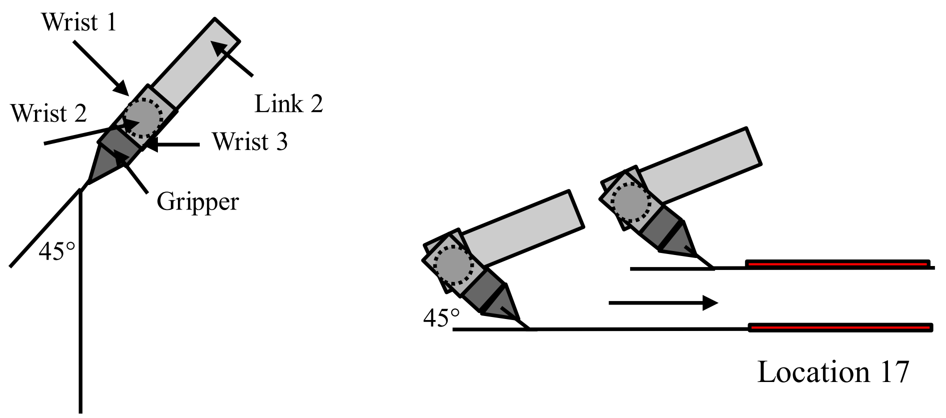


Figure 5.1.1.1-3 – Roll pin above the roll out area.

C1R2T4 *- Transfer the rolled-out pizza at pizza preparation location (see also* ***Figure 5.1.1.1-4****)*

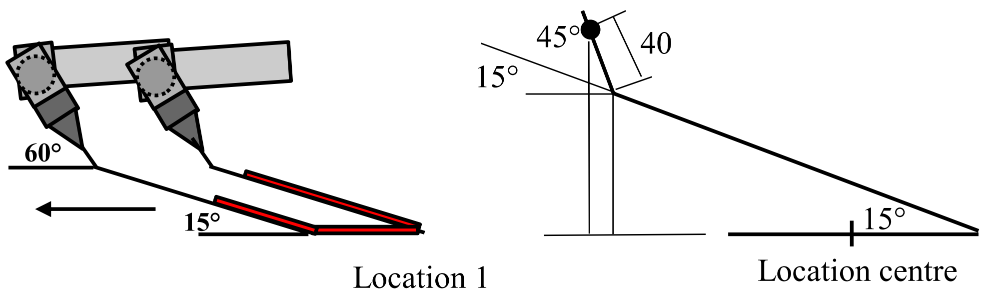
1. inform Robot 1 to be ready to transfer the rolled-out pizza to location **1** at position **pp**;
2. waiting for Robot 1 confirmation move the gripper open by 10 mm at 70 mm before (Northwise) position **ps2** at location **L18**, fingers with rest orientation (0°) and robot terminal part angled counterclockwise by 45° to the vertical (Wrist 2);

3. close the gripper, pick up the pizza shovel 2, raise up by 340 mm;
4. rotate Wrist 2 counterclockwise by further 90°;
5. move down and leftside to have the extremity of the shovel 2 at 160 mm to the left of location **L17** center (assuming 348 mm as the gripping point, or pick up point, distance to the extremity of the shovel and 28 mm as the gripping point distance to the bottom of the shovel), i.e. **GP** coordinates X=1708 mm, Y=670 mm, Z=778 mm;
6. now move rightwise by 320 mm, not changing Wrist 2 orientation and **GP** height, towards location **L17** – CART USE;
7. stand by till Robot 1 confirmation, then move up and towards location **L1** to have the extremity of the shovel on the point at 160 mm beyond location 1 center after be angled by 15°, i.e. **GP** coordinates X=719 mm, Y=670 mm, Z=867 mm – CART USE – Robot 1 cart need to move Eastwise by 800 mm to avoid the impact with the Robot 2 cart;
8. now rotate clockwise Wrist 2 by 15°;
9. perform a Westwise and Eastwise movement of 20 mm;
10. move back (Westwise) not changing Wrists 2 and 3 orientation and **GP** height, to the position reached at step 3 above;
11. rotate clockwise by 90° and then move down vertically by 330 mm;
12. open the gripper, disengage the shovel by moving Northwise by 70 mm, inform Robot 1 that can start or restart its tasks and go at rest.



To pick up the pizza the extremity of the shovel must be 160 mm before the location centre and the bottom of the shovel must be at table top level. Considering the shovel geometry, the gripping point must be:

160 + 320 + 40 * cos45° = **508** mm before, and
40 * sin 45° = **28** mm above the table top level



To leave the pizza the extremity of the shovel must be 160 mm ahead of the location centre and the bottom of the shovel must be at table top level. Considering the shovel geometry, the gripping point must be:

320 * cos 15° + 40 * cos 60° - 160 = **169** mm before the location centre, and
320 * sin 15° + 40 * sin 60° = **117** mm above the table top level

Figure 5.1.1.1-4 – Pizza shovel pick up and pizza transfer.

***C1R2Ti** - Further tasks*

- Now Robot 2 has to repeat all the above tasks with the only exception that the pizza dough trays to be picked up will be in sequence from **dpt2** to **dpt10** at locations from **L22** to **L30**.

5.1.1.2 C1 Robot 1 tasks

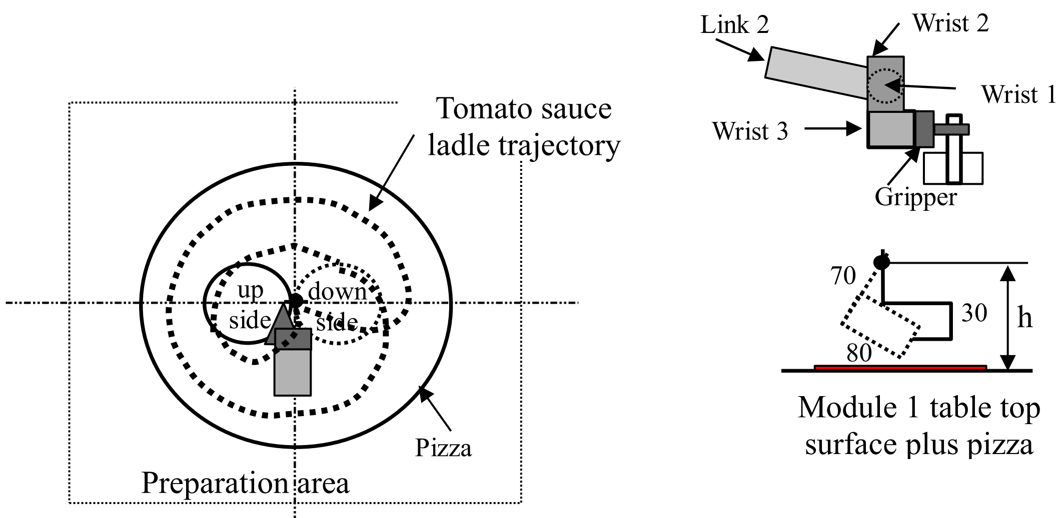
All the actions are referred to the gripping point **GP**, unless otherwise specified. Tasks are listed following the chronological sequence of execution and may be summarized as follows:

- tomato sauce ladle use: i.e. collect tomato sauce, reverse it on the pizza and spread over the pizza;
- condiment container use: i.e. fill the pizza with the required condiments for a given taste;
- condiment spreading tool use: i.e. spread condiments over the pizza;
- origan, salt and garlic containers use, i.e. reverse salt always, origan and garlic only for specific pizza tastes over the pizza;
- olive oil container use: i.e. reverse olive oil over the pizza for any taste;
- transfer the prepared pizza on the storage table.

***C1R1T1** - Tomato sauce ladle use (see also **Figure 5.1.1.2-1**)*

1. move the gripper open by 10 mm, fingers at 0°, robot terminal part horizontal and parallel to the front wall, to position **tsl** at location **L11**;
2. close the gripper, pick up the tomato sauce ladle and move forward (Northwise) by 60 mm and wait 3 seconds;
3. move back the tomato sauce ladle by 40 mm and raise up by 145 mm (120+25);

4. rotate W2 by 90° counterclockwise;
5. move above location **L1**, maintaining robot terminal part horizontal, and stop at the centre of the location; 120 mm is a value at least 5 mm (accounting for pizza thickness) greater than the distance of the ladle bottom corner, opposite to the pick-up point plus 5 mm [in this case $120 > (70^2 + 80^2)^{1/2}$];
6. rotate clockwise by 360° at 180°/s;
7. move down vertically by 115 mm and perform a spiral movement from the centre to the border of the pizza at a speed of 100 mm/s remaining 5 mm above the Module 1 table top surface, i.e. on the pizza;
8. raise up by 100 mm and move back above the position **tsl** at location **L11**;
9. rotate W2 by 90° clockwise;
10. move down vertically by 60 mm, open the gripper for 10 mm and raise up by 100 mm.



Tomato sauce ladle trajectory referring to pizza centre																								
X	[mm]	0	10	28	40	28	0	-28	-40	-52	-50	0	55	95	110	95	55	0	-55	-95	-110	-78	-35	0
Y	[mm]	0	17	28	0	-28	-40	-28	0	30	87	110	95	55	0	-55	-95	-110	-95	-55	0	45	20	0

Figure *5.1.1.2-1* – Tomato sauce ladle pick up and spreading.

C1R1T2 *- Typical condiment container use (see also* ***Figure 5.1.1.2-2****)*

1. move the gripper open by 10 mm, fingers at 0°, robot terminal part horizontal and perpendicular to the front wall, to position **cc1** at location **L3**;
2. close the gripper, pick up the condiment container and raise up by 120 mm;
3. move at a position 270 mm above location **1** and at a distance of 80 mm on the left of the center of the location maintaining robot terminal part horizontal; 270 mm is a value greater than the distance of the container bottom corner, opposite to the pick-up point, to the pizza plus any possible other condiment level [in this case $270 > (200^2 + 160^2)^{1/2}$];
4. rotate counterclockwise Wrist 3 by 180° at 180°/s;
5. move down vertically by 150 mm and suddenly move up by 20 mm in order to force the condiment fall down;
6. repeat the condiment shaking by moving vertically 150 mm up and suddenly 20 mm down and rotate clockwise by 180° Wirst 3 at 180°/s;
7. move back at 100 mm above position **cc1** at location **L3**;
8. move down vertically by 100 mm, open the gripper for 10 mm and raise up by 100 mm ready to catch another container, depending from the pizza taste.

For the other condiment containers, the task is the same. Only the position code and location number will change from code **cc2** to code **cc8** and from location **L4** to location **L10**. The task name will change from **C1R2T1-cc1** to **C1R2T1-cc8**.

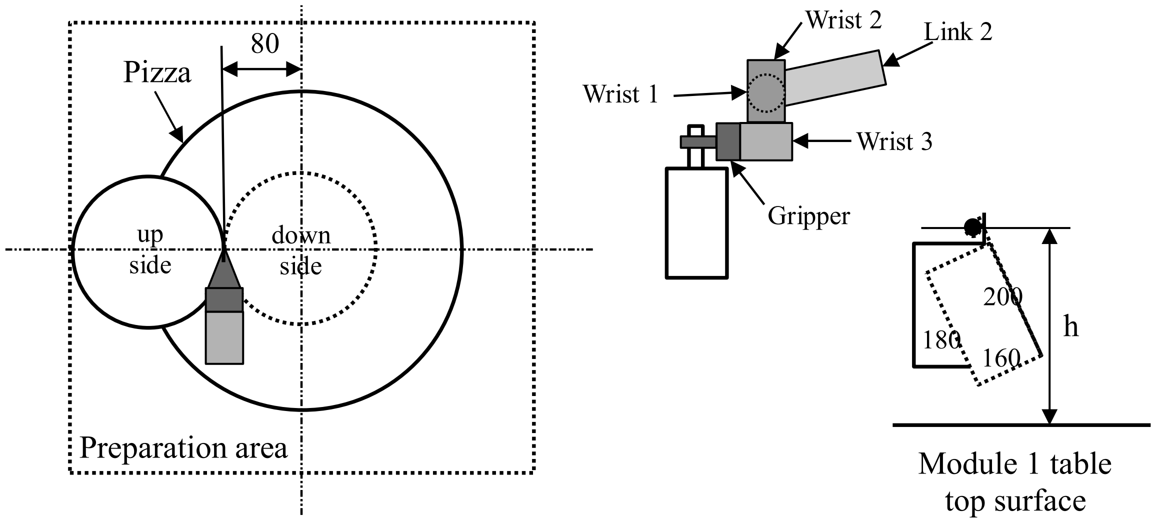
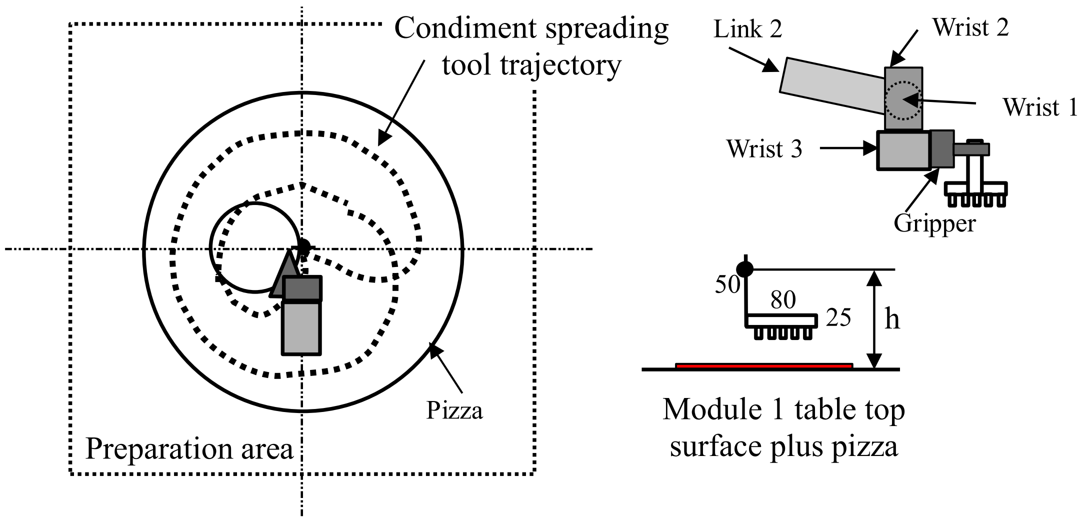


Figure ***5.1.1.2-2*** – Condiment container above the roll out area.

***C1R1T3** – Condiment spreading tool use (see also **Figure 5.1.1.2-3**)*

1. move the gripper open by 10 mm, fingers at 0°, robot terminal part horizontal and parallel to the front wall, to position **ts** at location **L12**;
2. close the gripper, pick up the condiment spreading tool and raise it up by 100 mm;
3. rotate W2 by 90° counterclockwise;
4. move the gripping point above location **2**, maintaining robot terminal part horizontal, and stop at the centre of the location;
5. move down vertically by 65 mm and perform a spiral movement from the centre to the border of the pizza at a speed of 100 mm/s remaining at the reached vertical position of 5 mm above the Module 1 table top surface, i.e. at pizza level;
6. raise up by 65 mm and move back at 100 mm above the position **cs** at location **L12**;
7. rotate W2 by 90° clockwise;
8. move down vertically by 100 mm, open the gripper for 10 mm and raise up by 100 mm.



Condiment spreading tool trajectory referring to pizza centre																								
X	[mm]	0	10	28	40	28	0	-28	-40	-52	-50	0	55	95	110	95	55	0	-55	-95	-110	-78	-35	0
Y	[mm]	0	17	28	0	-28	-40	-28	0	30	87	110	95	55	0	-55	-95	-110	-95	-55	0	45	20	0

Figure ***5.1.1.2-3*** – Condiment spreading tool pick up and spreading.

C1R1T4 *– Origan, salt and garlic containers use (see also* ***Figure 5.1.1.2-4)***

1. open the gripper at full width (85 mm), fingers at 0°, with robot terminal part horizontal and parallel to the front wall, and move towards the position **oc** (or **sc** or **gc**) at location **L13** (or **L14** or **L15**), but staying 142 mm above the pick-up point, i.e. Z=950 mm to overcome the container – CART USE;
2. move down by 142 mm, close the gripper, pick up the origan (or salt or garlic) container, raise it up by 130 mm;
3. move above location **L1** at 80 mm Northwise and at 80 mm Westwise with respect to the center of location **1**, maintaining the height of 130 mm from the table top surface and Wrist 3 horizontal - CART USE;
4. rotate Wrist 3 clockwise by 135° at 180°/s;
5. move up vertically by 20 mm and suddenly move down by 20 mm in order to force the origan, salt or garlic to fall down;

6. move 160 mm Eastwise and repeat the 20 mm up and down movement – CART USE;
7. move 160 mm Southwise and repeat the 20 mm up and down movement – CART USE;
8. move 160 mm Westwise and repeat the 20 mm up and down movement – CART USE;
9. rotate Wrist 3 counterclockwise by 135° at 180°/s;
10. move back at 142 mm above position **oc** (or **sc** or **gc**) at location **L13** (or **L14** or **L15**), maintaining robot terminal part horizontal, move down vertically by 142 mm, fully open the gripper rise up by 142 mm and move at center of location **L1** – CART USE.

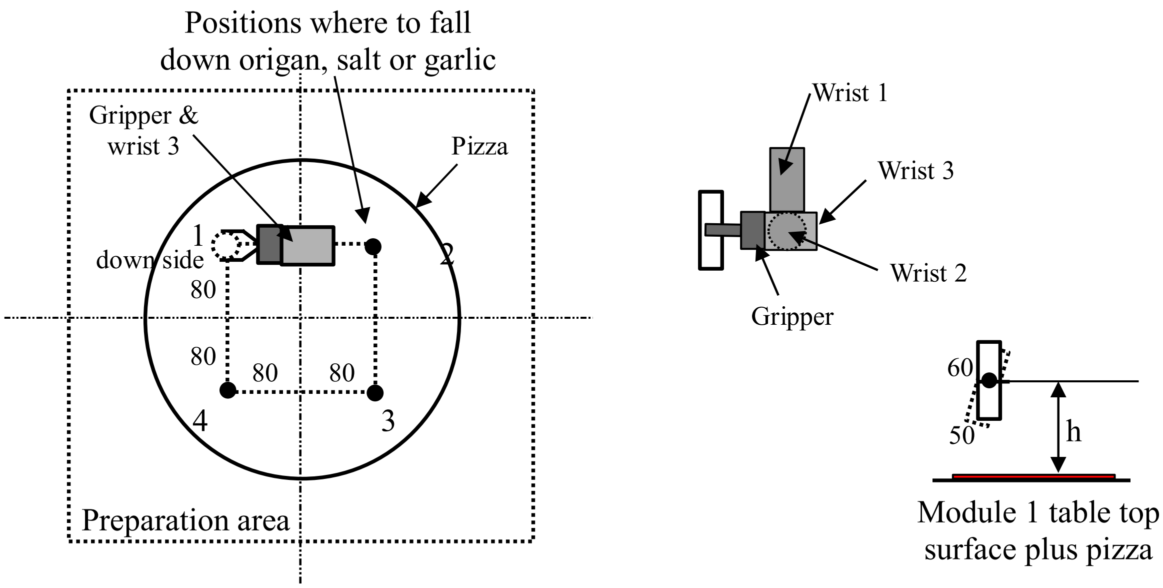


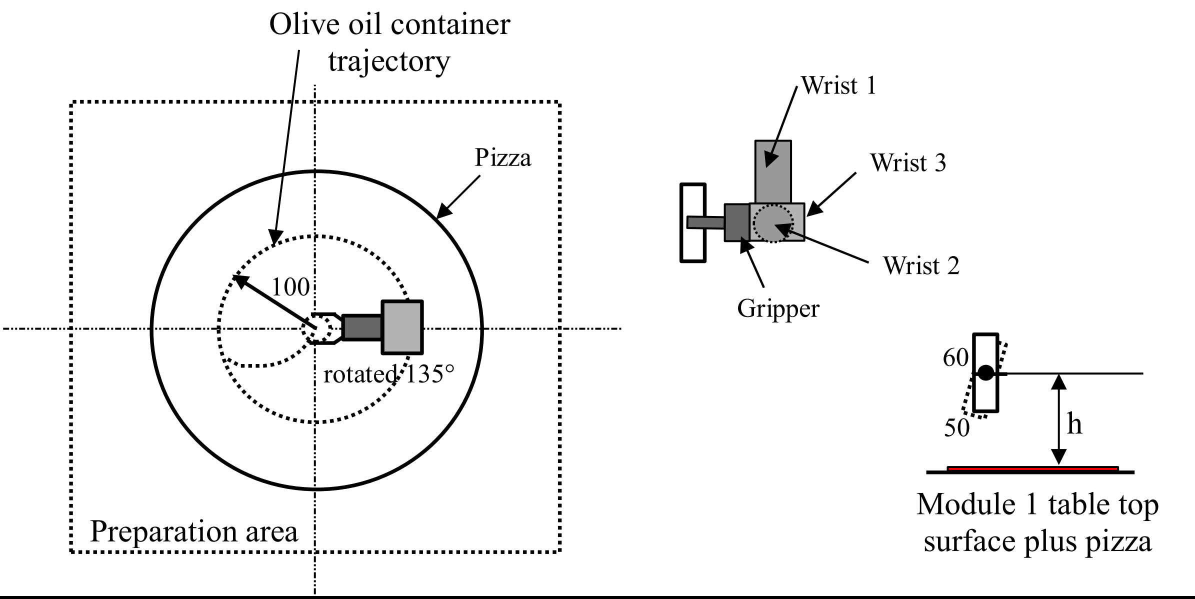
Figure ***5.1.1.2-4*** – Origan, salt or garlic container pick up and operation above the pizza.

C1R1T5 *– Olive oil container use (see also* ***Figure 5.1.1.2-5****)*

1. open the gripper at full width (85 mm), fingers at 0°, with robot terminal part horizontal and parallel to the front wall, and move towards the position **ooc** at location **L16**, but staying at 142 mm above

the pick-up point, i.e. Z=950 mm to overcome the container - CART USE;

2. move down by 142 mm, close the gripper, pick up the olive oil container, raise up by 142 mm;
3. move above the center of location **L1,** maintaining the height of 200 mm from the table top surface and Wrist 3 horizontal – CART USE;
4. rotate Wrist 3 clockwise by 135° at 180°/s;
5. start a sort of spiral movement over the pizza maintaining height, Wrist 3 and robot terminal part position;
6. once completed the circle rotate Wrist 3 counterclockwise by 135° at 180°/s;
7. move back above position **ooc** at location **L16**, maintaining Wrist 3 horizontal, move down vertically by 142 mm, fully open the gripper, raise up by 142 mm and move to center of location **L1**– CART USE.



Olive oil container trajectory referring to pizza centre																		
X	[mm]	0	20	42	87	100	87	71	50	0	-50	-71	-87	-100	-87	-71	-50	0
Y	[mm]	0	35	42	50	0	-50	-71	-87	-100	-87	-71	-50	0	50	71	87	100

Figure ***5.1.1.2-5*** – Olive oil container pick up and operation above the pizza.

***C1R1T6** - Transfer the prepared pizza on the storage table (see also **Figure 5.1.1.1-4**)*

1. inform Robot 2 (and Robot 3 for Configuration nr. 3) that is ready to transfer the prepared pizza on the rear storage table;
2. upon Robot 2 (and 3) confirmation, move the gripper open by 10 mm at 70 mm before (Northwise) position **ps1** at location **L2**, fingers with rest orientation (0°) and robot terminal part angled clockwise by 45° to the vertical (Wrist 2);
3. close the gripper, pick up the pizza shovel 1, raise up by 340 mm;
4. rotate Wrist 2 further counterclockwise by 90°;
5. move down and Westwise to have the extremity of the shovel 1 at 160 mm to the left of location **L1** center (assuming 348 mm as the gripping point, or pick up point, distance to the extremity of the shovel and 28 mm as the gripping point distance to the bottom of the shovel the, i.e. **GP** position will be at X=1008 mm, Y=670 mm, Z=778 mm);
6. now move Eastwise by 320 mm, not changing Wrist 2 orientation and **GP** height, towards location **L1** – CART USE;
7. move up vertically and rotate clockwise around the Base to have the extremity of the shovel 1 on the point at 160 mm beyond the center of location **C1PST1** when angled by 15°, i.e. **GP** at X=-131mm, Y=1920 mm, Z=967 mm; note that before the rotation around the base the GP height has been increased by 100 mm to avoid shovel interference with tools;
8. to be sure of manipulator clockwise rotation add first the crossing point aligned with the Base and then the calculated ones at $\alpha = 30°$, 60°, 120°, 150°, as necessary, according with the following equations:

$$X = X_B - (Y_B - Y_{loc1}) * \sin\alpha$$

$$Y = Y_B - (Y_B - Y_{loc1}) * \cos\alpha$$

9. move down by 100 mm and rotate Wrist 2 clockwise by 15°;
10. perform a Westwise and Eastwise movement of 20 mm;
11. move back (Westwise) by 340 mm not changing Wrist 3, robot terminal part orientation and **GP** height – CART USE;
12. raise up 100 mm more to avoid interference with tools during Base counterclockwise rotation according with steep 8;
13. move to the position reached at step 3 above;
14. rotate Wrist 2 clockwise by 90° and then move down vertically by 340 mm;
15. open the gripper disengage the shovel by moving Northwise by 70 mm;
16. raise by 100 mm, go at rest and inform Robot 2 that can start or restart its tasks.

After the accomplishment of this task Robot 1 has also to inform the kitchen assistant for pizza cooking that a prepared pizza has been stored on the storage table at location **c1pst1**, then **c1pst2** and **c1pst3**. From the fourth, the seventh and the tenth pizza the storage will restart from **c1pst1**.

The pizza transfer at locations **c1pst2** and **c1pst3** will be done as for **c1pst1**.

5.2 CONFIGURATION NR. 2 TASKS AND LAYOUT

For this configuration just one MMO-700 mobile manipulator is used but with a rigid structure on the top for the installation of a second UR10 manipulator arm. The two manipulators arms are spaced each other by 800 mm and more or less centered on the base, i.e. the left one axis is spaced by 250 mm from the axis of the standard installation point present on MMO-700 and the right one axis is spaced by 550 mm on the other side of the standard installation point (see the sketch in **Figure 5.2-1**). The rigid structure raises the Base height up to 787 mm (+20 mm).

It is evident for this configuration that when the mobility is required for the execution of the task by one robot, the other robot must be in standby.

There are two possibilities. One is to not use the mobile platform, but this means to cancel the Configuration nr.2, resulting equivalent to Configuration nr. 3. The other one is to optimize the cart movements in order to reduce as much as possible the dead times.

The second approach is followed, and the cart movements are limited to the tasks of pizza transfer from location **L17** to location **L1** and from location **L1** to the prepared pizza storage table.

The pizza dough partitions roll out task is performed not using the cart because of the long execution time required, which will have a negative impact on the other robot activities, in fact this robot is forced to be stopped for all the roll out task time.

For this configuration the mobile platform and the pizza storage table is placed as shown in **Figure 5.2-2**.

Figure 5.2-3 shows the overall kitchen lay out realized with the tool **SKETCHUP**. In detail the cart is placed parallel to the workstation and the axis of the Base of Robot 1 manipulator is at coordinates:

$X_{C2R1} = 400$ mm

$Y_{C2R1} = 1220$ mm

$Z_{C2R1} = 787$ mm

The Robot 1 gripping point coordinates at rest position in the global reference system are:

$X_{C2GP1} = 400 + 143 = 543$ mm

$Y_{C2GP1} = 1220 + 164 = 1384$ mm

$Z_{C2GP1} = 787 + 171 = 958$ mm

Consequently, the axis of the Base of Robot 2 manipulator stays at coordinates:

$X_{C2R2} = 1200$ mm

$Y_{C2R2} = 1220$ mm

$Z_{C2R2} = 787$ mm

and the Robot 2 gripping point coordinates at rest position in the global reference system are:

$X_{C2GP2} = 1200 - 143 = 1057$ mm

$Y_{C2GP2} = 1220 - 164 = 1056$ mm

$Z_{C2GP2} = 787 + 171 = 958$ mm

The coordinates of prepared pizza locations on the storage table are:

$X_{C2PST1} = 500$ mm	$X_{C2PST2} = 100$ mm	$X_{C2PST3} = -300$ mm
$Y_{C2PST1} = 2020$ mm	$Y_{C2PST2} = 2020$ mm	$Y_{C2PST3} = 2020$ mm
$Z_{C2PST1} = 750$ mm	$Z_{C2PST2} = 750$ mm	$Z_{C2PST3} = 750$ mm

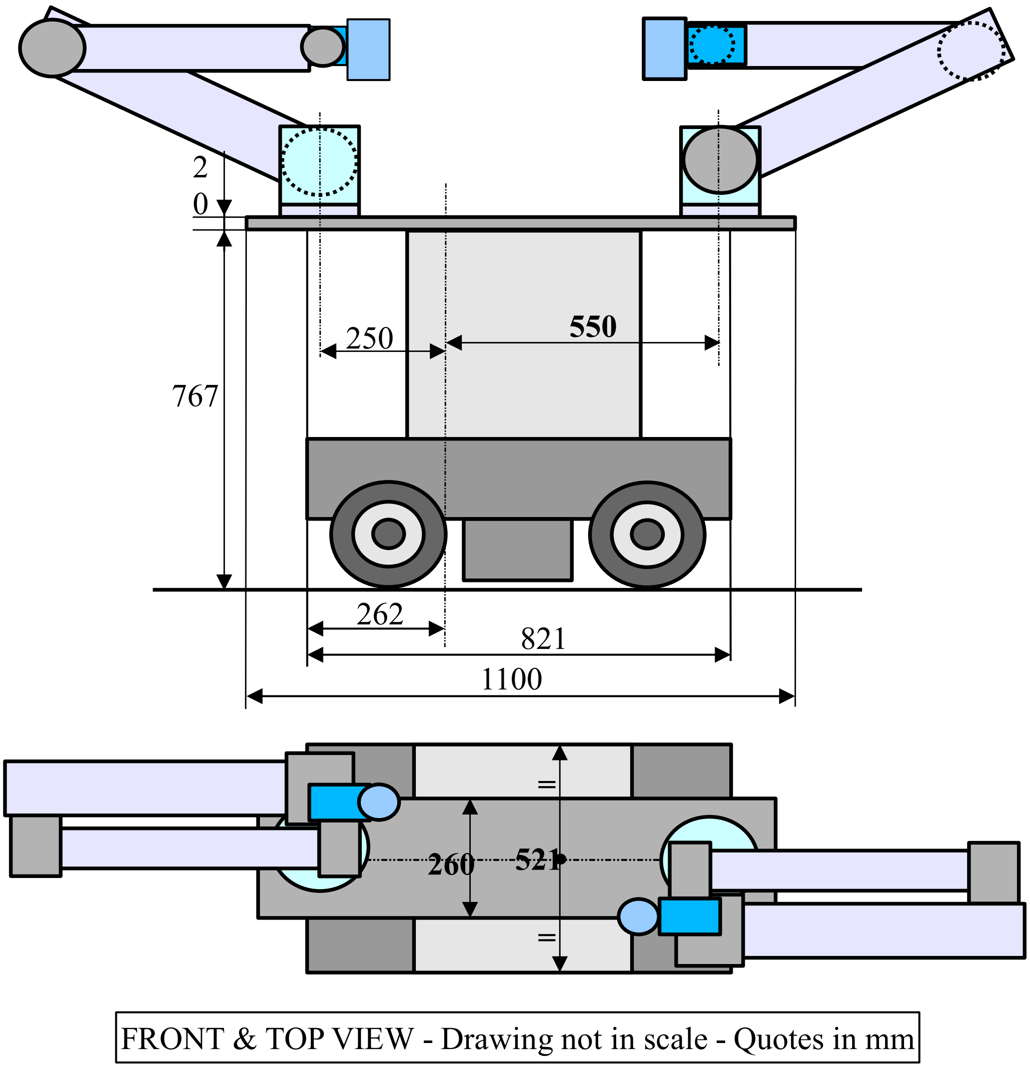


Figure 5.2-1 - UR10 manipulators disposition on MMO-700 for Configuration nr. 2.

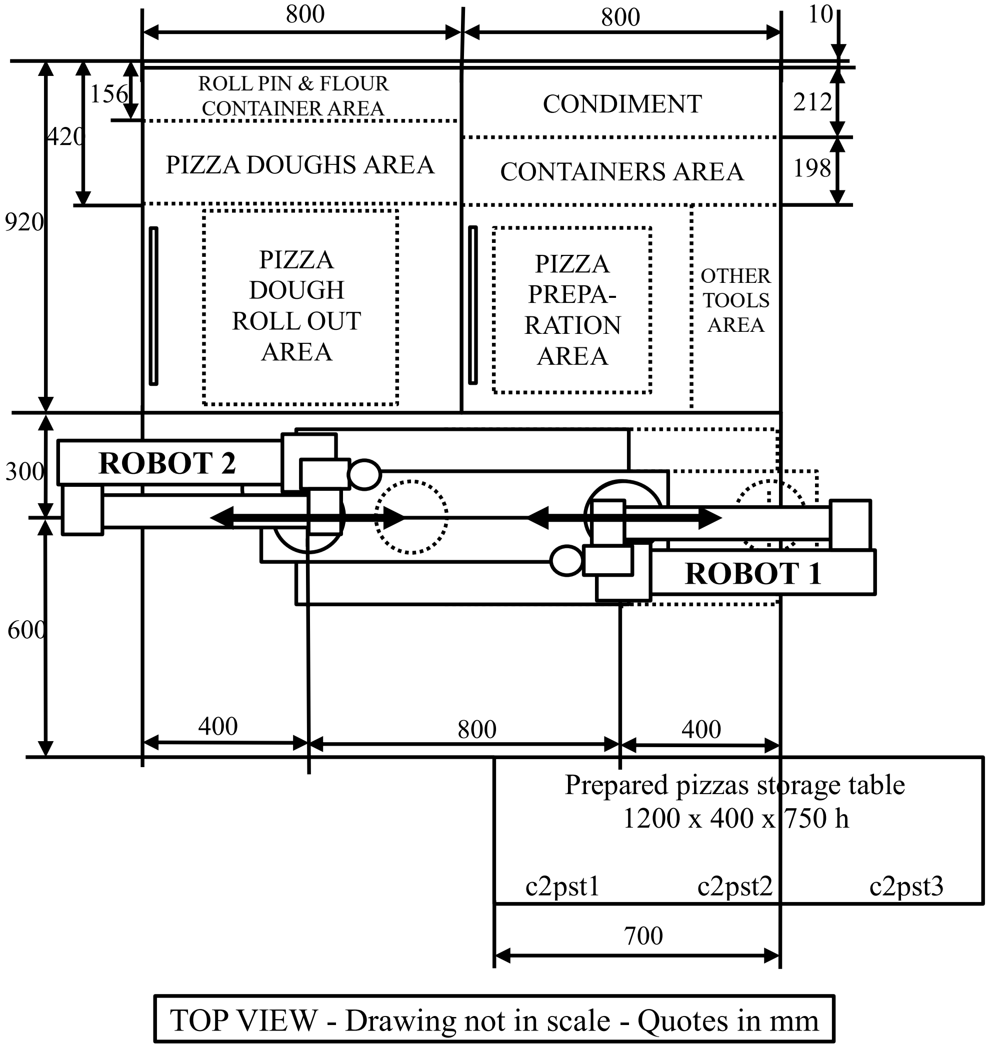


Figure 5.2-2 – Kitchen lay out for Configuration nr. 2.

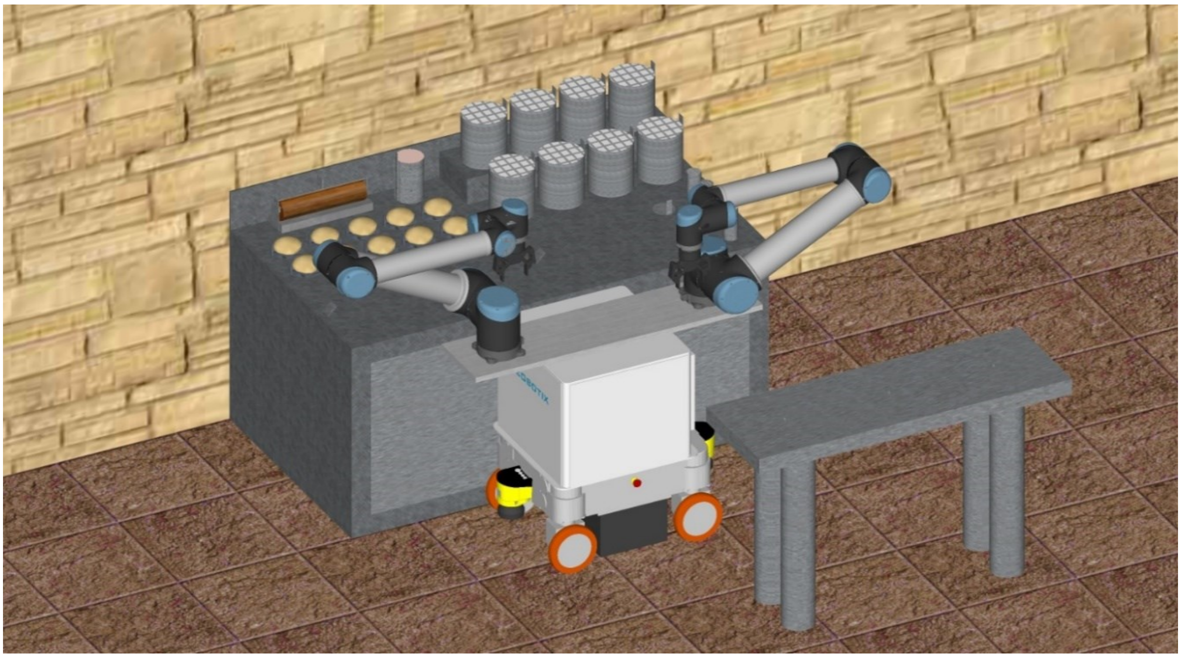


Figure 5.2-3 – Configuration nr. 2 kitchen lay out realized with the tool **SKETCHUP**.

5.2.1 ROBOT 2 AND 1 TASKS IN CONFIGURATION NR. 2

In the following it is described the sequence of tasks once the two robots have been positioned. When mobility is required the words "CART USE" are specified. Normally the two robot units operate in an independent way, with the same two exceptions described for Configuration nr. 1.

5.2.1.1 C2 Robot 2 tasks

C2R2T1 *- Flour container use (see also* ***Figure 5.1.1.1-1****)*

The sequence of movements is the same as per Configuration nr. 1.

C2R2T2 *- Typical dough partition try use (see also* ***Figure 5.1.1.1-2****)*

The sequence of movements is the same as per Configuration nr. 1.

C2R2T3 *- Pizza dough roll out using the roll pin (see also* ***Figure 5.1.1.1-3)***

The sequence of movements is the same as per Configuration nr. 1.

C2R2T4 *- Transfer the rolled-out pizza at pizza preparation location (see also* ***Figure 5.1.1.1-4)***

The sequence of movements is the same as per Configuration nr. 1. Obviously Robot 1 will move jointly with Robot 2.

C2R2Ti *- Further tasks*

As per Configuration nr. 1, Robot 2 has to repeat all the above tasks with the only exception that the pizza dough partition trays to be picked up will be in sequence from **dpt2** to **dpt10** at locations from **L22** to **L30**.

5.2.1.2 C2 Robot 1 tasks

C2R1T1 *- Tomato sauce ladle use (see also* ***Figure 5.1.1.2-1)***

The sequence of movements is the same as per Configuration nr. 1.

C2R1T2 *- Typical condiment container use (see also* ***Figure 5.1.1.2-2)***

The sequence of movements is the same as per Configuration nr. 1.

C2R1T3 *– Condiment spreading tool use (see also* ***Figure 5.1.1.2-3)***

The sequence of movements is the same as per Configuration nr. 1.

C2R1T4 *– Origan, salt and garlic containers use (see also* ***Figure 5.1.1.2-4)***

The sequence of movements is the same as per Configuration nr. 1 but <u>the cart will not be used</u>.

C2R1T5 *– Olive oil container use (see also **Figure 5.1.1.2-5)***

The sequence of movements is the same as per Configuration nr. 1 but the cart will not be used.

C2R1T6 *- Transfer the prepared pizza on the storage table (see also **Figure 5.1.1.2-6)***

The sequence of movements is the same as per Configuration nr. 1. The cart will be used both in right and left directions. After the position of shovel **1** at location **L2** and after the restart information sent to Robot 2, Robot 1 has to inform the kitchen assistant for pizza cooking that a prepared pizza has been stored on the storage table at location **c2pst1**, then **c2pst2** and **c2pst3**. From the fourth, the seventh and the tenth pizza the storage will restart from **c2pst1**.

The pizza transfer at locations **c2pst1, c2pst2** and **c2pst3** will be done as for **c1pst1**.

5.3 CONFIGURATION NR. 3 TASKS AND LAYOUT

For this configuration the pizza dough roll out and pizza preparation activities are performed by two UR10 manipulators installed at fixed positions close to the work station.

In addition, one mobile manipulator MMO-700 is used to transfer the prepared pizza in the oven, wait for cooking, extract the pizza from the oven and delivery it at desk. A special pizza shovel 3 is provided for Robot 3, which will be permanently gripped, also at rest position.

Pizza shovel 3 is a stainless-steel panel of 1 mm thickness and featured with a Z shape. The base is a flat squared panel 320 x 320 mm. The handle is achieved by a double fold of the panel with the first part trapezoidal and angled by 60° and the other part rectangular and parallel to the base, with two additional reinforced strips of 2 mm thickness on both sides (see **Figure 5.3-1**). The calculated weight of the shovel 3 is approximately 1,05 kg (stainless steel specific weight = 7,85 kg/dm^3).

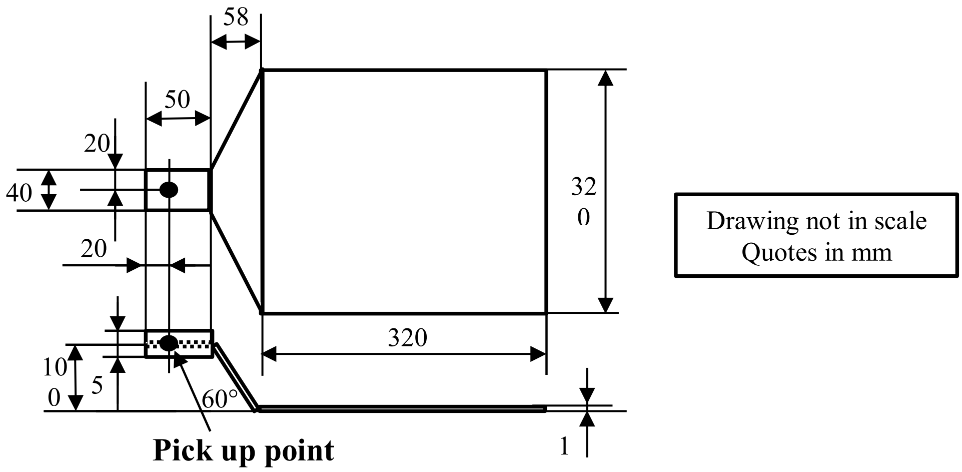
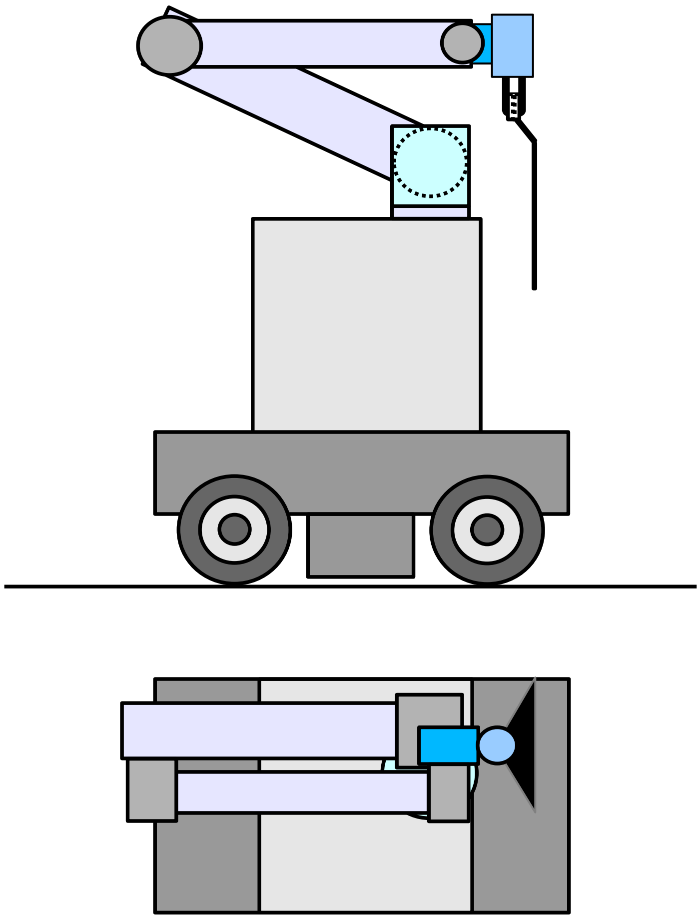


Figure 5.3-1 – Geometry of pizza shovel 3 used by Robot 3.

The two UR10 manipulators are spaced each other by 800 mm and centered in front of each Module, with the Base axis at a distance of 300 mm from the front edge of the respective Module.

The Robot 3 configuration at rest is as shown in **Figure 5.3-2**.



FRONT & TOP VIEW - Drawing not in scale - Quotes in

Figure 5.3-2 – Robot 3 configuration at rest.

The sketch in **Figure 5.3-3** shows the position of the two UR10 manipulators and the kitchen arrangement, which includes the pizza storage table, the oven and the desk (or cooked pizzas delivery table).

Figure 5.3-4 and **Figure 5.3-5** show the overall kitchen lay out realized with the tool **SKETCHUP**. In detail:

Robot 1 (UR10 manipulator arm) is fixed with its Base axis at coordinates:

X_{C3R1} = 400 mm

Y_{C3R1} = 1220 mm

Z_{C3R1} = 767 mm

The Robot 1 gripping point coordinates at rest position in the global reference system are:

X_{C3GP1} = 400 + 143 = 543 mm

Y_{C3GP1} = 1220 + 164 = 1384 mm

Z_{C3GP1} = 767 + 171 = 938 mm

Robot 2 manipulator is fixed with its Base axis at coordinates:

X_{C3R2} = 1200 mm

Y_{C3R2} = 1220 mm

Z_{C3R2} = 767 mm

The Robot 2 gripping point coordinates at rest position in the global reference system are:

X_{C3GP2} = 1200 - 143 = 1057 mm

Y_{C3GP2} = 1220 - 164 = 1056 mm

Z_{C3GP2} = 767 + 171 = 938 mm

Robot 3 initial position is with its Base axis at coordinates:

X_{C3R3} = 1300 mm

Y_{C3R3} = 2570 mm

Z_{C3R3} = 767 mm

The Robot 3 gripping point coordinates at rest position in the global reference system are:

$X_{C3GP3} = 1300 - 143 = 1157$ mm

$Y_{C3GP3} = 2570 - 164 = 2406$ mm

$Z_{C3GP3} = 767 + 171 = 938$ mm

The coordinates of prepared pizzas locations on the storage table are:

$X_{C3PST1} = 800$ mm $\quad X_{C3PST2} = 400$ mm $\quad X_{C3PST3} = 0$ mm

$Y_{C3PST1} = 1920$ mm $\quad Y_{C3PST2} = 1920$ mm $\quad Y_{C3PST3} = 1920$ mm

$Z_{C3PST1} = 750$ mm $\quad Z_{C3PST2} = 750$ mm $\quad Z_{C3PST3} = 750$ mm

The coordinates of pizza location in the oven are:

$X_{OVEN} = -700$ mm

$Y_{OVEN} = 2570$ mm

$Z_{OVEN} = 1000$ mm

The coordinates of cooked pizzas locations on the desk, including the dish, are:

$X_{CP1} = 0$ mm $\quad X_{CP2} = 400$ mm $\quad X_{CP3} = 800$ mm

$Y_{CP1} = 3520$ mm $\quad Y_{CP2} = 3520$ mm $\quad Y_{CP3} = 3520$ mm

$Z_{CP1} = 770$ mm $\quad Z_{CP2} = 770$ mm $\quad Z_{CP3} = 770$ mm

Also, for this configuration the execution of the pizza transfer task by one Robot requires the other Robot to be in standby at rest to avoid interferences.

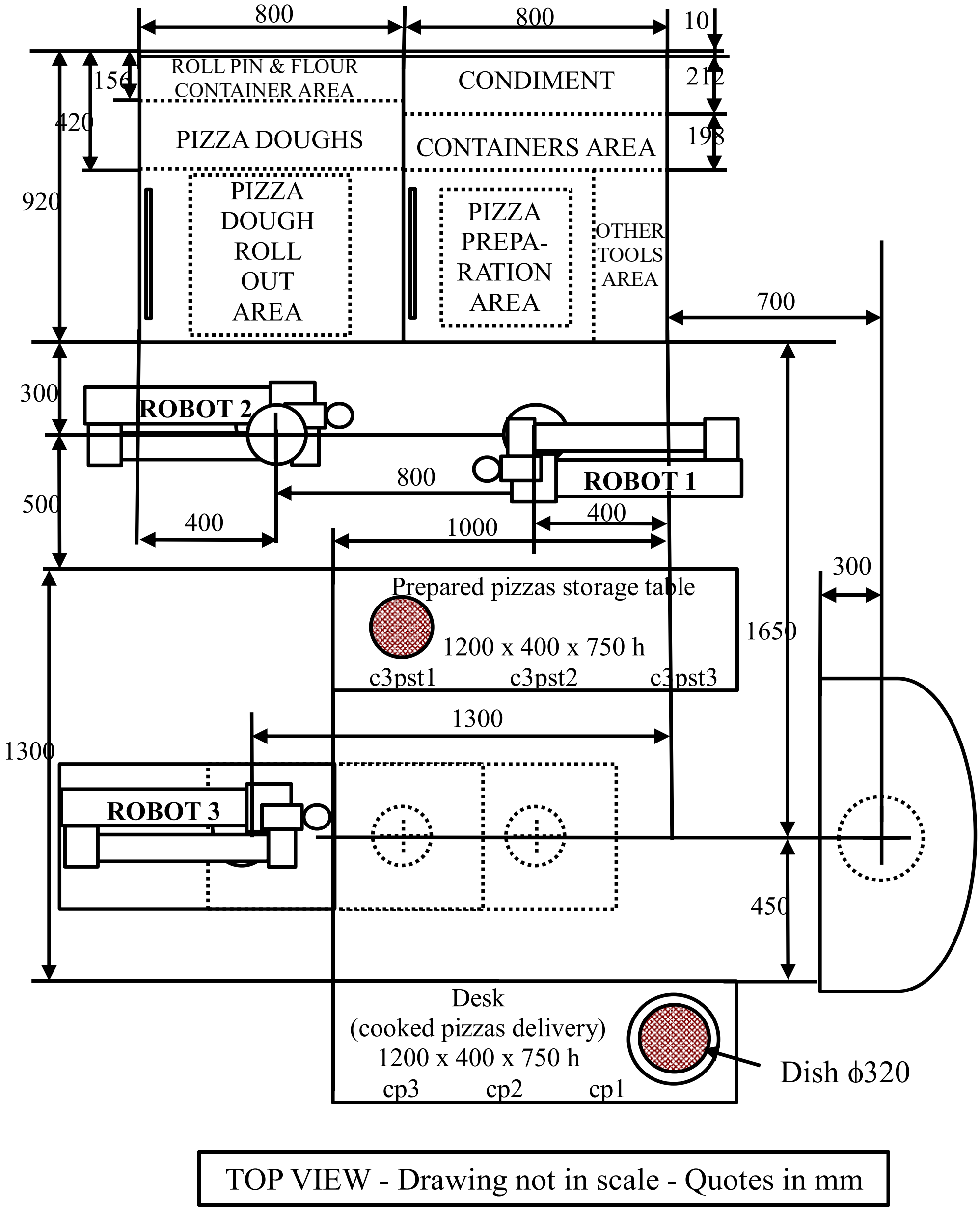


Figure 5.3-3 – Manipulators position and kitchen lay out for Configuration nr. 3.

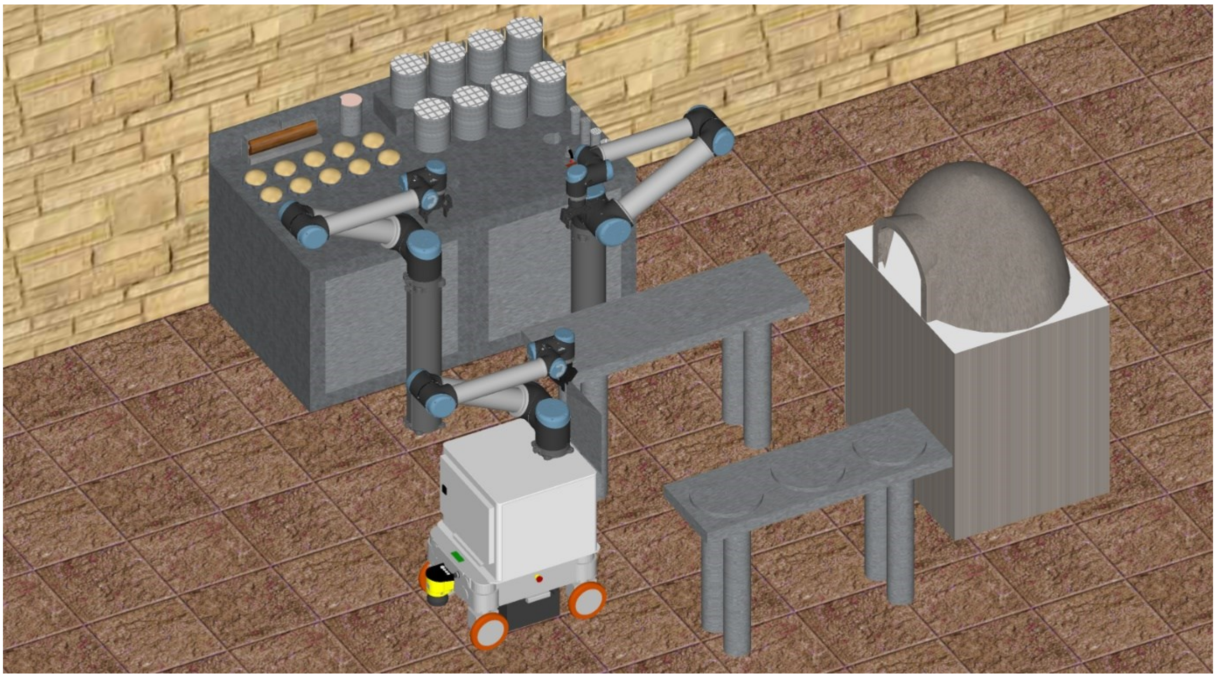


Figure 5.3-4 - Configuration nr. 3 kitchen lay out realized with the tool **SKETCHUP** (view from the left).

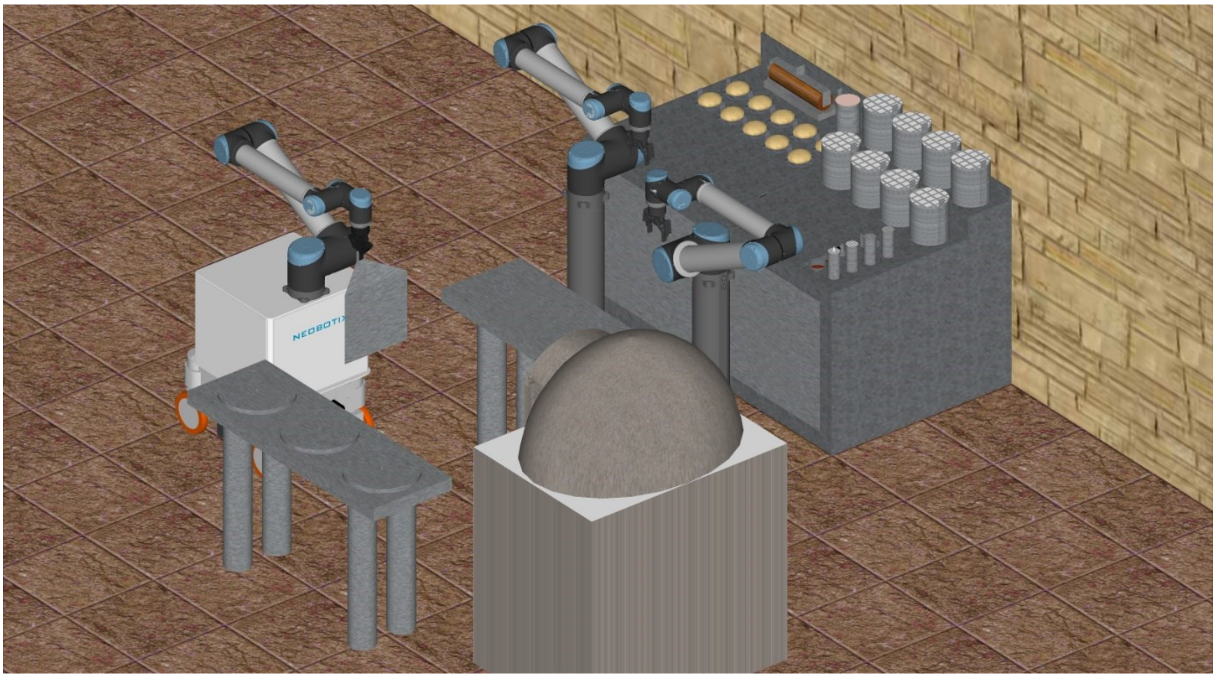


Figure 5.3-5 - Configuration nr. 3 kitchen lay out realized with the tool **SKETCHUP** (view from the right).

5.3.1 ROBOT 2 AND 1 TASKS IN CONFIGURATION NR. 3

In the following it is described the sequence of tasks of the three robots. Mobility is always required for Robot 3, which has all time its shovel 3 well tight in the gripper. Normally Robot 1 and 2 operate in an independent way, with the same two exceptions described for Configuration nr. 1.

5.3.1.1 C3 Robot 2 tasks

C3R2T1 *- Flour container use (see also* ***Figure 5.1.1.1-1****)*

The sequence of movements is the same as per Configuration nr. 1.

C3R2T2 *- Typical dough partition try use (see also* ***Figure 5.1.1.1-2****)*

The sequence of movements is the same as per Configuration nr. 1.

C3R2T3 *- Pizza dough roll out using the roll pin (see also* ***Figure 5.1.1.1-3****)*

The sequence of movements is the same as per Configuration nr. 1 excluding the cart use.

C3R2T4 *- Transfer the rolled-out pizza at pizza preparation location (see also* ***Figure 5.1.1.1-4****)*

The sequence of movements is the same as per Configuration Nr. 1 excluding the cart use.

C3R2Ti *- Further tasks*

As per Configuration nr. 1, Robot 2 has to repeat all the above tasks with the only exception that the pizza dough partition trays to be picked up will be in sequence from **dpt2** to **dpt10** at locations from **L22** to **L30**.

5.3.1.2 C3 Robot 1 tasks

C3R1T1 *- Tomato sauce ladle use (see also **Figure 5.1.1.2-1**)*

The sequence of movements is the same as per Configuration nr. 1.

C3R1T2 *- Typical condiment container use (see also **Figure 5.1.1.2-2**)*

The sequence of movements is the same as per Configuration nr. 1.

C3R1T3 *– Condiment spreading tool use (see also **Figure 5.1.1.2-3**)*

The sequence of movements is the same as per Configuration nr. 1.

C3R1T4 *– Origan, salt and garlic containers use (see also **Figure 5.1.1.2-4**)*

The sequence of movements is the same as per Configuration nr. 1 excluding the cart use.

C3R1T5 *– Olive oil container use (see also **Figure 5.1.1.2-5**)*

The sequence of movements is the same as per Configuration Nr. 1 excluding the cart use.

C3R1T6 *- Transfer the prepared pizza on the storage table (see also **Figure 5.1.1.2-6**)*

The sequence of movements is the same as per Configuration nr. 1 excluding the cart use. After the position of shovel 1 at location **2** and after the restart information sent to Robot 2, Robot 1 has to inform Robot 3 that a prepared pizza has been placed on the storage table at location **c3pst1**, then **c3pst2** and **c3pst3**. From the fourth, the seventh and the tenth pizza the storage will restart from **c3pst1**.

The pizza transfer at locations **c3pst1, c3pst2** and **c3pst3** will be done as for **c1pst1**.

5.3.1.3 C3 Robot 3 tasks

All the actions are referred to the gripping point **GP**, unless otherwise specified. Tasks are listed following the chronological sequence of execution and may be summarized as follows:

- pick up the prepared pizza from the storage table and put it in the oven;
- pick up the cooked pizza from the oven and put it on the delivery desk.

C3R3T1 *– Pick up the prepared pizza from the storage table and put in the oven (see also* ***Figure 5.3.1.3-1****)*

1. From the rest position, after receiving the information from Robot 1, move at location **c3pst1**, first pizza, with the base of shovel 3 horizontal, the axis perpendicular to the **X-Z** plane and at the height of 750 mm, i.e. **GP** at Z=850 mm, and the extremity at distance of 160 mm before the center of the storage location; robot terminal part horizontal (**GP** is 408 mm from the extremity and 100 mm from the base);
2. move horizontally the shovel along the pizza location radial direction (Northwise) by 320 mm;
3. raise up by (1000 + 202) - (750 + 100) = 352 mm and move towards the oven location with no Wrist 3 rotations and with the shovel axis or robot terminal part perpendicular to the oven entry;
4. move the shovel inside the oven till the shovel extremity reaches the X coordinate -700 + 208 = -492 mm and rotate Wrist 2 clockwise by 15° - CART USE;

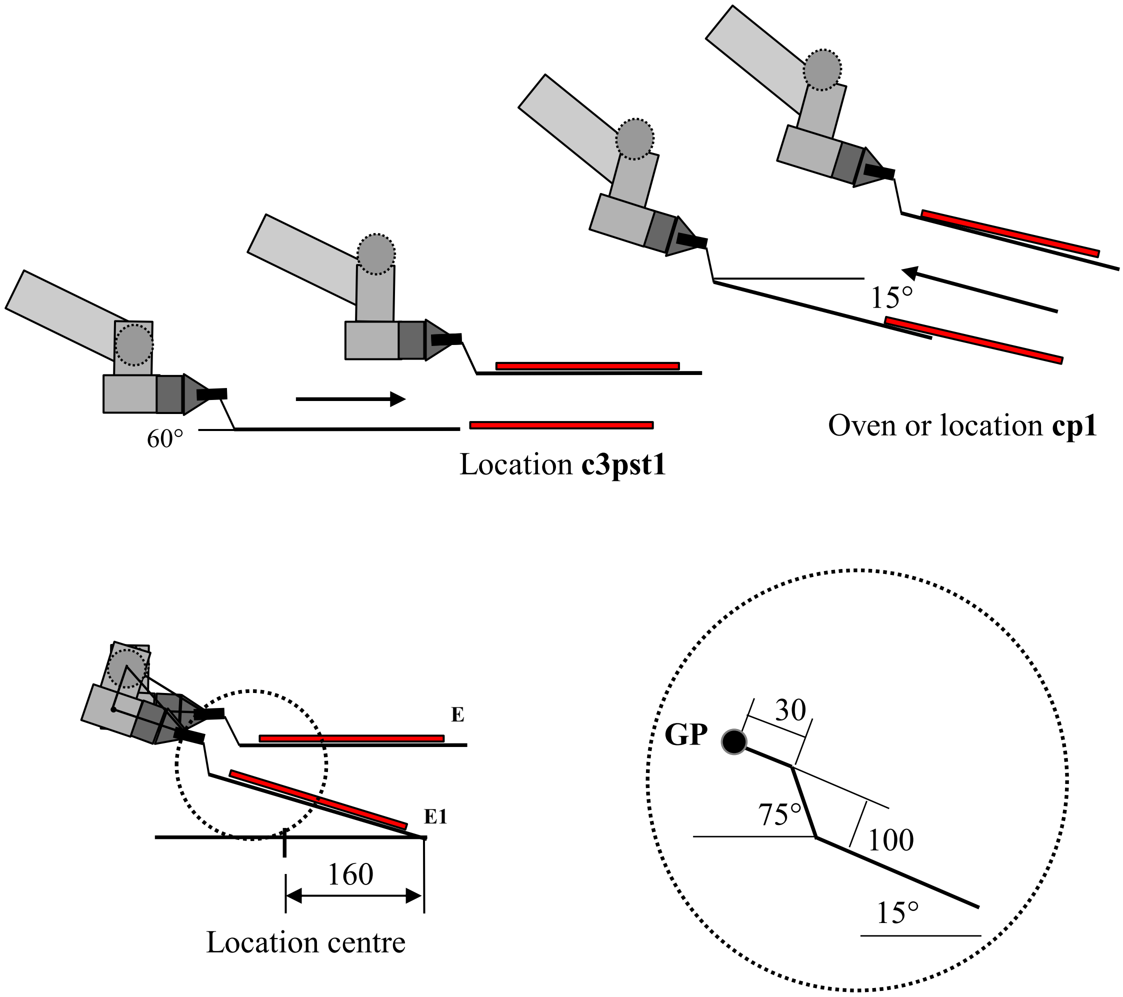
5. perform a fore and aft movement (Eastwise-Westwise) of 20 mm;
6. move back the shovel at the position before entry;
7. move back the cart to the initial position and return at rest waiting for the cooking time – CART USE.

Next similar tasks will consider the pick-up of a pizza stored at locations **c3pst2** and **c3pst3**; then other two cycles from **c3pst1** to **c3pst3**; finally, to complete the mission of ten pizzas at location **c3pst1**. The pick-up of the pizza at location **c3pst3** could require an additional cart movement.

C3R3T2 *– Pick up the cooked pizza from the oven and put on the delivery desk (see also* ***Figure 5.3.1.3-1****)*

1. At the end of the cooking time move in front of the oven from the rest position with the base of shovel 3 horizontal and the axis perpendicular to the oven (**Y-**Z plane);
2. with robot terminal part horizontal move inside the oven at a height of 1100 mm till the extremity of the shovel reaches the X coordinate -700 - 160 = -860 mm, i.e. **GP** at X=460 mm;
3. raise up by 10 mm and move back by 1000 mm;
4. proceed towards location **cp1** with the shovel axis perpendicular to the desk achieving a point at 208 mm before the center of location **cp1** and at a height of 202 + 20 = 222 mm above the desk surface (20 mm in the dish thickness);
5. rotate Wrist 2 counterclockwise by 15° and perform a fore and aft movement of 20 mm;
6. move back the shovel by 1000 mm;
7. rotate Wrist 2 clockwise by 75°, turn the shovel by 180° and come back at rest position;
8. inform the kitchen assistant that one cooked pizza is ready for delivery.

Next similar tasks will consider the delivery of cooked pizzas at locations **cp2** and **cp3**; then other two cycles from **cp1** to **cp3**; finally, to complete the mission of ten pizzas at location **cp1**.



At storage or delivery locations **c3pst1** or **cp1** the **GP** position when the extremity **E1** of the shovel inclined by 15° is at 160 mm beyond the centre of the location is:

208 mm (=368-160) before the location centre
[i.e. 30 * cos15° + (100/sin60°) * sin15° + 320 * cos15° = 368 mm]
202 mm above the table top level
[i.e. 30 * sin15° + (100/sin60°) * cos15° + 320 * sin15° = 202 mm]

Figure 5.3.1-1 – Explanation of shovel 3 use.

6 CONTROL ARCHITECTURE AND SIMULATION

The mathematical model of the collaborative robot (UR10) used for the control architecture is derived referring to [12].

In this paper it is shown how to set the modified DH parameters for the UR5 manipulator and how to perform the inverse kinematics (since the UR3, UR5 and UR10 have similar geometry the study is also valid for the chosen UR10 manipulator).

By performing the inverse kinematics from a given task space position it is possible to obtain up to 8 possible set of joints coordinates values matching that position. Therefore, each task has been previously investigated in order to select the best set of joints coordinates matching the task scope.

FORWARD KINEMATICS

Starting from the definition of a zero position for the robot, the various references frames needed to describe the joints are set (see **Figure 6-1**).

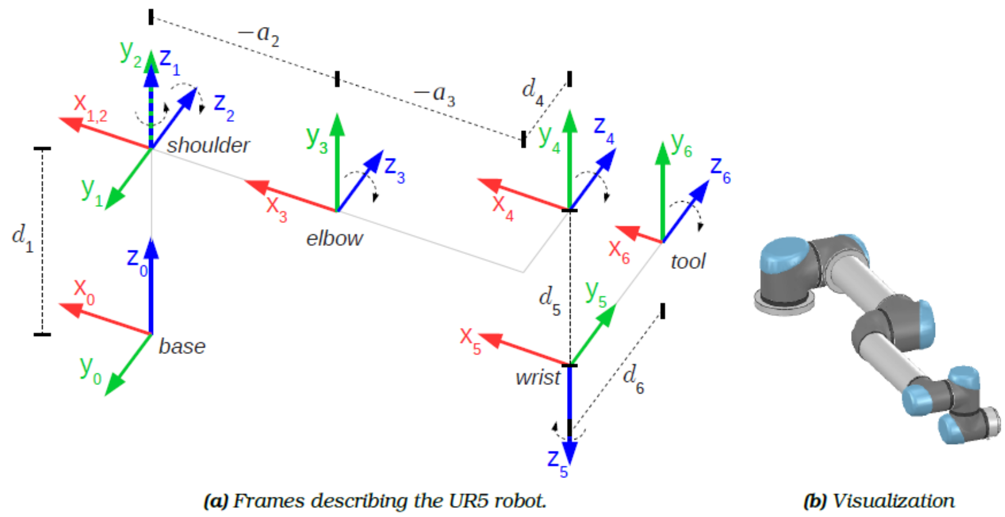


Figure 6-1 – Manipulator zero position and joints reference frames (from [12]).

The modified DH parameters for the defined configuration are reported in **Table 6-1**.

α *[rad]*	a *[m]*	d *[m]*	θ *[rad]*
0	0	d1	q1
π/2	0	0	q2
0	a2	0	q3
0	a3	d4	q4
π/2	0	d5	q5
-π/2	0	d6	q6

Table 6-1 - MDH parameters obtained from the robotic model (from [12]).

Using the homogeneous transformation matrix derived from the composition of basic transformations defined by MDH parameters it is possible to obtain the description for the forward kinematics.

INVERSE KINEMATICS

The study on the inverse kinematics is carried out considering the geometric constraints of the robot. The joints values are (equations from [12]):

$$\theta_1 = \operatorname{atan2}\left({}^0P_{5y}, {}^0P_{5x}\right) \pm \operatorname{acos}\left(\frac{d_4}{\sqrt{{}^0P_{5x}{}^2 + {}^0P_{5y}{}^2}}\right) + \frac{\pi}{2}$$

$$\theta_2 = \operatorname{atan2}(-{}^1P_{4z}, -{}^1P_{4x}) - \operatorname{asin}\left(\frac{-a_3 \sin\theta_3}{|{}^1P_{4xz}|}\right)$$

$$\theta_3 = \pm\operatorname{acos}\left(\frac{|{}^1P_{4xz}|^2 - a_2{}^2 - a_3{}^2}{2a_2a_3}\right)$$

$$\theta_4 = \text{atan2}({}^3\hat{X}_{4y}, {}^3\hat{X}_{4x})$$

$$\theta_5 = \pm\textbf{acos}\left(\frac{{}^0P_{6x}\sin\theta_1 - {}^0P_{6y}\cos\theta_1 - d_4}{d_6}\right)$$

$$\theta_6 = \text{atan2}\left(\frac{-{}^6\hat{X}_{0y}\cdot\sin\theta_1 + {}^6\hat{Y}_{0y}\cdot\cos\theta_1}{\sin\theta_5}, \frac{{}^6\hat{X}_{0x}\cdot\sin\theta_1 - {}^6\hat{Y}_{0x}\cdot\cos\theta_1}{\sin\theta_5}\right)$$

MATLAB MODEL

Using the MDH parameters of the UR10 model inside the Robotic Toolbox a model in **MATLAB** is derived. This model (see **Figure 6-1**) is useful for the study of the trajectories needed to accomplish the assigned tasks.

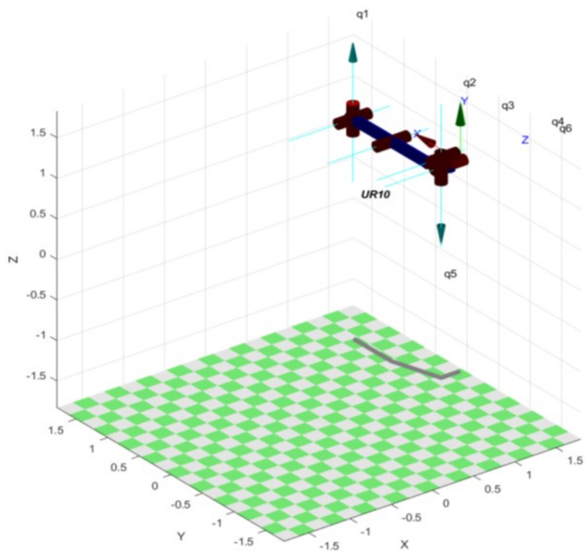


Figure 6-1 – **MATLAB** model using Robotic ToolBox.

6.1 GRIPPING POINT TASK PATHS AND TIME-OPTIMAL TRAJECTORIES

Once assigned and defined the positions of all the tools needed to prepare the pizza, a list of points that the gripper needs to cross to perform the tasks has been compiled for each robot and each configuration.

Then starting from this list, the entire trajectories for the robots' end effectors has been determined and imported in **MATLAB** for the further **SIMULINK** time performance analysis.

TASK PATHS

For each crossing point defined by its position in the task space it is initially evaluated, by performing the inverse kinematics analysis, which one among the set of nr. 8 possible manipulator configurations in terms of Joints angles (i.e. Elbow or Wrists orientations) is matching at best the required task.

Having discussed the gripper geometry at **Section 4.5**, the end effector control point, here also called Gripping Point (**GP**), is considered at 143 mm forward to the UR10 interface for the end effector.

The **GP** task paths are expressed in a matrix format with the following contents. It is assumed that at rest position the reference angles of the manipulator Joints are according to **Table 6.1-1**.

All the tasks normally start from the position reached in the previous task or from the rest position. The appropriate set of joint coordinates matching the task is specified in the top right cell. Sometimes one set only is not appropriated to perform the entire task, therefore a manually change of the set is introduced.

The 3D visualization of the tool **ARTE** has been used to verify the absence of interferences during the execution of the task. Appropriate changes have been introduced in case of discovered interferences.

UR10 Joint	Configuration nr. 1		Configuration nr. 2		Configuration nr. 3		
	Robot 1	Robot 2	Robot 1	Robot 2	Robot 1	Robot 2	Robot 3
Base	90	-90	90	-90	90	-90	-90
Shoulder	-153	-153	-153	-153	-153	-153	-153
Elbow	153	153	153	153	153	153	153
Wrist 1	-90	-90	-90	-90	-90	-90	-90
Wrist 2	-90	-90	-90	-90	-90	-90	-90
Wrist 3	0	0	0	0	0	0	0

Table 6.1-1 – UR10 manipulator reference joints angle at rest.

TASK PATH MATRIX DESCRIPTION

1st row – a general requirement for the accomplishment of the task;
Intermediate rows – key crossing points for the accomplishment of the task or specific action to be performed;
Last row – specific action to be performed, like stand by at rest position or continue with next task.

1st column - brief sub-task description;
2nd column - GP global reference system X coordinate in mm;
3rd column - GP global reference system Y coordinate in mm;
4th column - GP global reference system Z coordinate in mm;
5th column - global reference system rotation around X axis to match the required position of the **GP** in degrees;
6th column - global reference system rotation around Y axis to match the

required position of the **GP** in degrees;

7th column - global reference system rotation around Z axis to match the required position of the **GP** in degrees;

From 8th to 10th column - required priority for the specified global reference system rotations around X, Y and Z axes (i.e. 3, 1, 2 means that rotation around Y axis is required first, then rotation around Z axis and finally rotation around X axis);

11th column - specifies the gripper status 0 = open, 1 = closed;

12th column - specific clarification of requirement for waiting time, commands for other Robots, Wrists, Elbow, Shoulder or Base orientations, Cart use, Manipulator Joints set change, etc.

All the task paths have been included in an **EXCEL** file named ***Task paths.xlsx*** and are reported as images in the **Appendix C** for each robot and each robot configuration.

OPTIMIZED TRAJECTORIES

To generate the time-optimal gripper trajectories a novel method described in [12] is used. This method applies to differentiable joint-space paths within boundary limits of joints acceleration and velocity and includes a preprocessing method to convert non differentiable paths, i.e. those derived in **Appendix C**, in differentiable ones by adding circular blends to smooth the path's corner points, or waypoints connected by straight lines.

At the waypoint the path is instantaneously changing its direction, then it is not differentiable. To avoid the robot to stop at each waypoint a circular blend is added, which starts tangential to the linear path segment at a distance ***li*** before the waypoint and ends tangential to the linear path segment at a distance ***li*** after the waypoint. Moreover, a parameter δ is set to be sure that the circular segment stays within a minimum distance from the waypoint (see **Figure 6.1-1** derived from [13]).

An adaptation of the open-source software, available for download at http://www.golems.org/node/1570, is herein used by introducing the joints velocity and acceleration limits specified by the UR10 manufacturer.

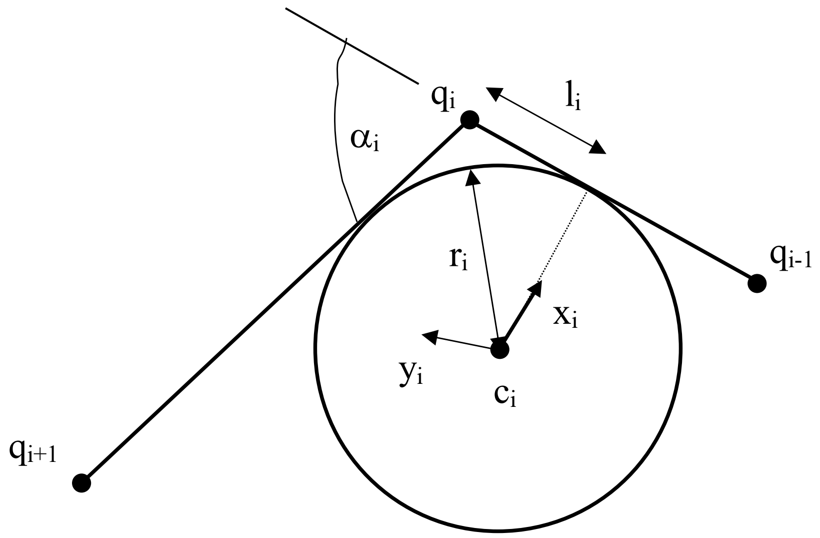


Figure 6.1-1 – Circular blend around waypoint (from [13]).

The software for the herein specific application has been named **TRAJ** and is developed using the **C++** code.

The software **TRAJ** generates the gripping point trajectories in terms of manipulator joints angles, therefore a conversion of the task paths is initially made to pass from gripping point space coordinates into joints angles (Base, Shoulder, Elbow, Wrist 1, Wrist 2, Wrist 3), in degrees, through the inverse kinematics.

Once obtained the joint angles at the crossing points, the joints performance speed [°/s] and acceleration [$°/s^2$] limits and the above defined parameters ***li*** and **δ** are added as input data to the software **TRAJ** in order to obtain the manipulator continuous trajectories with an integration interval of 10 μs and a time step definition of 1 ms.

The **TRAJ** executable code generates two files:

1. joints angles in degree (°) for steps of 1 ms;
2. joints speed in °/s for steps of 1 ms.

From the speed plots some singular points where the joint speed is fast changing in a very short time generating acceleration peaks exceeding the performance limits have been found. In most cases this occurs when a shaking movement is introduced to help the fall down of condiments, pizza dough partitions, rolled out pizza and prepared pizza.

To avoid robot stops at these singularities the trajectory is split in two parts by keeping all the trajectory before the singular point and adding all the trajectory after the singular point. This, from a physic point of view, implies a very short robot stop, i.e. of 1 ms, but the joints acceleration remains inside the performance limits.

The final task trajectories are collected per sheet in three **EXCEL** files, one for each configuration. Despite the task paths, here some time rows are added to include the opening and closing times of the gripper for each specific task. Moreover, the gripper status is redefined as follows:

-1 = Open at 70,6 mm (fully open 85 mm minus 18 steps of 0,8 mm);

0 = Open at 25 mm (fully open 85 mm minus 75 steps of 0,8 mm);

1 = Closed at a width depending from the tool.

In fact, the gripper is normally open 25 mm (status 0). When the manipulator reaches the tool pick up point it stops for the time needed to catch the tool. Considering the single finger speed movement of 150 mm/s for steps of 0,4 mm, i.e. closing/opening speed of 300 mm/s for steps of 0,8 mm, the gripper activation movement is performed with time steps of (0,8 / 300) s.

When the tool pick-up point thickness is 2 mm (flour container, dough partition trays, condiment containers, tomato sauce ladle, condiment spreading tool) the closing steps are (25 - 2) / 0,8 = 28,75, i.e. 29, and the closing time is 28,75 * 0,8 / 300 = 0,07667 s (used 77 ms, which means 28,875 or 29 steps and that the last closing step, for a tight grip, will be completed after manipulator restart).

When the tool pick-up point thickness is 3 mm (roll pin), the closing steps are (25 - 3) / 0,8 = 27,5, i.e. 28, and the closing time is 27,5 * 0,8 / 300 = 0,07333 s (used 75 ms, which means 28,125 or 29 steps and that the last closing step, for a tight grip, will be completed after manipulator restart).

When the tool pick-up point thickness is 5 mm (pizza shovels), the closing steps are (25 - 5) / 0,8 = 25 steps, and the closing time is 25 * 0,8 / 300 = 0,06667 s (used 67 ms, which means 25,125 or 26 steps and that the last closing step, for a tight grip, will be completed after manipulator restart).

When the tool pick-up point thickness is 50 mm (origan, salt, garlic and olive oil containers) the gripper must open first up to 70,6 mm, i.e. the opening steps are (70,6 – 25) / 0,8 = 57 and the opening time is 57 * 0,8 / 300 = 0,152 s (used 151 ms, which means 56,625 or 57 steps and that the last opening step will be completed before manipulator restart). Then the gripper must close at 50 mm, i.e. the closing steps are (70,6 – 50) / 0,8 = 25,75 or 26 and the closing time is 25,75 * 0,8 / 300 = 0,06867 s (used 68 ms, which means 25,5 or 26 steps and that the last closing step, for a tight grip, will be completed before manipulator restart).

The **EXCEL** files collecting the task trajectories are named:

Task trajectories Conf_1.xlsx
Task trajectories Conf_2.xlsx
Task trajectories Conf_3.xlsx

EXCEL FILES FOR MATLAB SIMULATION

For the execution of the time performance analysis by **SIMULINK**, the above files have been imported in **MATLAB** to have them correctly structured for the **SIMULINK** analysis.

The following **Figures 6.1-2**, **Figures 6.1-3** and **Figures 6.1-4** give an example of task path and the relevant task trajectory **EXCEL** file plus its final **MATLAB** version.

C2R2T1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 8
before to start check if a request to go at rest position arrives from R1											
at pos fc	1001	81	928	90	90	180	2	1	3	0	
pick up fc	1001	81	928	90	90	180	2	1	3	1	
raise up 100	1001	81	1028	90	90	180	2	1	3	1	
over Loc 17	1200	670	960	90	90	180	2	1	3	1	
flour spread	1220	705	960	90	90	240	2	1	3	1	
"	1242	712	960	90	90	300	2	1	3	1	
"	1287	720	960	90	90	360	2	1	3	1	
"	1300	670	960	90	90	90	2	1	3	1	
"	1287	620	960	90	90	180	2	1	3	1	
"	1271	599	960	90	90	240	2	1	3	1	
"	1250	583	960	90	90	300	2	1	3	1	
"	1200	570	960	90	90	360	2	1	3	1	
"	1150	583	960	90	90	60	2	1	3	1	
"	1129	599	960	90	90	120	2	1	3	1	
"	1113	620	960	90	90	180	2	1	3	1	
"	1100	670	960	90	90	240	2	1	3	1	
"	1113	720	960	90	90	360	2	1	3	1	
"	1129	741	960	90	90	60	2	1	3	1	
"	1150	757	960	90	90	120	2	1	3	1	
"	1200	770	960	90	90	180	2	1	3	1	
above pos fc	1001	81	1028	90	90	180	2	1	3	1	
leave fc	1001	81	928	90	90	180	2	1	3	1	
open gripper	1001	81	928	90	90	180	2	1	3	0	
raise up 100	1001	81	1028	90	90	180	2	1	3	0	
continue with next task											

Figures 6.1-2 - Example of C1R2T1 task path **EXCEL** file.

C1R2T1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	ity of rot			Gripper [mm]	Best joint manipulator set 8	-90 -1.5708		-153 -2.6704		153 2.6704		-90 -1.5708		-90 -1.5708		0 0	
ore to start check if a request to go at rest position arrives from											1.2000 1.2200 0.7670												
at pos fc	1001	81	928	90	90	180	2	1	3	0		3.1030	-3.1802	-2.3295		-1.3543		-2.5994		-1.6094		1.5708	
pick up fc	1001	81	928	90	90	180	2	1	3	1		3.1030	-3.1802	-2.3295		-1.3543		-2.5994		-1.6094		1.5708	
raise up 100	1001	81	1028	90	90	180	2	1	3	1		3.1030	-3.1802	-2.2525		-1.2957		-2.7350		-1.6094		1.5708	
over Loc 17	1200	670	960	90	90	180	2	1	3	1		3.6892	-2.5940	-1.3728		-2.5909		-2.3195		-1.0232		1.5708	
flour spread	1220	705	960	90	90	240	2	1	3	1		-2.4464		-1.2792		-2.6495		-2.3545		-0.8756		2.6180	
"	1242	712	960	90	90	300	2	1	3	1		-2.3532		-1.2655		-2.6572		-2.3606		-0.7824		-2.6180	3.6652
"	1287	720	960	90	90	360	2	1	3	1		-2.1958		-1.2738		-2.6526		-2.3569		-0.6250		-1.5708	4.7124
"	1300	670	960	90	90	90	2	1	3	1		-2.3149		-1.4100		-2.5642		-2.3090		-0.7441		0	6.2832
"	1287	620	960	90	90	180	2	1	3	1		-2.4553		-1.5053		-2.4862		-2.2917		-0.8845		1.5708	7.8540
"	1271	599	960	90	90	240	2	1	3	1		-2.5286		-1.5383		-2.4558		-2.2891		-0.9578		2.6180	8.9012
"	1250	583	960	90	90	300	2	1	3	1		-2.6010		-1.5615		-2.4334		-2.2883		-1.0302		-2.6180	9.9484
"	1200	570	960	90	90	360	2	1	3	1		3.5479	-2.7353	-1.5792		-2.4157		-2.2883		-1.1645		-1.5708	10.9956
"	1150	583	960	90	90	60	2	1	3	1		3.4347	-2.8485	-1.5615		-2.4334		-2.2883		-1.2777		-0.5236	12.0428
"	1129	599	960	90	90	120	2	1	3	1		3.3908	-2.8924	-1.5383		-2.4558		-2.2891		-1.3216		0.5236	13.0900
"	1113	620	960	90	90	180	2	1	3	1		3.3599	-2.9233	-1.5053		-2.4862		-2.2917		-1.3524		1.5708	14.1372
"	1100	670	960	90	90	240	2	1	3	1		3.3534	-2.9298	-1.4100		-2.5642		-2.3090		-1.3589		2.6180	15.1844
"	1113	720	960	90	90	360	2	1	3	1		3.4530	-2.8302	-1.2738		-2.6526		-2.3569		-1.2594		-1.5708	17.2788
"	1129	741	960	90	90	60	2	1	3	1		3.5599	-2.7233	-1.1914		-2.6944		-2.3973		-1.1525		-0.5236	18.3260
"	1150	757	960	90	90	120	2	1	3	1		3.7048	-2.5784	-1.1088		-2.7290		-2.4453		-1.0076		0.5236	19.3732
"	1200	770	960	90	90	180	2	1	3	1		4.0092	-2.2740	-1.0190		-2.7595		-2.5047		-0.7032		1.5708	20.4204
above pos fc	1001	81	1028	90	90	180	2	1	3	1		3.1030	-3.1802	-2.2525		-1.2957		-2.7350		-1.6094		1.5708	20.4204
leave fc	1001	81	928	90	90	180	2	1	3	1		3.1030	-3.1802	-2.3295		-1.3543		-2.5994		-1.6094		1.5708	20.4204
open gripper	1001	81	928	90	90	180	2	1	3	0		3.1030	-3.1802	-2.3295		-1.3543		-2.5994		-1.6094		1.5708	20.4204
raise up 100	1001	81	1028	90	90	180	2	1	3	0		3.1030	-3.1802	-2.2525		-1.2957		-2.7350		-1.6094		1.5708	20.4204
continue with next task																							

-3.1802	-182.2120	-2.3295	-133.4705	-1.3543	-77.5957	-2.5994	-148.9346	-1.6094	-92.2118	1.5708	90.0002
-3.1802	-182.2120	-2.3295	-133.4705	-1.3543	-77.5957	-2.5994	-148.9346	-1.6094	-92.2118	1.5708	90.0002
-3.1802	-182.2120	-2.2525	-129.0587	-1.2957	-74.2381	-2.7350	-156.7040	-1.6094	-92.2118	1.5708	90.0002
-2.5940	-148.6253	-1.3728	-78.6556	-2.5909	-148.4476	-2.3195	-132.8976	-1.0232	-58.6250	1.5708	90.0002
-2.4464	-140.1684	-1.2792	-73.2928	-2.6495	-151.8052	-2.3545	-134.9029	-0.8756	-50.1682	2.6180	150.0004
-2.3532	-134.8284	-1.2655	-72.5078	-2.6572	-152.2463	-2.3606	-135.2524	-0.7824	-44.8282	3.6652	210.0005
-2.1958	-125.8101	-1.2738	-72.9834	-2.6526	-151.9828	-2.3569	-135.0404	-0.6250	-35.8099	4.7124	270.0006
-2.3149	-132.6340	-1.4100	-80.7870	-2.5642	-146.9178	-2.3090	-132.2960	-0.7441	-42.6338	6.2832	360.0008
-2.4553	-140.6783	-1.5053	-86.2473	-2.4862	-142.4488	-2.2917	-131.3047	-0.8845	-50.6781	7.8540	450.0011
-2.5286	-144.8781	-1.5383	-88.1381	-2.4558	-140.7070	-2.2891	-131.1558	-0.9578	-54.8779	8.9012	510.0012
-2.6010	-149.0263	-1.5615	-89.4674	-2.4334	-139.4235	-2.2883	-131.1099	-1.0302	-59.0261	9.9484	570.0013
-2.7353	-156.7211	-1.5792	-90.4815	-2.4157	-138.4094	-2.2883	-131.1099	-1.1645	-66.7209	10.9956	630.0015
-2.8485	-163.2070	-1.5615	-89.4674	-2.4334	-139.4235	-2.2883	-131.1099	-1.2777	-73.2068	12.0428	690.0016
-2.8924	-165.7223	-1.5383	-88.1381	-2.4558	-140.7070	-2.2891	-131.1558	-1.3216	-75.7221	13.0900	750.0018
-2.9233	-167.4928	-1.5053	-86.2473	-2.4862	-142.4488	-2.2917	-131.3047	-1.3524	-77.4868	14.1372	810.0019
-2.9298	-167.8652	-1.4100	-80.7870	-2.5642	-146.9178	-2.3090	-132.2960	-1.3589	-77.8592	15.1844	870.0020
-2.8302	-162.1585	-1.2738	-72.9834	-2.6526	-151.9828	-2.3569	-135.0404	-1.2594	-72.1583	17.2788	990.0023
-2.7233	-156.0336	-1.1914	-68.2622	-2.6944	-154.3777	-2.3973	-137.3552	-1.1525	-66.0334	18.3260	1050
-2.5784	-147.7314	-1.1088	-63.5296	-2.7290	-156.3602	-2.4453	-140.1054	-1.0076	-57.7312	19.3732	1110
-2.2740	-130.2906	-1.0190	-58.3844	-2.7595	-158.1077	-2.5047	-143.5087	-0.7032	-40.2904	20.4204	1170
-3.1802	-182.2120	-2.2525	-129.0587	-1.2957	-74.2381	-2.7350	-156.7040	-1.6094	-92.2118	20.4204	1170
-3.1802	-182.2120	-2.3295	-133.4705	-1.3543	-77.5957	-2.5994	-148.9346	-1.6094	-92.2118	20.4204	1170
-3.1802	-182.2120	-2.3295	-133.4705	-1.3543	-77.5957	-2.5994	-148.9346	-1.6094	-92.2118	20.4204	1170
-3.1802	-182.2120	-2.2525	-129.0587	-1.2957	-74.2381	-2.7350	-156.7040	-1.6094	-92.2118	20.4204	1170

	PREVIOUS												0	
1s	-3.1802	-182.2120	-2.3295	-133.4705	-1.3543	-77.5957	-2.5994	-148.9346	-1.6094	-92.2118	1.5708	90.0002	0	Gripper Open
0.077 s	GRABBING												ramp	
	-3.1802	-182.2120	-2.3295	-133.4705	-1.3543	-77.5957	-2.5994	-148.9346	-1.6094	-92.2118	1.5708	90.0002	1	
	-3.1802	-182.2120	-2.2525	-129.0587	-1.2957	-74.2381	-2.7350	-156.7040	-1.6094	-92.2118	1.5708	90.0002	1	
	-2.5940	-148.6253	-1.3728	-78.6556	-2.5909	-148.4476	-2.3195	-132.8976	-1.0232	-58.6250	1.5708	90.0002	1	
	-2.4464	-140.1684	-1.2792	-73.2928	-2.6495	-151.8052	-2.3545	-134.9029	-0.8756	-50.1682	2.6180	150.0004	1	
	-2.3532	-134.8284	-1.2655	-72.5078	-2.6572	-152.2463	-2.3606	-135.2524	-0.7824	-44.8282	3.6652	210.0005	1	
	-2.1958	-125.8101	-1.2738	-72.9834	-2.6526	-151.9828	-2.3569	-135.0404	-0.6250	-35.8099	4.7124	270.0006	1	
	-2.3149	-132.6340	-1.4100	-80.7870	-2.5642	-146.9178	-2.3090	-132.2960	-0.7441	-42.6338	6.2832	360.0008	1	
	-2.4553	-140.6783	-1.5053	-86.2473	-2.4862	-142.4488	-2.2917	-131.3047	-0.8845	-50.6781	7.8540	450.0011	1	
	-2.5286	-144.8781	-1.5383	-88.1381	-2.4558	-140.7070	-2.2891	-131.1558	-0.9578	-54.8779	8.9012	510.0012	1	Gripper action 12.6230 s
	-2.6010	-149.0263	-1.5615	-89.4674	-2.4334	-139.4235	-2.2883	-131.1099	-1.0302	-59.0261	9.9484	570.0013	1	
	-2.7353	-156.7211	-1.5792	-90.4815	-2.4157	-138.4094	-2.2883	-131.1099	-1.1645	-66.7209	10.9956	630.0015	1	
	-2.8485	-163.2070	-1.5615	-89.4674	-2.4334	-139.4235	-2.2883	-131.1099	-1.2777	-73.2068	12.0428	690.0016	1	
	-2.8924	-165.7223	-1.5383	-88.1381	-2.4558	-140.7070	-2.2891	-131.1558	-1.3216	-75.7221	13.0900	750.0018	1	
	-2.9233	-167.4928	-1.5053	-86.2473	-2.4862	-142.4488	-2.2917	-131.3047	-1.3524	-77.4868	14.1372	810.0019	1	
	-2.9298	-167.8652	-1.4100	-80.7870	-2.5642	-146.9178	-2.3090	-132.2960	-1.3589	-77.8592	15.1844	870.0020	1	
	-2.8302	-162.1585	-1.2738	-72.9834	-2.6526	-151.9828	-2.3569	-135.0404	-1.2594	-72.1583	17.2788	990.0023	1	
	-2.7233	-156.0336	-1.1914	-68.2622	-2.6944	-154.3777	-2.3973	-137.3552	-1.1525	-66.0334	18.3260	1050	1	
	-2.5784	-147.7314	-1.1088	-63.5296	-2.7290	-156.3602	-2.4453	-140.1054	-1.0076	-57.7312	19.3732	1110	1	
	-2.2740	-130.2906	-1.0190	-58.3844	-2.7595	-158.1077	-2.5047	-143.5087	-0.7032	-40.2904	20.4204	1170	1	
	-3.1802	-182.2120	-2.2525	-129.0587	-1.2957	-74.2381	-2.7350	-156.7040	-1.6094	-92.2118	20.4204	1170	1	
12.053 s	-3.1802	-182.2120	-2.3295	-133.4705	-1.3543	-77.5957	-2.5994	-148.9346	-1.6094	-92.2118	20.4204	1170	1	
0.077 s	OPENING												deramp	
	-3.1802	-182.2120	-2.3295	-133.4705	-1.3543	-77.5957	-2.5994	-148.9346	-1.6094	-92.2118	20.4204	1170	0	
0.416 s	-3.1802	-182.2120	-2.2525	-129.0587	-1.2957	-74.2381	-2.7350	-156.7040	-1.6094	-92.2118	20.4204	1170	0	

Figures 6.1-3 - Example of C1R2T1 task trajectory **EXCEL** file.

time	q1	q2	q3	q4	q5	q6	gripper
0	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0
0,001	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,01298701
0,002	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,02597403
0,003	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,03896104
0,004	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,05194805
0,005	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,06493506
0,006	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,07792208
0,007	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,09090909
0,008	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,1038961
0,009	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,11688312
0,01	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,12987013
0,011	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,14285714
0,012	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,15584416
0,013	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,16883117
0,014	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,18181818
0,015	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,19480519
0,016	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,20779221
0,017	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,22077922
0,018	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,23376623
0,019	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,24675325
0,02	-182,212	-133,47	-77,5957	-148,935	-92,2118	90,0002	0,25974026

Figures 6.1-4 - Example of C1R2T1 task trajectory imported in **MATLAB** (first 20 ms).

6.2 SIMULATION ASSUMPTIONS

To identify the most time performant robot configuration, among the three, a specific mission has been defined for an objective comparison.

The **Mission** is the preparation of nr. 10 pizzas of different tastes among those possible with the available condiments.

These are the nr. 6 basic pizza tastes listed below.

1. marinara (tomato sauce, salt, origan, garlic, and olive oil).
2. margherita (tomato sauce, salt, mozzarella cheese and olive oil).
3. ortolana (tomato sauce, salt, mozzarella cheese, aubergines, zucchini, peppers, origan

and olive oil).

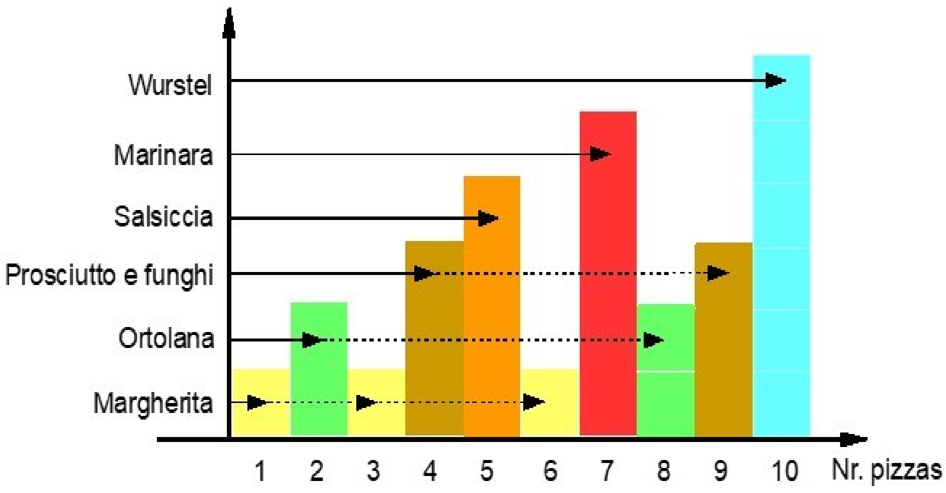
4. wurstel (tomato sauce, salt, mozzarella cheese, wurstel and olive oil).
5. salsiccia (tomato sauce, salt, mozzarella cheese, sausages and olive oil).
6. prosciutto e funghi (tomato sauce, salt, mozzarella cheese, ham, mushrooms and olive oil).

The available condiments are the following (in parenthesis the workstation location and the container code):

- mozzarella cheese (**L3**, **cc1**),
- aubergines (**L4**, **cc2**),
- zucchini (**L5**, **cc3**),
- peppers (**L6**, **cc4**),
- wurstels (**L7**, **cc5**),
- sausages (**L8**, **cc6**),
- mushrooms (**L9**, **cc7**),
- ham (**L10**, **cc8**),
- tomato sauce (**L11, tsl**),
- origan (**L13, oc**),
- salt (**L14, sc**),
- garlic (**L15, gc**), and
- olive oil (**L16, ooc**).

The pizza taste can be prepared upon a random generation, like normally occurring in pizzeria. However, for the comparative performance analysis it is important to compare the same tasks. For this reason, a specific **Pizza Preparation Mission** or **Mission** is defined. Details are given in the following, where in parenthesis is indicated the sequence of tools to be used, identified by the robot number (**R3** only for Configuration nr. 3) and the workstation location.

A graphic representation of the **Mission** is given by **Figure 6.2-1**.



Figures 6.2-1 - Sequence of pizza tastes to be prepared for the performance analysis (**Mission**).

- Nr. 1 pizza margherita
  - (**R2**: L20, L21, L19, L18; **R1**: L11, L14, L3, L12, L16, L2; **R3**: pst1, oven, cp1)
- Nr. 1 pizza ortolana
  - (**R2**: L20, L24, L19, L18; **R1**: L11, L14, L3, L4, L5, L6, L12, L13, L16, L2; **R3**: pst2, oven, cp2)
- Nr. 1 pizza margherita
  - (**R2**: L20, L21, L19, L18; **R1**: L11, L14, L3, L12, L16, L2; **R3**: pst3, oven, cp3)
- Nr. 1 pizza prosciutto e funghi
  - (**R2**: L20, L26, L19, L18; **R1**: L11, L14, L3, L10, L9, L12, L16, L2; **R3**: pst1, oven, cp1)
- Nr. 1 pizza salsiccia
  - (**R2**: L20, L28, L19, L18; **R1**: L11, L14, L3, L8, L12, L16, L2; **R3**: pst2, oven, cp2)

- Nr. 1 pizza margherita
  - (**R2**: L20, L21, L19, L18; **R1**: L11, L14, L3, L12, L16, L2; **R3**: pst3, oven, cp3)
- Nr. 1 pizza marinara
  - (**R2**: L20, L29, L19, L18; **R1**: L11, L14, L13, L15, L16, L2; **R3**: pst1, oven, cp1)
- Nr. 1 pizza ortolana
  - (**R2**: L20, L24, L19, L18; **R1**: L11, L14, L3, L4, L5, L6, L12, L13, L16, L2; **R3**: pst2, oven, cp2)
- Nr. 1 pizza prosciutto e funghi
  - (**R2**: L20, L26, L19, L18; **R1**: L11, L14, L3, L10, L9, L12, L16, L2; **R3**: pst3, oven, cp3)
- Nr. 1 pizza wurstel
  - (**R2**: L20, L30, L19, L18; **R1**: L11, L14, L3, L7, L12, L16, L2; **R3**: pst1, oven, cp1)

The activities for pizza cooking, oven extraction and final delivery at desk are not part of the simulation and are left to a human kitchen assistant. For the third robot inside the Configuration nr. 3 only task paths and gripper point trajectories for pizza cooking and final delivery are derived.

TASK SEQUENCE TO ACCOMPLISH THE MISSION

CONFIGURATION NR. 1

ROBOT 2

1. C1R2T1, C1R2T2-dpt1, C1R2T3, C1R2T4;
2. C1R2T1, C1R2T2-dpt2, C1R2T3, C1R2T4;
3. C1R2T1, C1R2T2-dpt3, C1R2T3, C1R2T4;
4. C1R2T1, C1R2T2-dpt4, C1R2T3, C1R2T4;

5. C1R2T1, C1R2T2-dpt5, C1R2T3, C1R2T4;
6. C1R2T1, C1R2T2-dpt6, C1R2T3, C1R2T4;
7. C1R2T1, C1R2T2-dpt7, C1R2T3, C1R2T4;
8. C1R2T1, C1R2T2-dpt8, C1R2T3, C1R2T4;
9. C1R2T1, C1R2T2-dpt9, C1R2T3, C1R2T4;
10. C1R2T1, C1R2T2-dpt10, C1R2T3, C1R2T4.

ROBOT 1

1. C1R1T1, C1R1T4-sc, C1R1T2-cc1, C1R1T3, C1R1T5, C1R1T6-c1pst1;
2. C1R1T1, C1R1T4-sc, C1R1T2-cc1, C1R1T2-cc2, C1R1T2-cc3, C1R1T2-cc4, C1R1T3, C1R1T4-oc, C1R1T5, C1R1T6-c1pst2;
3. C1R1T1, C1R1T4-sc, C1R1T2-cc1, C1R1T3, C1R1T5, C1R1T6-c1pst3;
4. C1R1T1, C1R1T4-sc, C1R1T2-cc1, C1R1T2-cc8, C1R1T2-cc7, C1R1T3, C1R1T5, C1R1T6-c1pst1;
5. C1R1T1, C1R1T4-sc, C1R1T2-cc1, C1R1T2-cc6, C1R1T3, C1R1T5, C1R1T6-c1pst2;
6. C1R1T1, C1R1T4-sc, C1R1T2-cc1, C1R1T3, C1R1T5, C1R1T6-c1pst3;
7. C1R1T1, C1R1T4-sc, C1R1T4-oc, C1R1T4-gc, C1R1T5, C1R1T6-c1pst1;
8. C1R1T1, C1R1T4-sc, C1R1T2-cc1, C1R1T2-cc2, C1R1T2-cc3, C1R1T2-cc4, C1R1T3, C1R1T4-oc, C1R1T5, C1R1T6-c1pst2;
9. C1R1T1, C1R1T4-sc, C1R1T2-cc1, C1R1T2-cc8, C1R1T2-cc7, C1R1T3, C1R1T5, C1R1T6-c1pst3;
10. C1R1T1, C1R1T4-sc, C1R1T2-cc1, C1R1T2-cc5, C1R1T3, C1R1T5, C1R1T6-c1pst1.

CONFIGURATION NR. 2

ROBOT 2

1. C2R2T1, C2R2T2-dpt1, C2R2T3, C2R2T4;
2. C2R2T1, C2R2T2-dpt2, C2R2T3, C2R2T4;
3. C2R2T1, C2R2T2-dpt3, C2R2T3, C2R2T4;
4. C2R2T1, C2R2T2-dpt4, C2R2T3, C2R2T4;
5. C2R2T1, C2R2T2-dpt5, C2R2T3, C2R2T4;
6. C2R2T1, C2R2T2-dpt6, C2R2T3, C2R2T4;
7. C2R2T1, C2R2T2-dpt7, C2R2T3, C2R2T4;
8. C2R2T1, C2R2T2-dpt8, C2R2T3, C2R2T4;
9. C2R2T1, C2R2T2-dpt9, C2R2T3, C2R2T4;
10. C2R2T1, C2R2T2-dpt10, C2R2T3, C2R2T4.

ROBOT 1

1. C2R1T1, C2R1T4-sc, C2R1T2-cc1, C2R1T3, C2R1T5, C2R1T6-c2pst1;
2. C2R1T1, C2R1T4-sc, C2R1T2-cc1, C2R1T2-cc2, C2R1T2-cc3, C2R1T2-cc4, C2R1T3, C2R1T4-oc, C2R1T5, C2R1T6-c2pst2;
3. C2R1T1, C2R1T4-sc, C2R1T2-cc1, C2R1T3, C2R1T5, C2R1T6-c2pst3;
4. C2R1T1, C2R1T4-sc, C2R1T2-cc1, C2R1T2-cc8, C2R1T2-cc7, C2R1T3, C2R1T5, C2R1T6-c2pst1;
5. C2R1T1, C2R1T4-sc, C2R1T2-cc1, C2R1T2-cc6, C2R1T3, C2R1T5, C2R1T6-c2pst2;
6. C2R1T1, C2R1T4-sc, C2R1T2-cc1, C2R1T3, C2R1T5, C2R1T6-c2pst3;
7. C2R1T1, C2R1T4-sc, C2R1T4-oc, C2R1T4-gc, C2R1T5, C2R1T6-c2pst1;
8. C2R1T1, C2R1T4-sc, C2R1T2-cc1, C2R1T2-cc2, C2R1T2-cc3, C2R1T2-cc4, C2R1T3, C2R1T4-oc, C2R1T5, C2R1T6-c2pst2;
9. C2R1T1, C2R1T4-sc, C2R1T2-cc1, C2R1T2-cc8, C2R1T2-cc7, C2R1T3,

C2R1T5, C2R1T6-c2pst3;

10. C2R1T1, C2R1T4-sc, C2R1T2-cc1, C2R1T2-cc5, C2R1T3, C2R1T5, C2R1T6-c2pst1.

CONFIGURATION NR. 3

ROBOT 2

1. C3R2T1, C3R2T2-dpt1, C3R2T3, C3R2T4;
2. C3R2T1, C3R2T2-dpt2, C3R2T3, C3R2T4;
3. C3R2T1, C3R2T2-dpt3, C3R2T3, C3R2T4;
4. C3R2T1, C3R2T2-dpt4, C3R2T3, C3R2T4;
5. C3R2T1, C3R2T2-dpt5, C3R2T3, C3R2T4;
6. C3R2T1, C3R2T2-dpt6, C3R2T3, C3R2T4;
7. C3R2T1, C3R2T2-dpt7, C3R2T3, C3R2T4;
8. C3R2T1, C3R2T2-dpt8, C3R2T3, C3R2T4;
9. C3R2T1, C3R2T2-dpt9, C3R2T3, C3R2T4;
10. C3R2T1, C3R2T2-dpt10, C3R2T3, C3R2T4.

ROBOT 1

1. C3R1T1, C3R1T4-sc, C3R1T2-cc1, C3R1T3, C3R1T5, C3R1T6-c3pst1;
2. C3R1T1, C3R1T4-sc, C3R1T2-cc1, C3R1T2-cc2, C3R1T2-cc3, C3R1T2-cc4, C3R1T3, C3R1T4-oc, C3R1T5, C3R1T6-c3pst2;
3. C3R1T1, C3R1T4-sc, C3R1T2-cc1, C3R1T3, C3R1T5, C3R1T6-c3pst3;
4. C3R1T1, C3R1T4-sc, C3R1T2-cc1, C3R1T2-cc8, C3R1T2-cc7, C3R1T3, C3R1T5, C3R1T6-c3pst1;
5. C3R1T1, C3R1T4-sc, C3R1T2-cc1, C3R1T2-cc6, C3R1T3, C3R1T5, C3R1T6-c3pst2;
6. C3R1T1, C3R1T4-sc, C3R1T2-cc1, C3R1T3, C3R1T5, C3R1T6-c3pst3;
7. C3R1T1, C3R1T4-sc, C3R1T4-oc, C3R1T4-gc, C3R1T5, C3R1T6-

c3pst1;

8. C3R1T1, C3R1T4-sc, C3R1T2-cc1, C3R1T2-cc2, C3R1T2-cc3, C3R1T2-cc4, C3R1T3, C3R1T4-oc, C3R1T5, C3R1T6-c3pst2;
9. C3R1T1, C3R1T4-sc, C3R1T2-cc1, C3R1T2-cc8, C3R1T2-cc7, C3R1T3, C3R1T5, C3R1T6-c3pst3;
10. C3R1T1, C3R1T4-sc, C3R1T2-cc1, C3R1T2-cc5, C3R1T3, C3R1T5, C3R1T6-c3pst1.

ROBOT 3 (excluded from the simulation)

- C3R3T1-c3pst1ov; C3R3T2-ovcp1;
- C3R3T1-c3pst2ov; C3R3T2-ovcp2
- C3R3T1-c3pst3ov; C3R3T2-ovcp3;
- C3R3T1-c3pst1ov; C3R3T2-ovcp1;
- C3R3T1-c3pst2ov; C3R3T2-ovcp2
- C3R3T1-c3pst3ov; C3R3T2-ovcp3;
- C3R3T1-c3pst1ov; C3R3T2-ovcp1;
- C3R3T1-c3pst2ov; C3R3T2-ovcp2
- C3R3T1-c3pst3ov; C3R3T2-ovcp3;
- C3R3T1-c3pst1ov; C3R3T2-ovcp1.

6.3 SIMULATION LOGIC

The simulation analysis is performed using **SIMULINK**.

The time performance evaluation starts from the workstation fully equipped with tools, the containers filled with condiments cut in small pieces, the origan, salt, garlic, flour and olive oil containers full, the pizza dough partitions ready on the trays with flour below and above. Each robot at rest and for Configuration nr. 3

the shovel tight in the gripper of Robot 3.

As anticipated in the previous Sections, the two robots operate in parallel with few exceptions. Robot 3 has been not included in the performance study comparison analysis. The Robot 3 logic, as well as the kitchen assistant logic, is described but not included in the **SIMULINK** structure.

The logic of the actions sequence considers the fact that Robot 1 can operate only if a rolled-out pizza is at location **L1**, similarly Robot 2 can transfer the rolled-out pizza to location **L1** only when this location is free. In addition, during the transfer of the rolled-out pizza and during the liberation of location **L1**, i.e. prepared pizza transfer on the pizza storage table, the robot not busy in these tasks must be at rest, including Robot 3 but only if the busy robot is Robot **L1**.

As a consequence Robot 1 starts from the rest position and goes back to the rest position after completing the pizza preparation tasks till the storage of the prepared pizza on the rear table with no interruptions, but could remain in standby after the last pizza preparation task to wait for Robot 2 to go at rest after having sent a proper request for pizza transfer on the storage table. When at rest, after completing the pizza transfer at storage table, Robot 1 informs Robot 2 that another rolled out pizza dough partition is expected at location **L1**.

On the contrary Robot 2 starts its tasks from the rest position but may be interrupted upon the request of pizza transfer on the storage table from Robot 1. In this case Robot 2 completes the task in course and will put itself at rest. The sequence of its tasks is completed after receiving the restart message from Robot 1.

Considering also the information that Robot 1 must send to the kitchen assistant or Robot 3 for Configuration nr. 3, i.e. pizza ready for cooking at the specified location, the control logic is based on Questions & Answers and is summarized as follows.

Robot 2:

- before each task, check if there is a request to go at rest from R1; if yes go at rest, if not continue with next task;
- terminating the roll out sequence, check if the rolled pizza transfer has been authorized by R1; if yes transfer the pizza, if not wait for authorization.

Robot 1:

- from rest position, after confirmation from R2 of pizza presence at location **L1**, complete the own cycle of pizza preparation tasks and wait for R2 and R3 transfer authorizations at last reached position;
- after transfer completion inform R2 and kitchen assistant, or R3, and stay at rest waiting for next pizza on location **L1**.

Robot 3 (not implemented):

- from rest position, after confirmation from R1 of pizza presence at location **psti** complete the pizza put in the oven task and inform R1 for location **psti** free;
- before the pizza delivery task, check if there is a request to go at rest from R1; if yes and there is time greater than 25 sec to the pizza exit from the oven task, allow R1 for transfer and remain at rest till R1 pizza transfer task is completed; if there is no request from R1 or if its request arrives when there are less than 25 sec to the pizza exit from the oven task,

complete the pizza delivery task and inform the kitchen assistant for pizza ready at desk, then go to rest and allow R1 pizza transfer. Note that the calculated (by simulation) overall time required by R1 from request sent to prepared pizza transferred on the pizza storage table is 24,875 sec (the task alone lasts 3 sec less).

Kitchen assistant (not implemented):

- after confirmation from R1 of pizza presence at location **psti** pick up the pizza for cooking and inform R1 for location **psti** free;
- after confirmation from R3 of pizza presence at location **cpi** pick up the pizza for customer delivery and inform R3 for location **cpi** free.

6.4 SIMULINK ARCHITECTURE

The **SIMULINK** time performance analysis is structured as described in the following and replicated per each robot configuration. A schematic block diagram is showed in **Figure 6.4-1**.

At top level there is a chart named ***SIM_Configuration_i.slx*** *(i = 1, 2, 3*) representing the overview of the "**Mission**" execution process by the given robot configuration. Here there are collected the time variation values during the execution of the "**Mission**" of any parameter of interest, like Robot status, pizza taste in execution, task in execution, etc..

A representation of this chart is given in **Figure 6.4-2**.

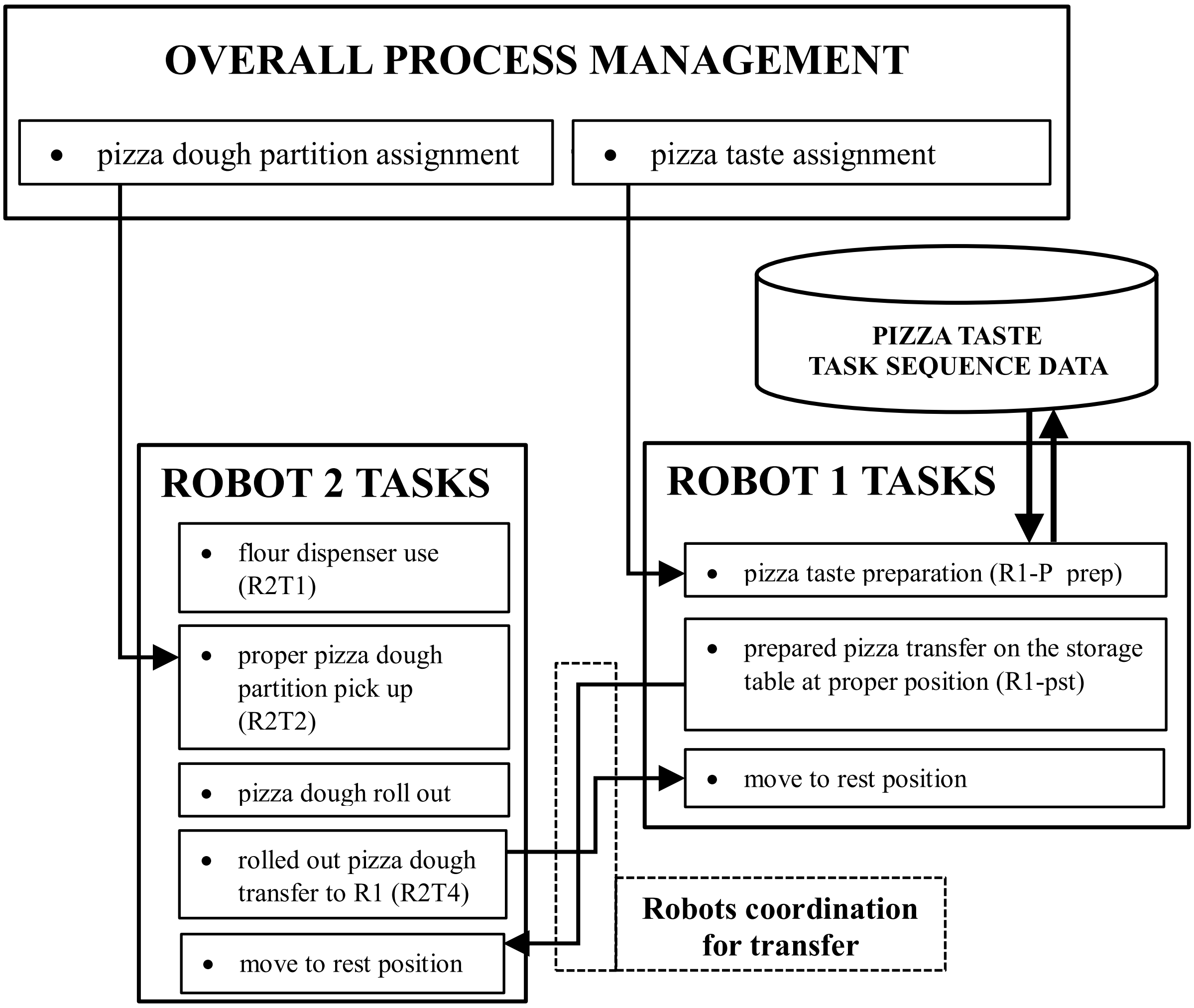


Figure 6.4-1 – **SIMULINK** model structure – Schematic block diagram.

At level one there is a chart named ***SIM_Core_Configuration_i*** *(i = 1, 2, 3)* representing the overall management of the "**Mission**" execution process by the given robot configuration. Here each Robot is managed in the execution of the "**Mission**" through dedicated libraries of high-level tasks and simple tasks.

A representation of the Core chart is given in **Figure 6.4-3**.

The high-level tasks are those requiring specific logic checks or inputs before and/or after their execution; simple tasks are those requiring execution only.

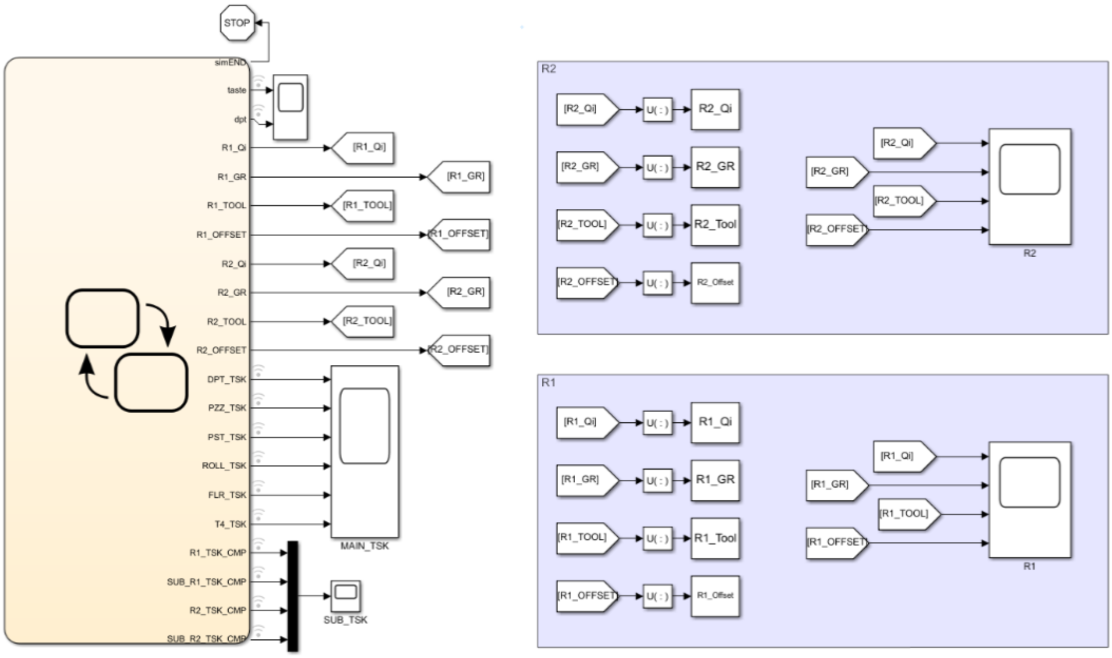


Figure 6.4-2 - Top level chart *SIM_Configuration_i*.

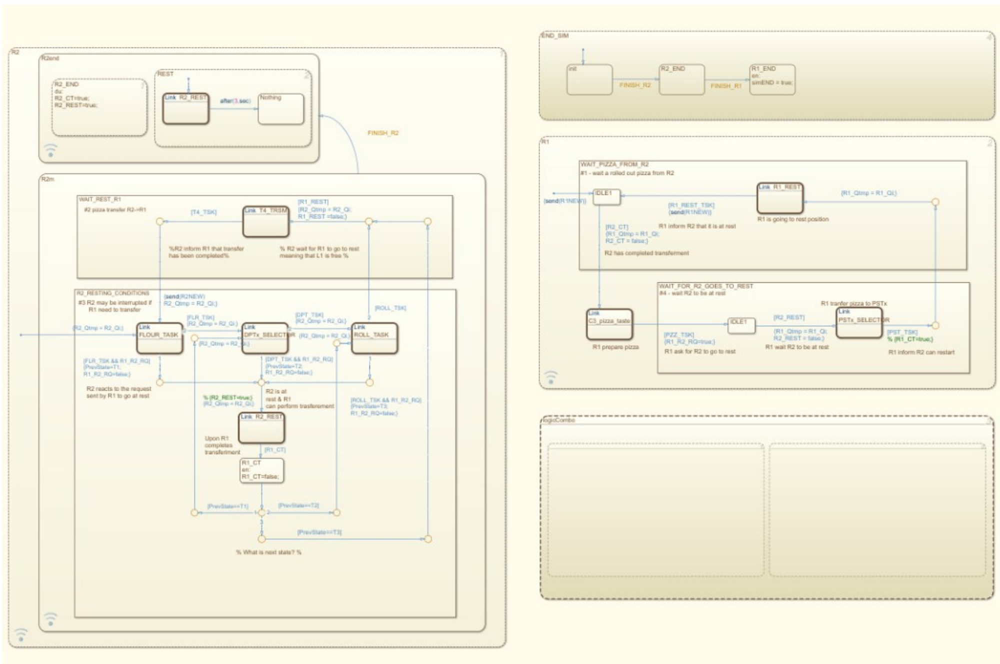


Figure 6.4-3 - Level 1 chart *SIM_Core_Configuration_i*.

The high-level tasks, contained in ***Ci_utilityBlocks.slx*** *(i = 1, 2, 3)* file, are the followings, see also **Figure 6.4-4**:

1. Pizza taste definition: chart name ***Pizza_taste***
2. Selection of position where a prepared pizza must be allocated: chart name ***Select_pstx***
3. Selection of which pizza dough partition tray must be used: chart name ***Select_dptx***
4. Execution start required: chart name ***Roll_task***
5. Execution start required: chart name ***Flour_task***
6. Execution start required: chart name ***Transfer_task***
7. Execution start required: chart name ***R2_at_rest_task***
8. Execution start required: chart name ***R1_at_rest_task***

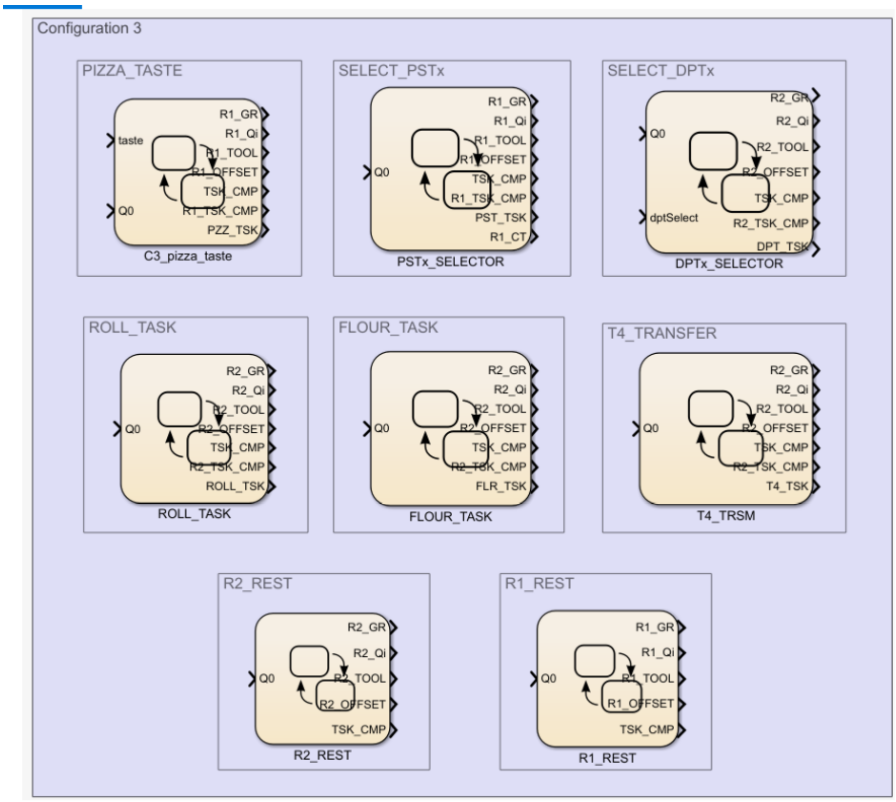


Figure 6.4-4 – High-level tasks (utility chart) for Configuration nr. 3.

The low-level tasks are those that can be performed in sequence with no interruption once the mission pizza taste has been demanded. Each low-level chart includes the transition action from the final step of the preceding task and the task to be executed.

The low-level tasks for each pizza taste are managed by the Chart ***Ci_pizza_taste*** *(i = 1, 2, 3*), see **Figure 6.4-5**.

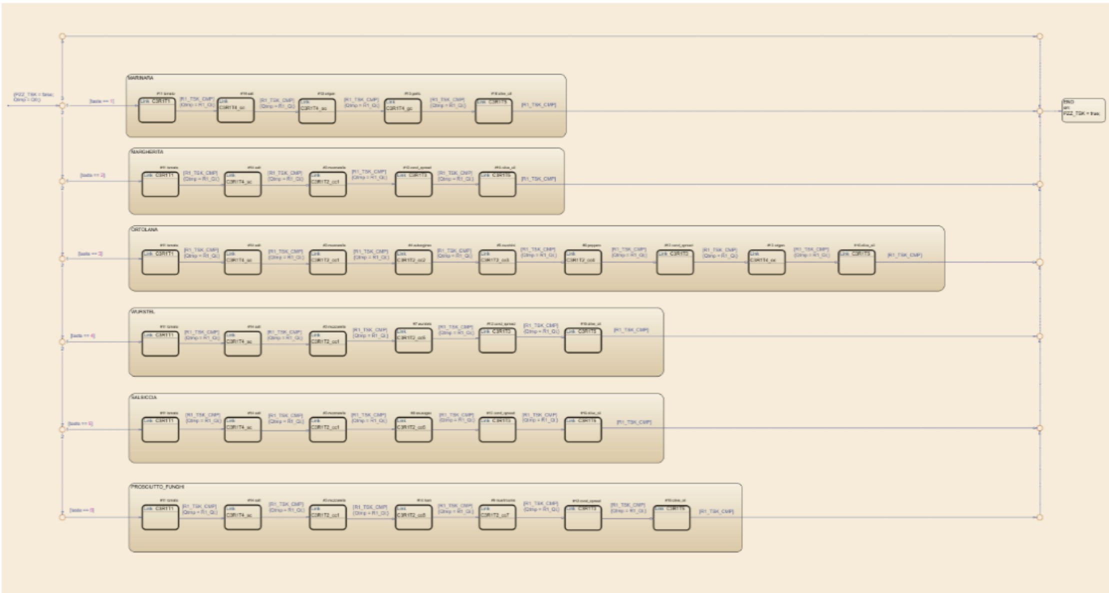


Figure 6.4-5 – Low-level tasks management chart *Ci-pizza_taste*. In sequence from the upper side Marinara, Margherita, Ortolana, Wurstel, Salsiccia, Prosciutto e Funghi.

7 SIMULATION RESULTS AND DISCUSSION

The simulation analysis includes two scenarios:

1. **scenario 1** to compare the times spent by each configuration to prepare each single pizza taste of the six possible defined tastes;

2. **scenario 2** to compare the total times spent by each configuration to complete the then pizzas of the defined mission.

Most relevant results are herein reported by post processing using **EXCEL** the **SIMULINK** outputs. The more detailed **SIMULINK** outputs are collected in **Appendix D**.

7.1 SCENARIO 1

This scenario helps to understand the task time execution differences among the robot configurations.

The set of plots in figures from **Figure 7.1-1** to **Figure 7.1-12** shows the progressive times spent by each robot configuration to accomplish each task and the single task duration times, noting that the different sub tasks needed to prepare each pizza taste by Robot 1 are grouped in one task.

The overall time, represented by the last bar of the progressive task times histograms, is always lower for the Configuration nr. 3 and this is justified by the lower speed of the cart in comparison with the manipulator one (cart speed

0,9 m/s, manipulator speed 1 m/s).

When the cart is used, see tasks R2T3, R2T4 and R1-P_prep, the task time is always higher. The time increment is small for tasks R2T3 and R2T4, which use the cart only one time, but is higher for task R1-P_prep as function of the number of tasks using the cart included in the pizza taste preparation, i.e. 4 times for the marinara taste and 2 times for the other pizza taste (see **Figure 7.1-2** as an example).. A special case is the pizza Ortolana taste, which includes two tasks using the cart but requires more ingredients and, therefore, more tasks in total (see **Table 7.1-1** third raw).

In summary Configuration nr. 3 gains the number of seconds reported in **Table 7.1-1** versus the other two robot configurations. The table includes also the Configuration nr. 2 gain of seconds versus the Configuration nr. 1.

The **SIMULINK** output data used in this Section are collected in an **EXCEL** file named ***Single pizza production times.xlsx***.

Pizza taste	Time gain [sec]			Pizza taste preparation details
	C3 vs C1	C3 vs C2	C2 vs C1	
Marinara	24,888	4,673	20,215	Cart used 4 times – 6 tasks
Margherita	15,237	4,654	10,583	Cart used 2 times – 6 tasks
Ortolana	20,040	4,935	15,105	Cart used 2 times – 10 tasks
Wurstel	15,237	4,727	10,510	Cart used 2 times – 7 tasks
Salsiccia	15,237	4,731	10,506	Cart used 2 times – 7 tasks
Prosciutto & Funghi	15,237	4,828	10,409	Cart used 2 times – 8 tasks

Table 7.1-1 - Delta times among the configurations for each single pizza taste.

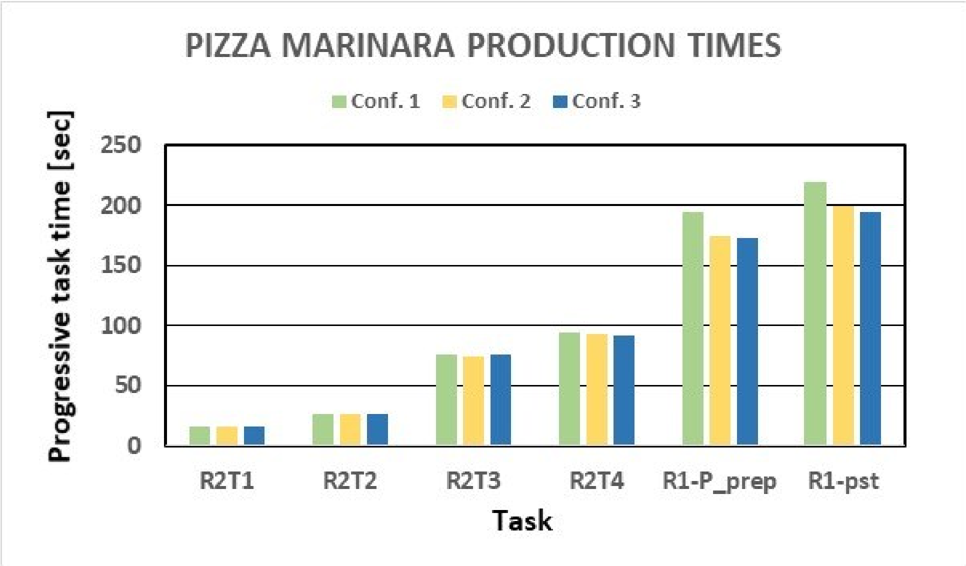


Figure 7.1-1 – Pizza Marinara progressive production task times.

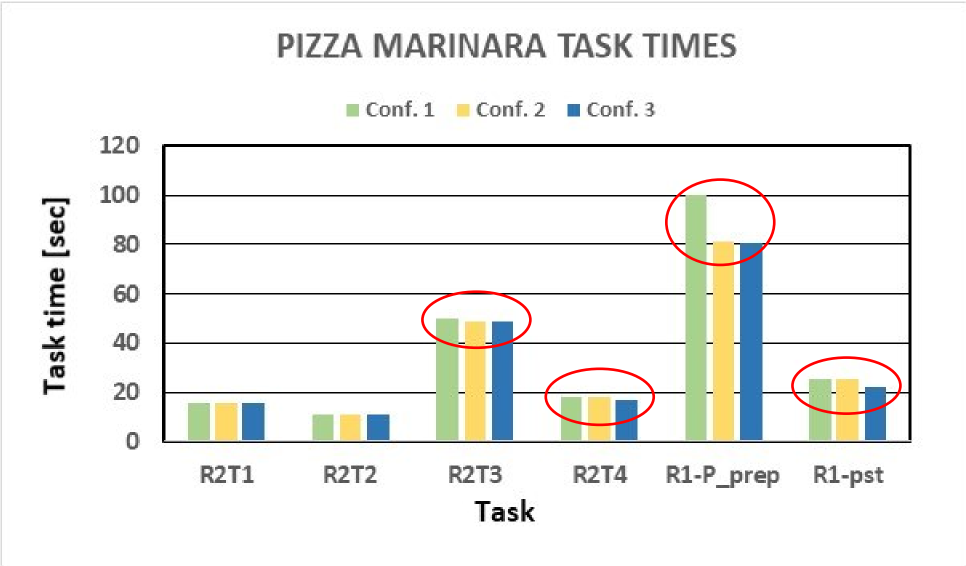


Figure 7.1-2 – Pizza Marinara production task times.

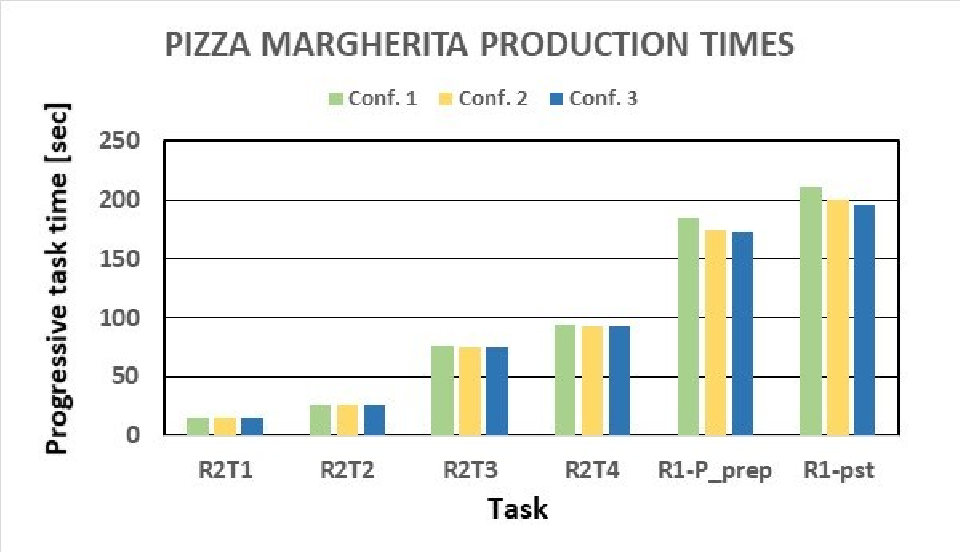


Figure 7.1-3 – Pizza Margherita progressive production task times.

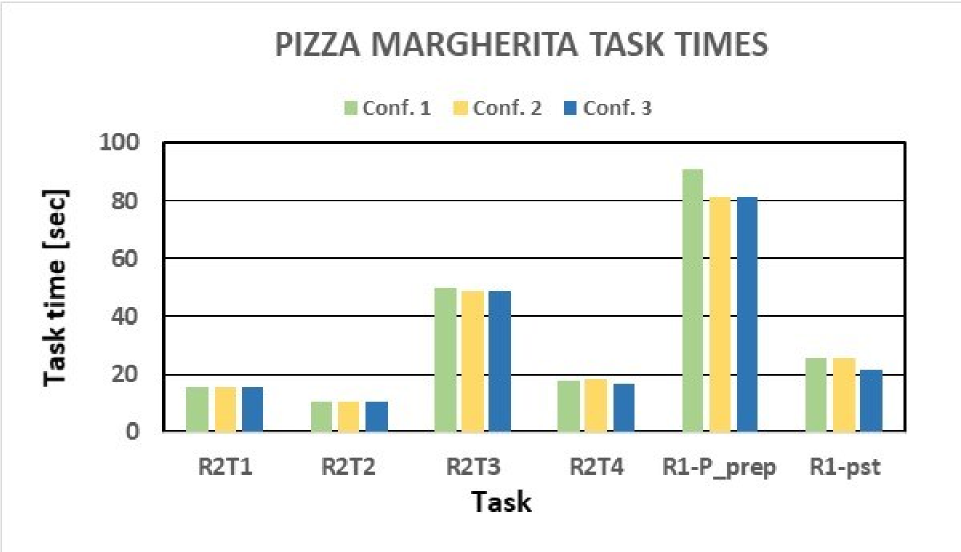


Figure 7.1-4 - Pizza Margherita production task times.

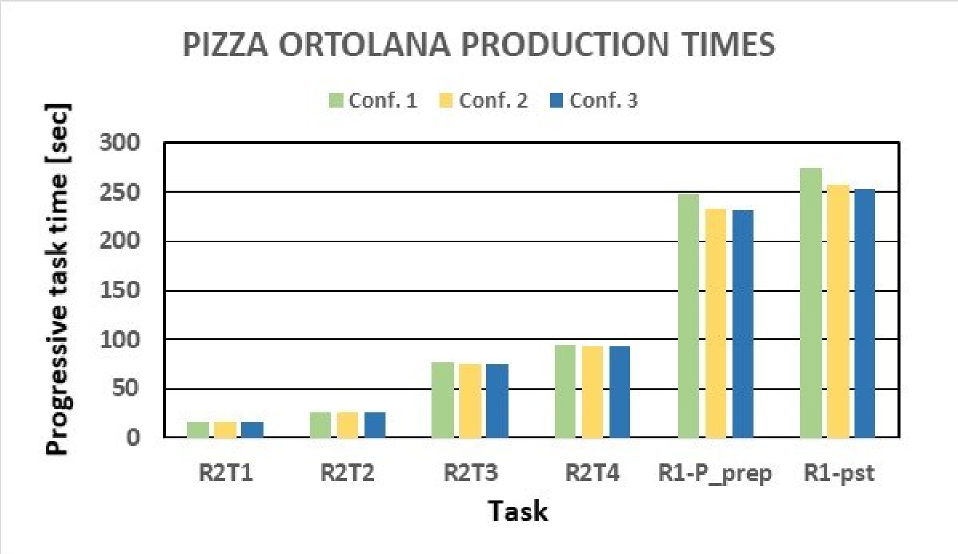


Figure 7.1-5 – Pizza Ortolana progressive production task times.

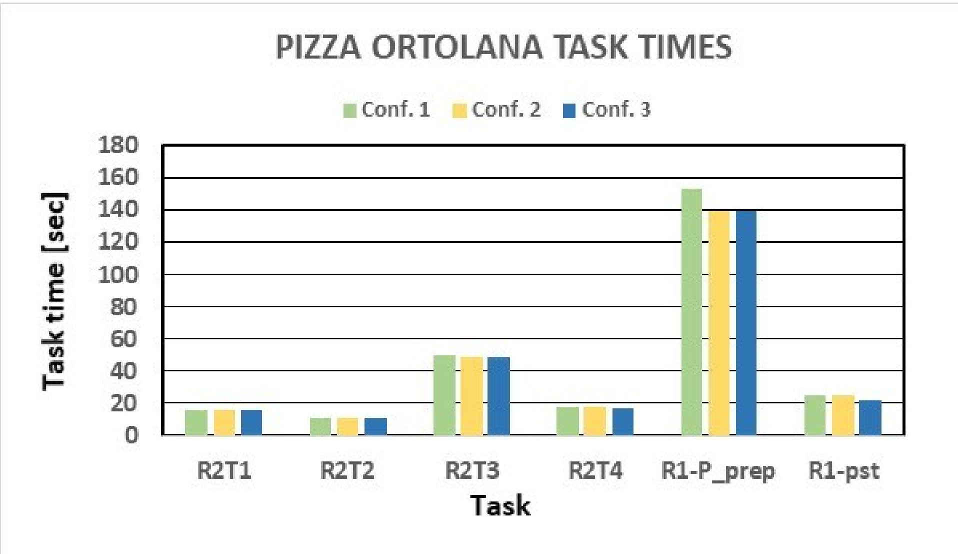


Figure 7.1-6 - Pizza Ortolana production task times.

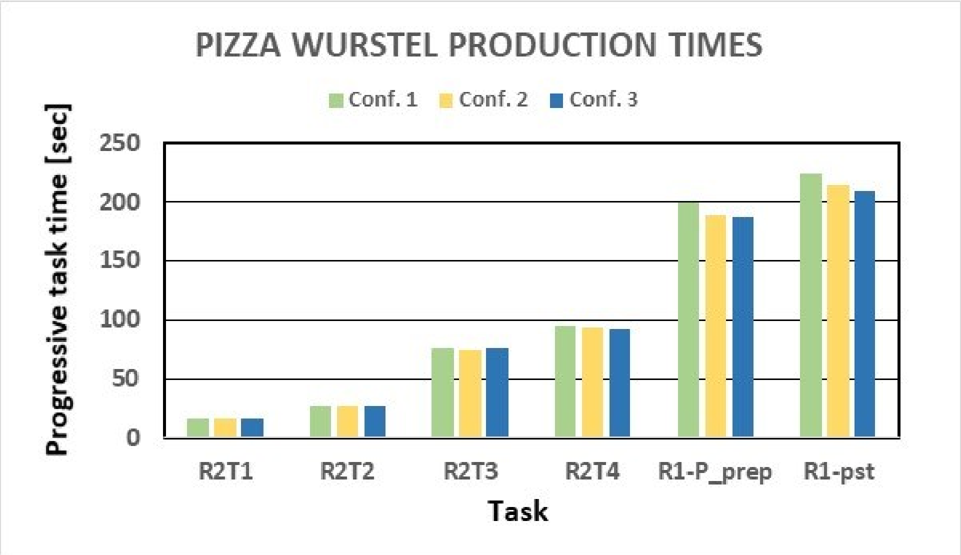


Figure 7.1-7 – Pizza Wurstel progressive production task times.

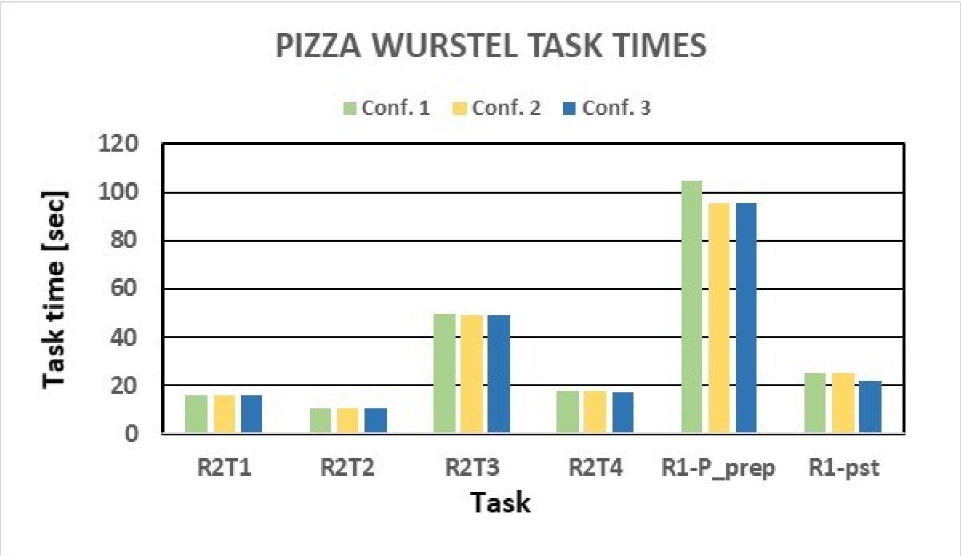


Figure 7.1-8 - Pizza Wurstel production task times.

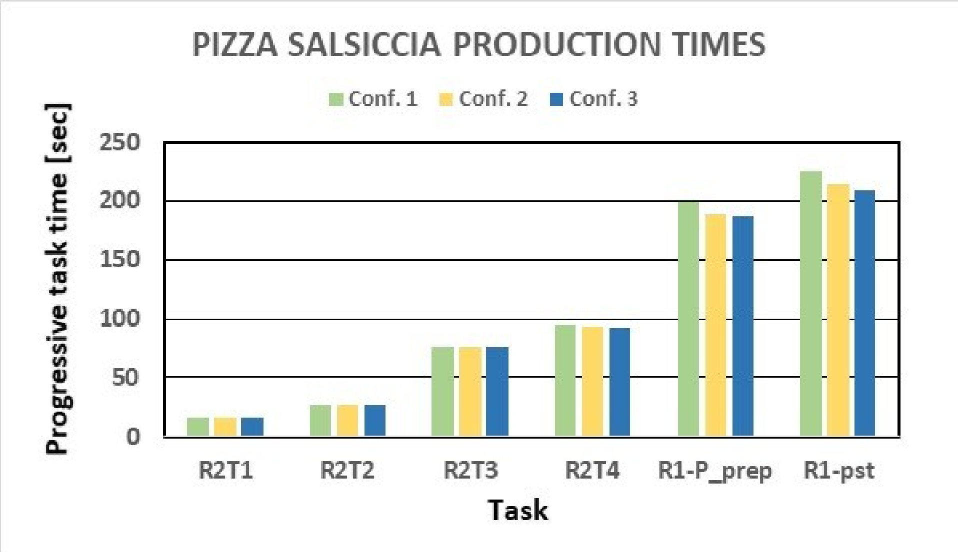


Figure 7.1-9 – Pizza Salsiccia progressive production task times.

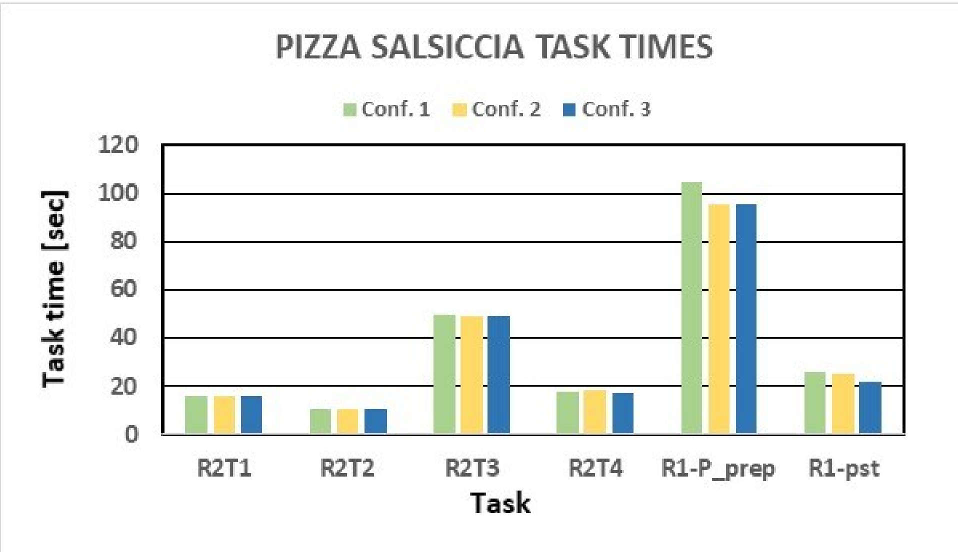


Figure 7.1-10 - Pizza Salsiccia production task times.

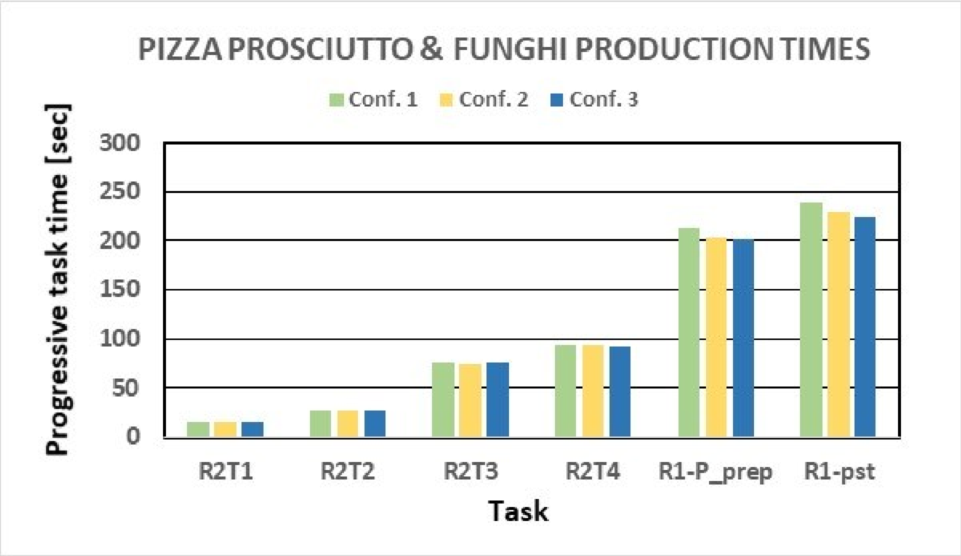


Figure 7.1-11 – Pizza Prosciutto & Funghi progressive production task times.

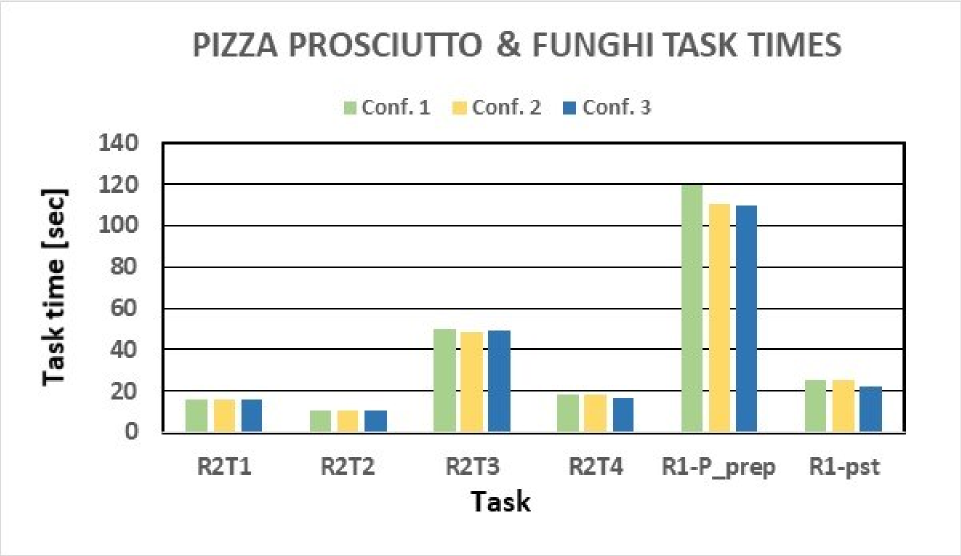


Figure 7.1-12 - Pizza Prosciutto & Funghi production task times.

7.2 SCENARIO 2

In this scenario the full mission production times are simulated and compared among the three robot configurations.

This scenario allows also to evaluate the influence of each robot operating activity on the other robot tasks and the effectiveness of the configuration in terms of operating and not operating times.

The **SIMULINK** output data used in this Section are collected in an **EXCEL** file named ***Mission performance times.xlsx***.

7.2.1 MISSION PERFORMANCE TIMES

The plot in **Figure 7.2.1-1** shows the progressive pizza taste execution time inside the mission for each robot configuration, whilst the details of task progressive times are reported in **Table 7.2.1-1**. Here the different sub tasks needed to prepare each pizza taste by Robot 1 are grouped in one task (R1-Pi_Prep, i = {1,   , 10}).

The main outcoming is that the configuration using two fixed manipulator arms (Configuration nr. 3) is the most performant, which is a good result being this configuration the less expensive among the three.

The better performance of Configuration nr. 3 is evident not only on the final mission result, but also on the production times of any pizza taste, as showed in **Figure 7.2.1-2** and **Figure 7.2.1-3** and in **Table 7.2.1-2** and **Table 7.2.1-3**, which report each pizza production time inside the **Mission** both as progressive time and dedicated time.

As expected, the first pizza production requires more time than the time dedicated to the same pizza inside the mission, see Margherita pizza 1 time compared with Margherita pizza 2 and 3 times in **Figure 7.2.1-3** and **Table 7.2.1-3**. The reason for this is related to the fact that at starting of the mission production process Robot 1 is in standby to wait the first pizza on its location. After the completion of the first pizza the two robots work in parallel reducing the single pizza production time.

The total time required to prepare the defined set of ten pizzas is in a range of 24 – 26 min, being Configuration nr. 3 the most performant one and Configuration nr. 1 the less performant. These times are well competitive with a human pizzaiolo performance times.

In detail the Configuration nr. 3 gains about 150 sec on Configuration nr. 1 and about 37 sec on Configuration nr. 2. Similarly Configuration nr. 2 gains about 113 sec on Configuration nr. 1. This result is detailed in **Figure 7.2.1-4**.

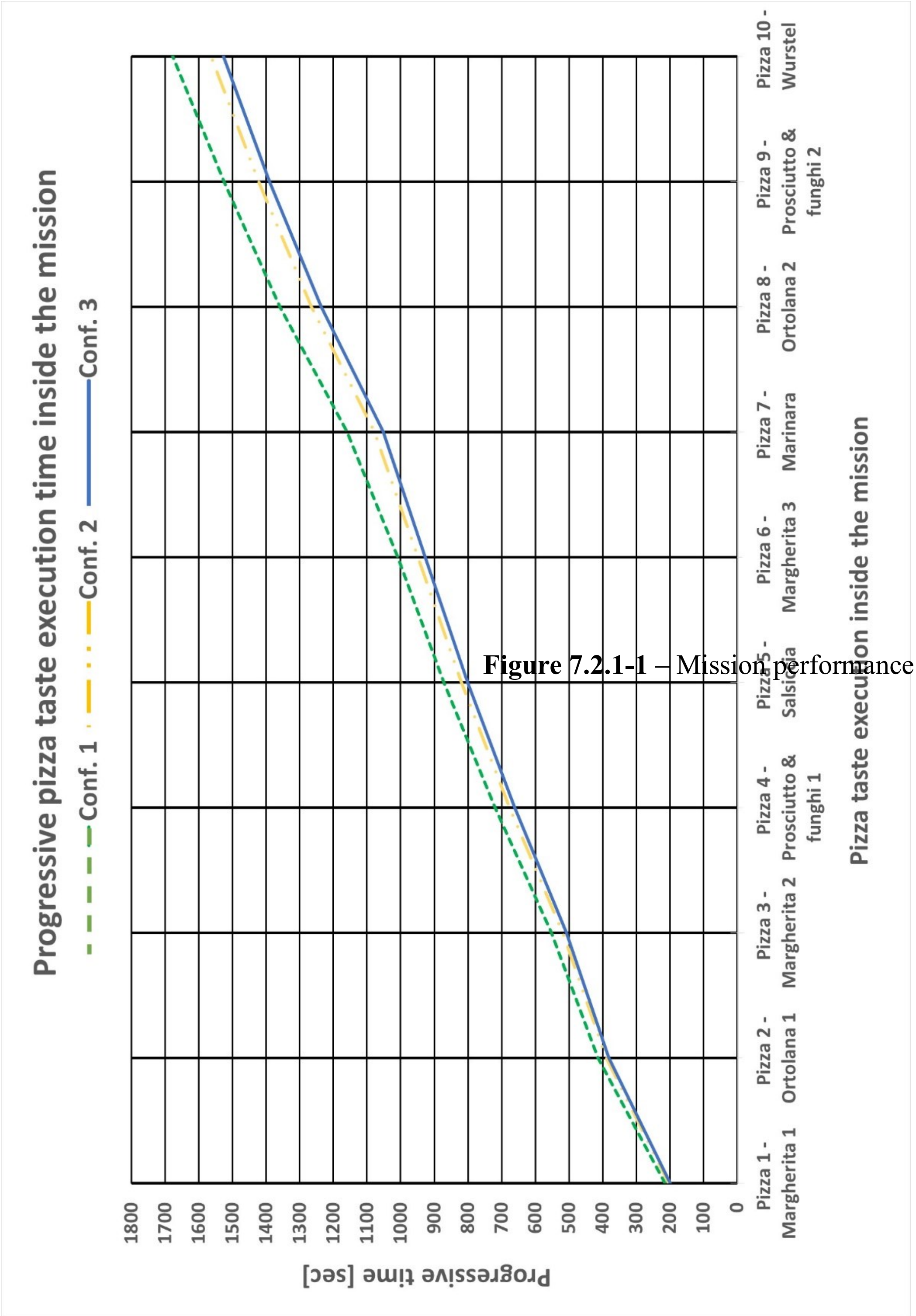


Figure 7.2.1-1 – Mission performance progressive time of ea

Robot 1 or 2 task	Grouped tasks	Progessive time [sec]		
		Conf. 1	Conf. 2	Conf. 3
		R1 + R2	R1 + R2	R1 + R2
R2_Start		0,000	0,000	0,000
R2T1		15,627	15,556	15,627
R2T2-dpt1		26,355	26,294	26,355
R2T3		76,244	75,024	75,294
R2T4 - R1_Start		94,256	93,144	92,211
R2T1		109,883	108,700	107,838
R2T2-dpt2		120,517	119,342	118,472
R1-P1_Prep	[T1+T4-sc+T2-cc1+T3+T5]	185,264	174,687	173,491
R2T3		185,265	174,688	173,492
R1T6-pst1		213,624	203,041	198,387
R2T4 - R1_Start		234,638	224,163	218,306
R2T1		250,265	239,719	233,933
R2T2-dpt3		260,854	250,322	244,522
R1-P2_Prep	[T1+T4-sc+T2-cc1+T2-cc2+T2-cc3+T2-cc4+T3+T4-oc+T5]	388,421	363,959	357,558
R2T3		388,422	363,960	357,559
R1T6-pst2		414,568	390,139	381,964
R2T4 - R1_Start		435,582	411,261	401,883
R2T1		451,209	426,817	417,510
R2T2-dpt4		461,801	437,422	428,102
R1-P3_Prep	[T1+T4-sc+T2-cc1+T3+T5]	526,590	492,804	483,163
R2T3		526,591	492,805	483,164
R1T6-pst3		551,842	518,158	507,763
R2T4 - R1_Start		572,856	539,280	527,682
R2T1		588,483	554,836	543,309
R2T2-dpt5		599,126	565,487	553,952
R1-P4_Prep	[T1+T4-sc+T2-cc1+T2-cc8+T2-cc7+T3+T5]	692,211	649,344	637,309
R2T3		692,212	649,345	637,310
R1T6-pst1		720,571	677,698	662,205
R2T4 - R1_Start		741,585	698,820	682,124
R2T1		757,212	714,376	697,751
R2T2-dpt6		767,639	724,839	708,178
R1-P5_Prep	[T1+T4-sc+T2-cc1+T2-cc6+T3+T5]	846,518	794,365	777,329
R2T3		846,519	794,366	777,330
R1T6-pst2		872,665	820,545	801,735
R2T4 - R1_Start		893,679	841,667	821,654
R2T1		909,306	857,223	837,281
R2T2-dpt7		919,643	867,598	847,618
R1-P6_Prep	[T1+T4-sc+T2-cc1+T3+T5]	984,687	923,210	902,934
R2T3		984,688	923,211	902,935
R1T6-pst3		1009,939	948,564	927,534
R2T4 - R1_Start		1030,953	969,686	947,453
R2T1		1046,580	985,242	963,080
R2T2-dpt8		1056,869	995,571	973,369
R1-P7_Prep	[T1+T4-sc+T4-oc+T4-gc+T2-cc1+T5]	1130,988	1050,624	1028,109
R2T3		1130,989	1050,625	1028,110
R1T6-pst1		1159,348	1078,978	1053,005
R2T4 - R1_Start		1180,362	1100,100	1072,924
R2T1		1195,989	1115,656	1088,551
R2T2-dpt9		1206,285	1125,990	1098,847
R1-P8_Prep	[T1+T4-sc+T2-cc1+T2-cc2+T2-cc3+T2-cc4+T3+T4-oc+T5]	1334,145	1239,896	1212,176
R2T3		1334,146	1239,897	1212,177
R1T6-pst2		1360,292	1266,076	1236,582
R2T4 - R1_Start		1381,306	1287,198	1256,501
R2T1		1396,933	1302,754	1272,128
R2T2-dpt10		1407,311	1313,179	1282,506
R1-P9_Prep	[T1+T4-sc+T2-cc1+T2-cc8+T2-cc7+T3+T5]	1500,661	1397,262	1366,128
R2T3		1500,662	1397,263	1366,129
R1T6-pst3		1525,913	1422,616	1390,728
R2T4 - R1_Start		1546,927	1443,738	1410,647
R1-P10_Prep	[T1+T4-sc+T2-cc1+T2-cc5+T3+T5]	1651,916	1539,335	1505,908
R1T6-pst1		1677,275	1564,688	1527,803
	C1 - C2	**C1 - C3**	**112,587**	**149,472**
	C2 - C3			**36,885**

Table 7.2.1-1 – Mission performance progressive time of each robot configuration.

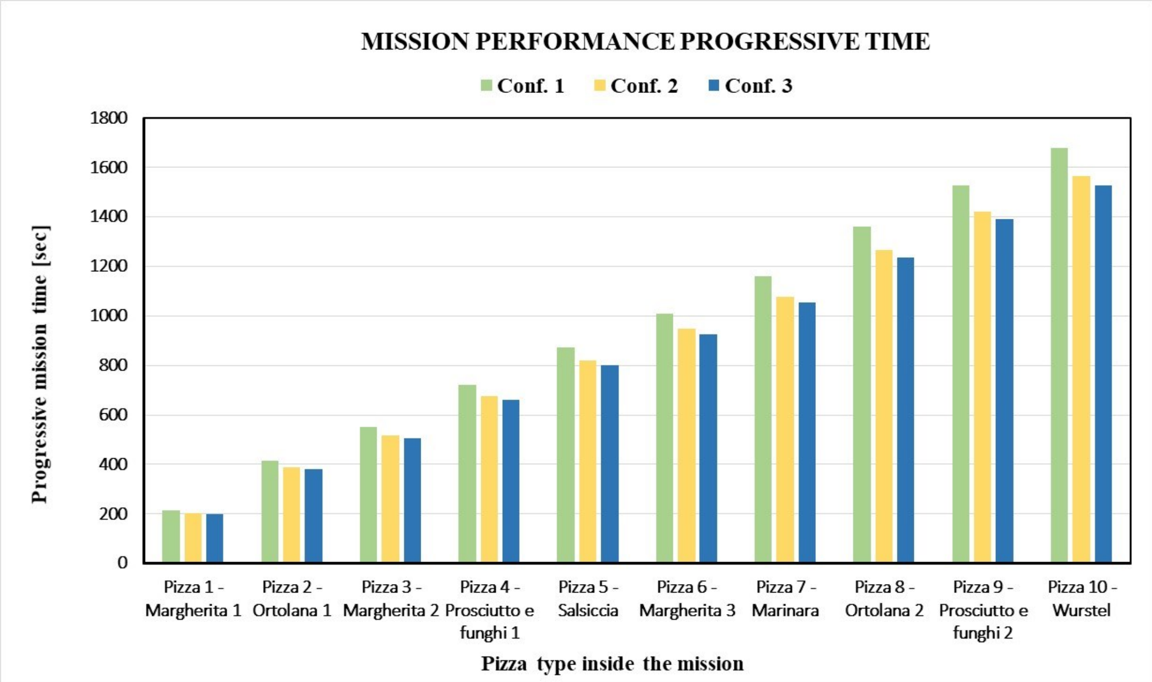


Figure 7.2.1-2 – Mission performance progressive time of each mission pizza taste.

Mission's pizza	Progessive mission time [sec]		
	Conf. 1	**Conf. 2**	**Conf. 3**
Pizza 1 - Margherita 1	213,624	203,041	198,387
Pizza 2 - Ortolana 1	414,568	390,139	381,964
Pizza 3 - Margherita 2	551,842	518,158	507,763
Pizza 4 - Prosciutto e funghi 1	720,571	677,698	662,205
Pizza 5 - Salsiccia	872,665	820,545	801,735
Pizza 6 - Margherita 3	1009,939	948,564	927,534
Pizza 7 - Marinara	1159,348	1078,978	1053,005
Pizza 8 - Ortolana 2	1360,292	1266,076	1236,582
Pizza 9 - Prosciutto e funghi 2	1525,913	1422,616	1390,728
Pizza 10 - Wurstel	1677,275	1564,688	1527,803

Table 7.2.1-2 – Mission performance progressive time of each mission pizza taste.

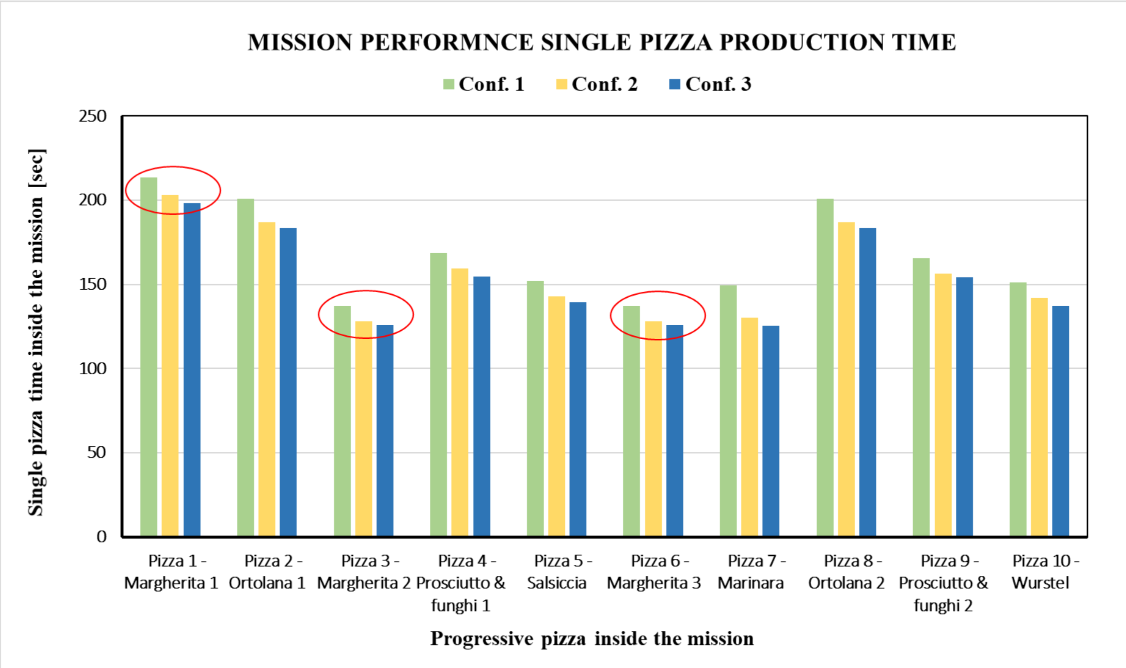


Figure 7.2.1-3 – Mission performance dedicated time to each mission pizza taste.

Mission's pizza	Single pizza time inside the mission [sec]		
	Conf. 1	Conf. 2	Conf. 3
Pizza 1 - Margherita 1	213,624	203,041	198,387
Pizza 2 - Ortolana 1	200,944	187,098	183,577
Pizza 3 - Margherita 2	137,274	128,019	125,799
Pizza 4 - Prosciutto e funghi 1	168,729	159,540	154,442
Pizza 5 - Salsiccia	152,094	142,847	139,530
Pizza 6 - Margherita 3	137,274	128,019	125,799
Pizza 7 - Marinara	149,409	130,414	125,471
Pizza 8 - Ortolana 2	200,944	187,098	183,577
Pizza 9 - Prosciutto e funghi 2	165,621	156,540	154,146
Pizza 10 - Wurstel	151,362	142,072	137,075

Table 7.2.1-3 – Mission performance dedicated time to each mission pizza taste.

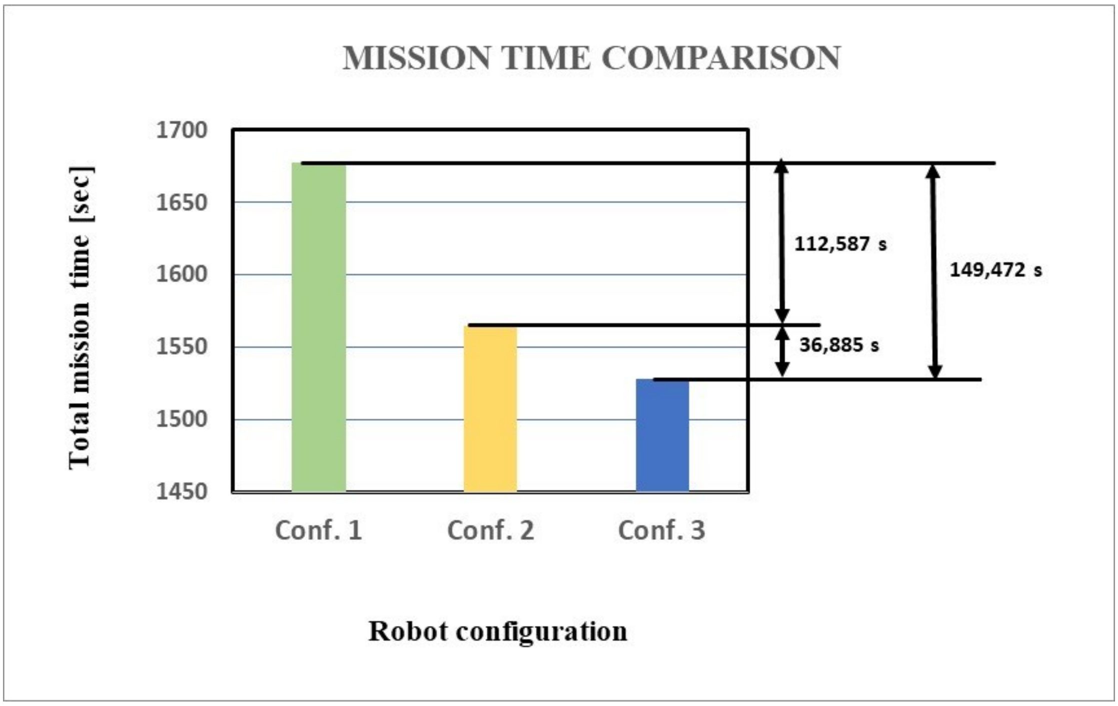


Figure 7.2.1-4 – Mission performance times comparison among the three robot configurations.

7.2.2 CONFIGURATION EFFECTIVENESS

The two robot operates with good coherence and synchronization of task times, in fact the waiting time periods are acceptably small for each robot configuration, as can be seen in figures from **Figure 7.2.2-1** to **Figure 7.2.2-6** and in tables from **Table 7.2.2-1** to **Table 7.2.2-3**.

The not productive times are acceptably small for all the three configurations; in detail they are less than 20% for Robot 2 (pizza roll out activities) and about 10% for Robot 1 (pizza preparation activities). This result is shown in **Figure 7.2.2-7** and **Figure 7.2.2-8.**

The task requiring more time is the pizza dough roll out task, which results to be of the same order of the pizza taste preparation time, not including the pizza transfer on the storage table. However, its impact on the total mission time is not relevant because the pizza roll out activity is always in the shadow of the pizza taste preparation activity, i.e. it terminates before the completion of the pizza preparation (see figures from **Figure 7.2.2-1** to **Figure 7.2.2-6** and tables from **Table 7.2.2-1** to **Table 7.2.2-3**).

From all the above considerations, no performance improvements can be obtained by the reduction of Robot 2 activity time, for example by substituting the pin roll use with a press for the spreading of the pizza dough partitions.

The total mission time can be instead reduced with a more performant manipulator arm for Configuration nr. 3 and more performant cart and manipulator for Configuration nr. 1 and 2.

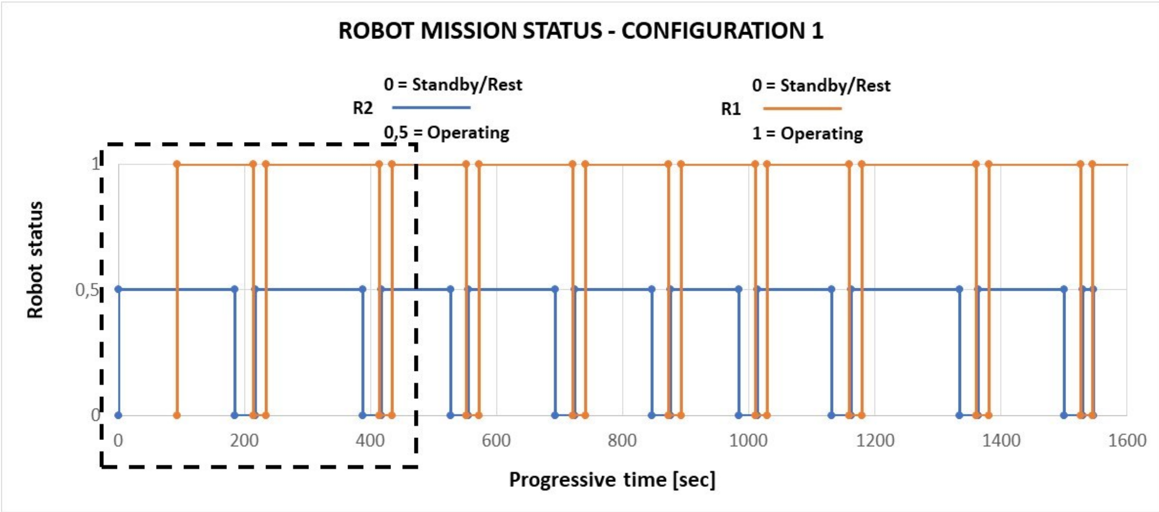


Figure 7.2.2-1 – Robots mission status for Configuration nr. 1.

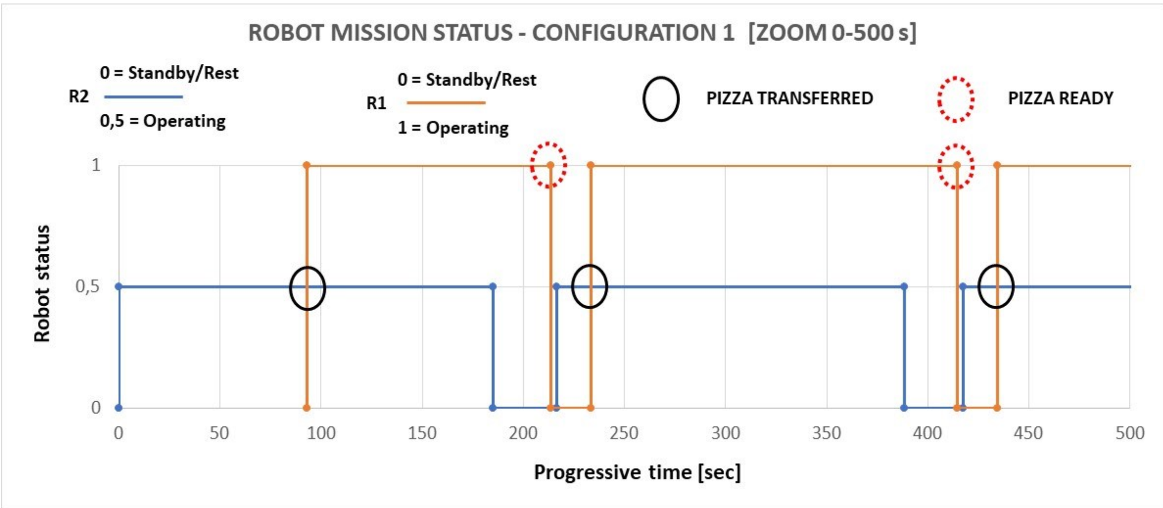


Figure 7.2.2-2 – Robots mission status for Configuration nr. 1 – Zoom on first 500 sec.

Configuration 1							
R2				R1			
Time [sec]	Task/Status	Detail	Pizza	Time [sec]	Task/Status	Detail	Pizza
0,000	None			0,000	None		
0,000	None			0,000	IDLE1		
0,000	FLOUR_TASK	Task start		93,213	C3_pizza_taste	Task start	
15,627	DPTx_SELECTOR	Task start	P1	185,264	IDLE1	Task end	P1
26,355	ROLL_TASK	Task start	P1	188,266	PSTx_SELECTOR	Task start	
76,244	T4_TRSM	Task start	P1	213,624	R1_REST	Task start - Transfer end	P1
94,256	FLOUR_TASK	Task start	P1	216,626	IDLE1		
109,883	DPTx_SELECTOR	Task start	P2	233,595	C3_pizza_taste	Task start	
120,517	ROLL_TASK	Task start	P2	388,421	IDLE1	Task end	P2
185,265	R2_REST	Task start	P2	391,423	PSTx_SELECTOR	Task start	
212,587	R1_CT			414,568	R1_REST	Task start - Transfer end	P2
216,626	T4_TRSM	Task start		417,570	IDLE1		
234,638	FLOUR_TASK	Task start	P2	434,539	C3_pizza_taste	Task start	
250,265	DPTx_SELECTOR	Task start	P3	526,590	IDLE1	Task end	P3
260,854	ROLL_TASK	Task start	P3	529,592	PSTx_SELECTOR	Task start	
388,422	R2_REST	Task start	P3	551,842	R1_REST	Task start - Transfer end	P3
413,531	R1_CT			554,844	IDLE1		
417,570	T4_TRSM	Task start		571,813	C3_pizza_taste	Task start	
435,582	FLOUR_TASK	Task start	P3	692,211	IDLE1	Task end	P4
451,209	DPTx_SELECTOR	Task start	P4	695,213	PSTx_SELECTOR	Task start	
461,801	ROLL_TASK	Task start	P4	720,571	R1_REST	Task start - Transfer end	P4
526,591	R2_REST	Task start	P4	723,573	IDLE1		
550,805	R1_CT			740,542	C3_pizza_taste	Task start	
554,844	T4_TRSM	Task start		846,518	IDLE1	Task end	P5
572,856	FLOUR_TASK	Task start	P4	849,520	PSTx_SELECTOR	Task start	
588,483	DPTx_SELECTOR	Task start	P5	872,665	R1_REST	Task start - Transfer end	P5
599,126	ROLL_TASK	Task start	P5	875,667	IDLE1		
692,212	R2_REST	Task start	P5	892,636	C3_pizza_taste	Task start	
719,534	R1_CT			984,687	IDLE1	Task end	P6
723,573	T4_TRSM	Task start		987,689	PSTx_SELECTOR	Task start	
741,585	FLOUR_TASK	Task start	P5	1009,939	R1_REST	Task start - Transfer end	P6
757,212	DPTx_SELECTOR	Task start	P6	1012,941	IDLE1		
767,639	ROLL_TASK	Task start	P6	1029,910	C3_pizza_taste	Task start	
846,519	R2_REST	Task start	P6	1130,988	IDLE1	Task end	P7
871,628	R1_CT			1133,990	PSTx_SELECTOR	Task start	
875,667	T4_TRSM	Task start		1159,348	R1_REST	Task start - Transfer end	P7
893,679	FLOUR_TASK	Task start	P6	1162,350	IDLE1		
909,306	DPTx_SELECTOR	Task start	P7	1179,319	C3_pizza_taste	Task start	
919,643	ROLL_TASK	Task start	P7	1334,145	IDLE1	Task end	P8
984,688	R2_REST	Task start	P7	1337,147	PSTx_SELECTOR	Task start	
1008,902	R1_CT			1360,292	R1_REST	Task start - Transfer end	P8
1012,941	T4_TRSM	Task start		1363,294	IDLE1		
1030,953	FLOUR_TASK	Task start	P7	1380,263	C3_pizza_taste	Task start	
1046,580	DPTx_SELECTOR	Task start	P8	1500,661	IDLE1	Task end	P9
1056,869	ROLL_TASK	Task start	P8	1503,663	PSTx_SELECTOR	Task start	
1130,989	R2_REST	Task start	P8	1525,913	R1_REST	Task start - Transfer end	P9
1158,311	R1_CT			1528,915	IDLE1		
1162,350	T4_TRSM	Task start		1545,884	C3_pizza_taste	Task start	
1180,362	FLOUR_TASK	Task start	P8	1651,916	IDLE1	Task end	P10
1195,989	DPTx_SELECTOR	Task start	P9	1651,917	PSTx_SELECTOR	Task start	
1206,285	ROLL_TASK	Task start	P9	1677,275	R1_REST	Task start - Transfer end	P10
1334,146	R2_REST	Task start	P9	1680,277	IDLE1		
1359,255	R1_CT			1680,277	C3_pizza_taste		
1363,294	T4_TRSM	Task start					
1381,306	FLOUR_TASK	Task start	P9				
1396,933	DPTx_SELECTOR	Task start	P10				
1407,311	ROLL_TASK	Task start	P10				
1500,662	R2_REST	Task start	P10				
1524,876	R1_CT						
1528,915	T4_TRSM	Task start					
1546,927	FLOUR_TASK		P10				
1546,927	R2end						

Table 7.2.2-1 – Robots mission status for Configuration nr. 1.

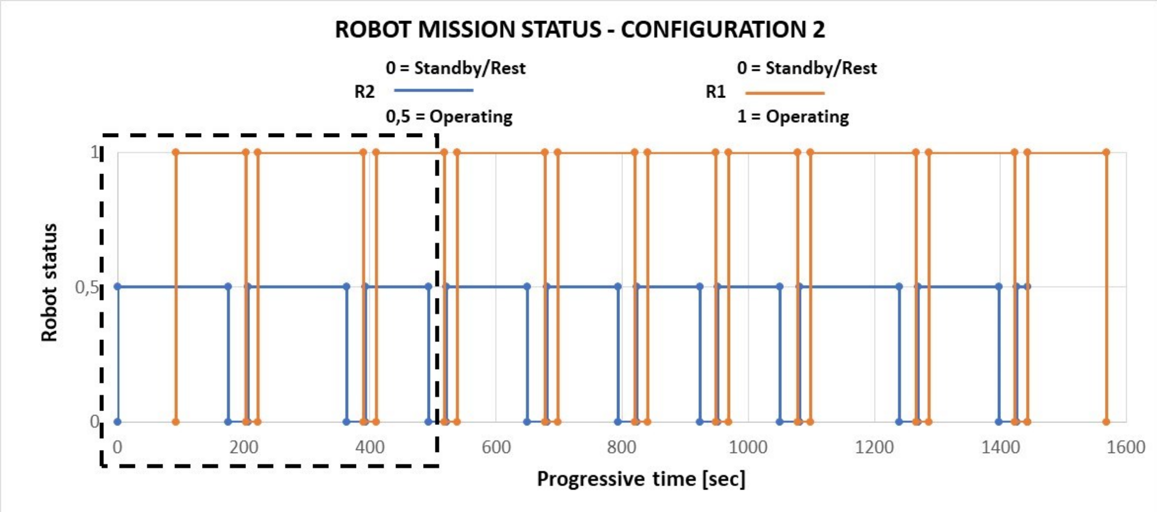


Figure 7.2.2-3 – Robots mission status for Configuration nr. 2.

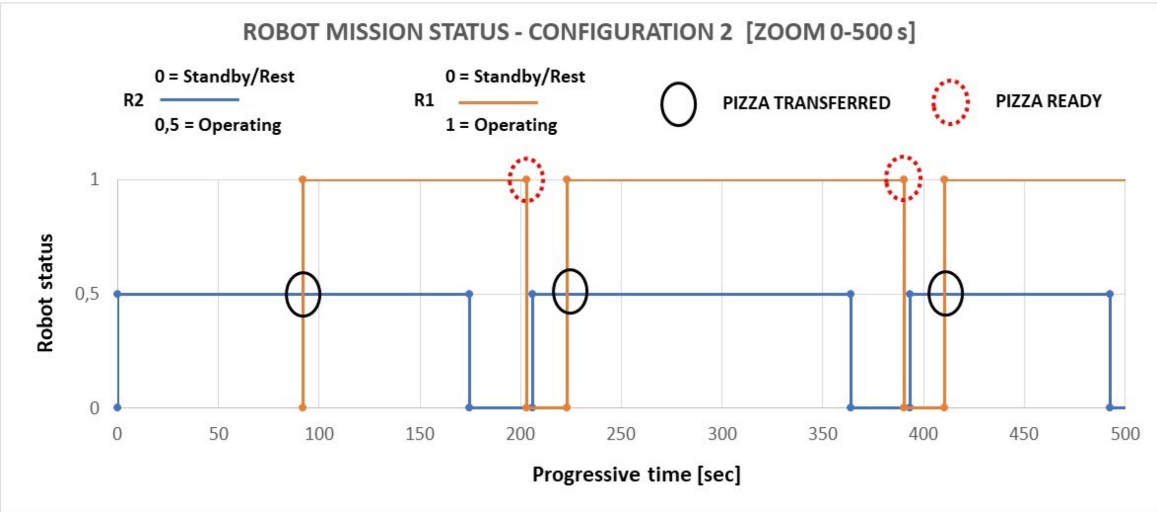


Figure 7.2.2-4 – Robots mission status for Configuration nr. 2 – Zoom on first 500 sec.

Configuration 2							
R2				R1			
Time [sec]	Task/Status	Detail	Pizza	Time [sec]	Task/Status	Detail	Pizza
0,000	None			0,000	None		
0,000	None			0,000	IDLE1		
0,000	FLOUR_TASK	Task start		92,089	C3_pizza_taste	Task start	
15,556	DPTx_SELECTOR	Task start	P1	174,687	IDLE1	Task end	P1
26,294	ROLL_TASK	Task start	P1	177,689	PSTx_SELECTOR	Task start	
75,024	T4_TRSM	Task start	P1	203,041	R1_REST	Task start - Transfer end	P1
93,144	FLOUR_TASK	Task start	P1	206,043	IDLE1		
108,700	DPTx_SELECTOR	Task start	P2	223,108	C3_pizza_taste	Task start	
119,342	ROLL_TASK	Task start	P2	363,959	IDLE1	Task end	P2
174,688	R2_REST	Task start	P2	366,961	PSTx_SELECTOR	Task start	
201,997	R1_CT			390,139	R1_REST	Task start - Transfer end	P2
206,043	T4_TRSM	Task start		393,141	IDLE1		
224,163	FLOUR_TASK	Task start	P2	410,206	C3_pizza_taste	Task start	
239,719	DPTx_SELECTOR	Task start	P3	492,804	IDLE1	Task end	P3
250,322	ROLL_TASK	Task start	P3	495,806	PSTx_SELECTOR	Task start	
363,960	R2_REST	Task start	P3	518,158	R1_REST	Task start - Transfer end	P3
389,095	R1_CT			521,160	IDLE1		
393,141	T4_TRSM	Task start		538,225	C3_pizza_taste	Task start	
411,261	FLOUR_TASK	Task start	P3	649,344	IDLE1	Task end	P4
426,817	DPTx_SELECTOR	Task start	P4	652,346	PSTx_SELECTOR	Task start	
437,422	ROLL_TASK	Task start	P4	677,698	R1_REST	Task start - Transfer end	P4
492,805	R2_REST	Task start	P4	680,700	IDLE1		
517,114	R1_CT			697,765	C3_pizza_taste	Task start	
521,160	T4_TRSM	Task start		794,365	IDLE1	Task end	P5
539,280	FLOUR_TASK	Task start	P4	797,367	PSTx_SELECTOR	Task start	
554,836	DPTx_SELECTOR	Task start	P5	820,545	R1_REST	Task start - Transfer end	P5
565,487	ROLL_TASK	Task start	P5	823,547	IDLE1		
649,345	R2_REST	Task start	P5	840,612	C3_pizza_taste	Task start	
676,654	R1_CT			923,210	IDLE1	Task end	P6
680,700	T4_TRSM	Task start		926,212	PSTx_SELECTOR	Task start	
698,820	FLOUR_TASK	Task start	P5	948,564	R1_REST	Task start - Transfer end	P6
714,376	DPTx_SELECTOR	Task start	P6	951,566	IDLE1		
724,839	ROLL_TASK	Task start	P6	968,631	C3_pizza_taste	Task start	
794,366	R2_REST	Task start	P6	1050,624	IDLE1	Task end	P7
819,501	R1_CT			1053,626	PSTx_SELECTOR	Task start	
823,547	T4_TRSM	Task start		1078,978	R1_REST	Task start - Transfer end	P7
841,667	FLOUR_TASK	Task start	P6	1081,980	IDLE1		
857,223	DPTx_SELECTOR	Task start	P7	1099,045	C3_pizza_taste	Task start	
867,598	ROLL_TASK	Task start	P7	1239,896	IDLE1	Task end	P8
923,211	R2_REST	Task start	P7	1242,898	PSTx_SELECTOR	Task start	
947,520	R1_CT			1266,076	R1_REST	Task start - Transfer end	P8
951,566	T4_TRSM	Task start		1269,078	IDLE1		
969,686	FLOUR_TASK	Task start	P7	1286,143	C3_pizza_taste	Task start	
985,242	DPTx_SELECTOR	Task start	P8	1397,262	IDLE1	Task end	P9
995,571	ROLL_TASK	Task start	P8	1400,264	PSTx_SELECTOR	Task start	
1050,625	R2_REST	Task start	P8	1422,616	R1_REST	Task start - Transfer end	P9
1077,934	R1_CT			1425,618	IDLE1		
1081,980	T4_TRSM	Task start		1442,683	C3_pizza_taste	Task start	
1100,100	FLOUR_TASK	Task start	P8	1539,335	IDLE1	Task end	P10
1115,656	DPTx_SELECTOR	Task start	P9	1539,336	PSTx_SELECTOR	Task start	
1125,990	ROLL_TASK	Task start	P9	1564,688	R1_REST	Task start - Transfer end	P10
1239,897	R2_REST	Task start	P9	1567,690	IDLE1		
1265,032	R1_CT			1567,690	C3_pizza_taste		
1269,078	T4_TRSM	Task start					
1287,198	FLOUR_TASK	Task start	P9				
1302,754	DPTx_SELECTOR	Task start	P10				
1313,179	ROLL_TASK	Task start	P10				
1397,263	R2_REST	Task start	P10				
1421,572	R1_CT						
1425,618	T4_TRSM	Task start					
1443,738	FLOUR_TASK		P10				
1443,738	R2end						

Table 7.2.2-2 – Robots mission status for Configuration nr. 2.

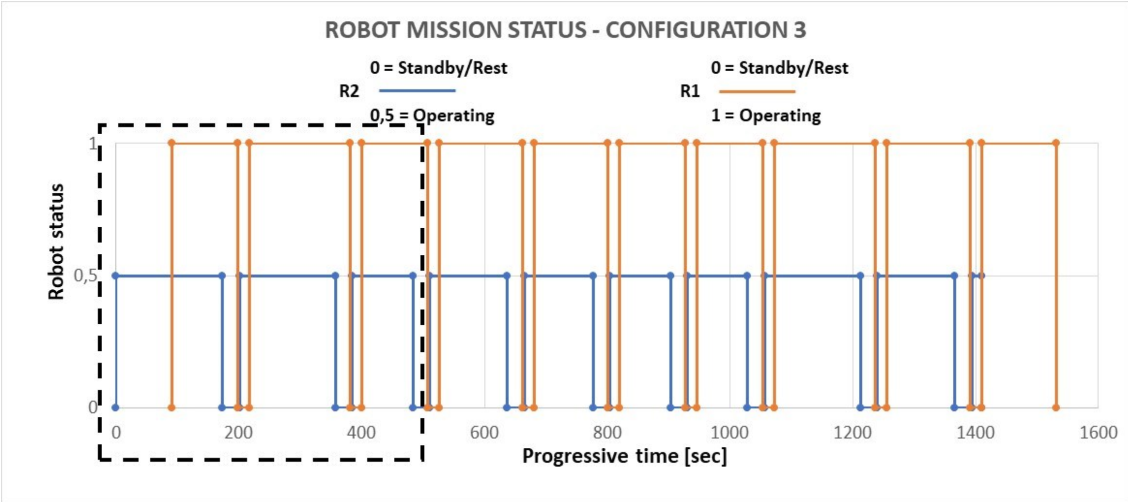


Figure 7.2.2-5 – Robots mission status for Configuration nr. 3.

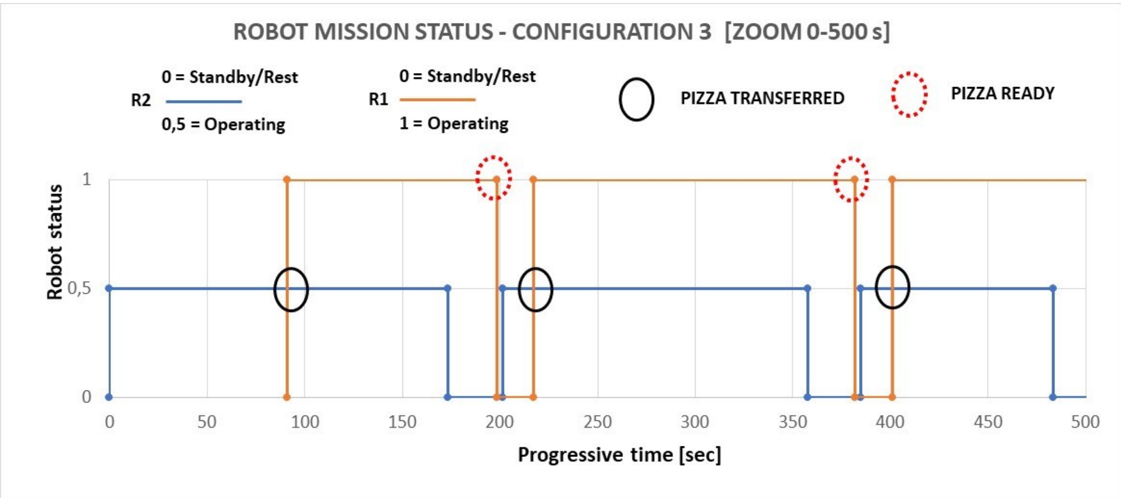


Figure 7.2.2-6 – Robots mission status for Configuration nr. 3 – Zoom on first 500 sec.

Configuration 3							
R2				R1			
Time [sec]	Task/Status	Detail	Pizza	Time [sec]	Task/Status	Detail	Pizza
0,000	None			0,000	None		
0,000	None			0,000	IDLE1		
0,000	FLOUR_TASK	Task start		91,168	C3_pizza_taste	Task start	
15,627	DPTx_SELECTOR	Task start	P1	173,491	IDLE1	Task end	P1
26,355	ROLL_TASK	Task start	P1	176,493	PSTx_SELECTOR	Task start	
75,294	T4_TRSM	Task start	P1	198,387	R1_REST	Task start - Transfer end	P1
92,211	FLOUR_TASK	Task start	P1	201,389	IDLE1		
107,838	DPTx_SELECTOR	Task start	P2	217,263	C3_pizza_taste	Task start	
118,472	ROLL_TASK	Task start	P2	357,558	IDLE1	Task end	P2
173,492	R2_REST	Task start	P2	360,560	PSTx_SELECTOR	Task start	
197,350	R1_CT			381,964	R1_REST	Task start - Transfer end	P2
201,389	T4_TRSM	Task start		384,966	IDLE1		
218,306	FLOUR_TASK	Task start	P2	400,840	C3_pizza_taste	Task start	
233,933	DPTx_SELECTOR	Task start	P3	483,163	IDLE1	Task end	P3
244,522	ROLL_TASK	Task start	P3	486,165	PSTx_SELECTOR	Task start	
357,559	R2_REST	Task start	P3	507,763	R1_REST	Task start - Transfer end	P3
380,927	R1_CT			510,765	IDLE1		
384,966	T4_TRSM	Task start		526,639	C3_pizza_taste	Task start	
401,883	FLOUR_TASK	Task start	P3	637,309	IDLE1	Task end	P4
417,510	DPTx_SELECTOR	Task start	P4	640,311	PSTx_SELECTOR	Task start	
428,102	ROLL_TASK	Task start	P4	662,205	R1_REST	Task start - Transfer end	P4
483,164	R2_REST	Task start	P4	665,207	IDLE1		
506,726	R1_CT			681,081	C3_pizza_taste	Task start	
510,765	T4_TRSM	Task start		777,329	IDLE1	Task end	P5
527,682	FLOUR_TASK	Task start	P4	780,331	PSTx_SELECTOR	Task start	
543,309	DPTx_SELECTOR	Task start	P5	801,735	R1_REST	Task start - Transfer end	P5
553,952	ROLL_TASK	Task start	P5	804,737	IDLE1		
637,310	R2_REST	Task start	P5	820,611	C3_pizza_taste	Task start	
661,168	R1_CT			902,934	IDLE1	Task end	P6
665,207	T4_TRSM	Task start		905,936	PSTx_SELECTOR	Task start	
682,124	FLOUR_TASK	Task start	P5	927,534	R1_REST	Task start - Transfer end	P6
697,751	DPTx_SELECTOR	Task start	P6	930,536	IDLE1		
708,178	ROLL_TASK	Task start	P6	946,410	C3_pizza_taste	Task start	
777,330	R2_REST	Task start	P6	1028,109	IDLE1	Task end	P7
800,698	R1_CT			1031,111	PSTx_SELECTOR	Task start	
804,737	T4_TRSM	Task start		1053,005	R1_REST	Task start - Transfer end	P7
821,654	FLOUR_TASK	Task start	P6	1056,007	IDLE1		
837,281	DPTx_SELECTOR	Task start	P7	1071,881	C3_pizza_taste	Task start	
847,618	ROLL_TASK	Task start	P7	1212,176	IDLE1	Task end	P8
902,935	R2_REST	Task start	P7	1215,178	PSTx_SELECTOR	Task start	
926,497	R1_CT			1236,582	R1_REST	Task start - Transfer end	P8
930,536	T4_TRSM	Task start		1239,584	IDLE1		
947,453	FLOUR_TASK	Task start	P7	1255,458	C3_pizza_taste	Task start	
963,080	DPTx_SELECTOR	Task start	P8	1366,128	IDLE1	Task end	P9
973,369	ROLL_TASK	Task start	P8	1369,130	PSTx_SELECTOR	Task start	
1028,110	R2_REST	Task start	P8	1390,728	R1_REST	Task start - Transfer end	P9
1051,968	R1_CT			1393,730	IDLE1		
1056,007	T4_TRSM	Task start		1409,604	C3_pizza_taste	Task start	
1072,924	FLOUR_TASK	Task start	P8	1505,908	IDLE1	Task end	P10
1088,551	DPTx_SELECTOR	Task start	P9	1505,909	PSTx_SELECTOR	Task start	
1098,847	ROLL_TASK	Task start	P9	1527,803	R1_REST	Task start - Transfer end	P10
1212,177	R2_REST	Task start	P9	1530,805	IDLE1		
1235,545	R1_CT			1530,805	C3_pizza_taste		
1239,584	T4_TRSM	Task start					
1256,501	FLOUR_TASK	Task start	P9				
1272,128	DPTx_SELECTOR	Task start	P10				
1282,506	ROLL_TASK	Task start	P10				
1366,129	R2_REST	Task start	P10				
1389,691	R1_CT						
1393,730	T4_TRSM	Task start					
1410,647	FLOUR_TASK		P10				
1410,647	R2end						

Table 7.2.2-3 – Robots mission status for Configuration nr. 3.

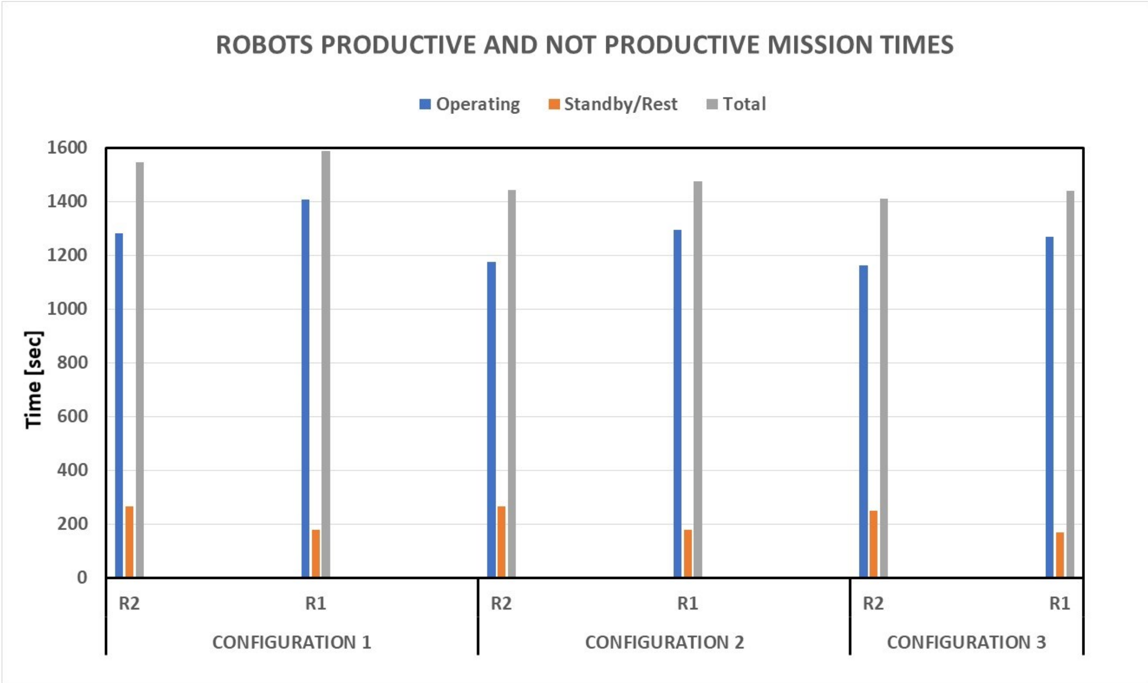


Figure 7.2.2-7 – Robots productive and not productive mission times for each configuration.

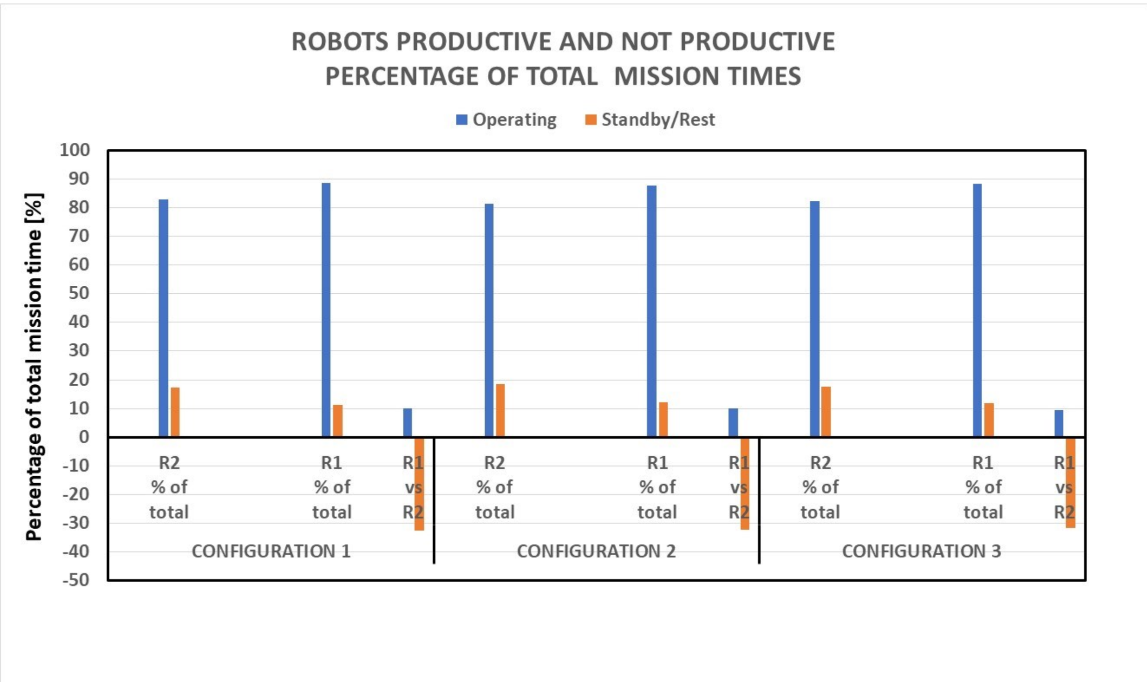


Figure 7.2.2-8 – Robots productive and not productive percentage of mission times for each configuration.

7.2.3 CONFIGURATION ADVANTAGES AND DISADVANTAGES

The contents of **Table 7.2.3-1** report the main advantages and disadvantages of each robot configuration.

From this table it is possible to derive an optimized solution that can completely substitute a human pizzaiolo in the pizza preparation process.

In fact, the roll out process can be optimized using a fixed manipulator, taking advantage of its better performance and low costs. Similarly, the pizza preparation process can be demanded to a mobile manipulator in order to take advantage of its mobility to pick up a variety of condiment containers, by extending the workstation, in order to produce a big list of pizza taste.

Robot configuration	Advantages	Disadvantages
Nr. 1	1. Cart mobility gives the possibility to extend the workstation longitudinal dimension in order to allocate more condiment containers to increase the number of pizza taste preparation	1. High costs 2. Cart speed lower than manipulator end effector speed
Nr. 2	1. Reduced costs if compared with Config. nr. 1	1. Cart speed lower than manipulator end effector speed 2. Cart mobility cannot be extended for Robot 1 otherwise Robot 2 is forced to be stopped
Nr. 3	1. Lower cost 2. Best time performance	1. Limited range of action, which does not allow to increase the number of condiment containers and then the number of pizza taste preparation

Table 7.2.3-1 – Advantages and disadvantages of each robot configuration.

8 CONCLUSIONS

The feasibility study for the design of a pizza maker robot using of a simple architecture of hybrid robot (cart-like type) with the possibility to assemble two identical robot units for the execution of high complexity tasks has led to the definition of a robot and relevant workstation of big dimensions requiring a very large kitchen space for their accommodation. This result, which is strictly dependent from the choice to use a 5 DOF cart-like type robot, has not encouraged to carry out a performance study using this robot type.

Consequently, it has been investigated the possibility to use a commercial and collaborative manipulator arm of more complex design (6 DOF) and available on the market also in a mobile version.

Then the workstation and the kitchen lay out have been adapted to the selected commercial UR10 manipulator and its mobile version MMO-700. For this robot a **MATLAB** model has been developed using the characterisation of the end effector forward and inverse kinematics.

Three different configurations of two robots, using always the same type of manipulator arm, have been investigated, upon the definition of a different list of tasks for each robot unit.

The task paths of the end effector (commercial Robotiq 2F-85 gripper) have been derived and the performance time for the preparation of a number of ten pizzas of different taste has been evaluated by **SIMULINK** for each configuration, in order to find the most time performant one and to evaluate if some configuration changes using the same available robot could be done to improve the time performance. Cooking and delivery time have been taken outside of the performance analysis, as part of kitchen assistant work, but a dedicated robot to these tasks has been included in one configuration for further implementation of pizza cooking and delivery activities.

For the analysed configurations one robot is dedicated to the pizza dough roll out activity, called Robot 2, and another one to the pizza preparation activity (filling with condiments), called Robot 1.

A third robot, called Robot 3, is dedicated to the activities of pizza cooking and delivery at a desk; its tasks, as already said before, have been developed only for one configuration (Configuration nr. 3) but have been excluded from the simulation.

The results of the performance simulation show that for any configuration the pizza preparation times are well competitive if compared with a human pizzaiolo performance times. Moreover, the configuration using two fixed manipulator arms (Configuration nr. 3) is the most effective. This is justified by the lower speed of the cart in comparison with the manipulator one (cart speed 0,9 m/s, manipulator speed 1 m/s).

The two robot operates with good coherence of task times, in fact the periods of not productive activity are acceptably small for all the three configurations, i.e. they are less than 20% for Robot 2 (pizza roll out activity) and about 10% for Robot 1 (pizza preparation activity).

The total time required to prepare the defined set of ten pizzas is in a range of 24 – 26 min, being Configuration nr. 3 the most performant one and Configuration nr. 1 the less performant. These times are well competitive with a human pizzaiolo performance times.

The robot task requiring more time is the pizza dough roll out, which results to be of the same order of the pizza taste preparation time, not including the pizza transfer on the storage table. However, its impact on the total mission time is not relevant because the pizza roll out activity is always in the shadow of the pizza taste preparation activity, i.e. it terminates before the completion of the pizza preparation.

From all the above, no performance improvements can be obtained by the reduction of Robot 2 activity time, for example by substituting the roll pin use with a press for the spreading of the pizza dough partitions.

The total mission time can be instead reduced with a more performant manipulator arm for Configuration nr. 3 and more performant cart and manipulator for Configuration nr. 1 and 2.

Finally, an optimized solution to fully cover the variety of pizza tastes normally available in a pizzeria, could be a fixed manipulator dedicated to the pizza dough roll out activity, to take advantage of its better performance and low costs, and a mobile manipulator dedicated to the pizza preparation process, to take advantage of its mobility to pick up a variety of condiment containers in order to produce a big list of pizza taste. Of course, a workstation extension would be necessary.

Figure 8-1 gives a sketch of the layout for this configuration.

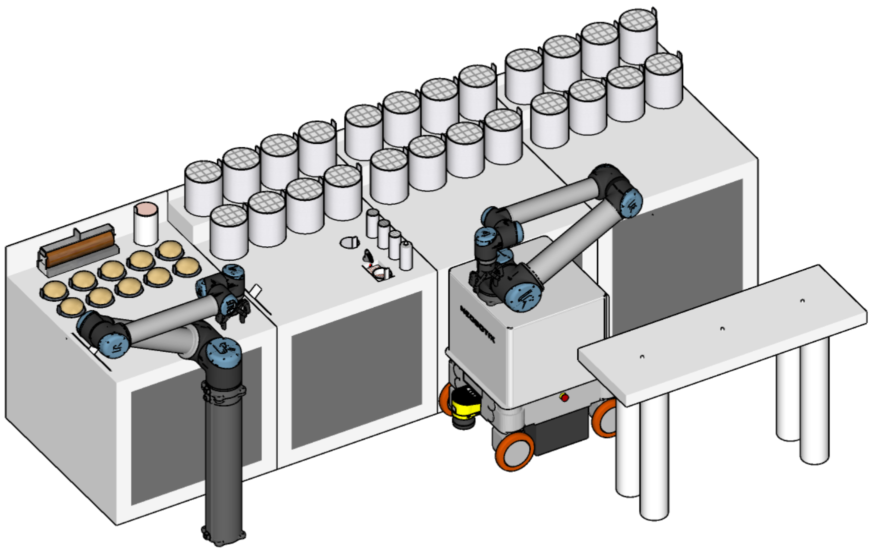


Figure 8-1 – Optimized robot configuration layout to extend the pizza taste variety that could be prepared.

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APPENDIX A

A1 FEASIBILITY STUDY FOR THE DESIGN OF A PIZZA MAKER HYBRID ROBOT ARCHITECTURE

The criterion adopted for the feasibility study of a pizza maker hybrid robot is to use of a simple robot configuration, whose complexity of performed tasks could be increased by the assembly of two or more similar units.

As a consequence, the identified architecture for each robot unit is a *hybrid modular reconfigurable robot* (HMRR) composed by a cart with wheels that permits the mono-directional motion on a plane, a robotic arm composed by four revolute joints attached to arm links of different lengths on top of it and finally an end effector, i.e. a gripper, at the end of the chain provided with rotational characteristics (4 DOF for the robotic arm plus 1 DOF for the cart).

The first three joints, starting from the cart, which could move along the **X** axis only, permit the rotation of the links around the **X** axis. The fourth joint allows the rotation of the end effector around the third link axis.

The first two links are assembled in a serial configuration in a **Y-Z** plan. The final link with a gripper moves in a plan parallel to the other two links **Y-Z** plan, but with an offset imposed by the tasks to be performed. Physically the offset is a small link orthogonal to the **Y-Z** plan.

The feasibility study model has then 5 degrees of freedoms (DOF) and is schematically shown in **Figure A1-1**.

The initial foreseen list of tasks to be performed by two robot units is:

- assembly;
- pizza dough partition placement at workstation roll out position;
- roll pin pick up and pizza dough partition roll out;
- disassembly;
- pizza filling with condiments;
- store filled pizzas at a place for later cooking in the oven;
- repositioning of the two robot units at the starting position.

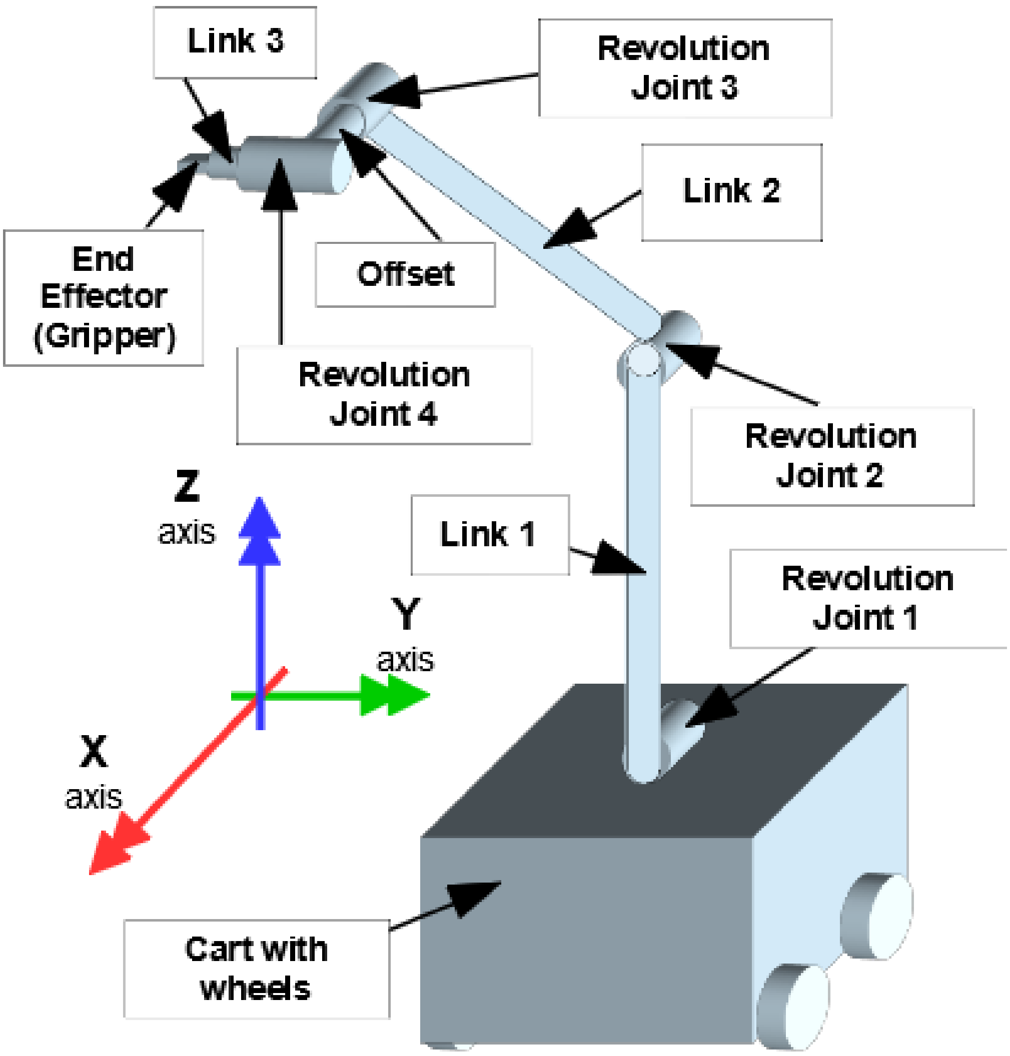


Figure A1-1 - Physical model sketch for the feasibility study single robot unit.

A2 PIZZA MAKER HYBRID ROBOT GEOMETRY DEFINITION

The definition of each robot unit geometry and the design of the overall work environment arrangement requires a sort of loop, because different requirements are to be satisfied all together. In the following there are details of the list of the adopted requirements.

A2.1 ADOPTED REQUIREMENTS

In the following there is the list of the used requirements to avoid the risk that some adopted dimensions result in conflict with some tasks to be performed.

A2.1.1 LONGITUDINAL DESIGN (X AXIS)

- the cart length (**X** axis dimension) must be reduced to a minimum because it represents the distance between the grippers of the two robot units in the assembled configuration, having influence on the workstation overall dimensions;
- Link 3 (**L3**) must have an offset from Link 2 (**L2**) in order to avoid interferences with the pizza shovel when the prepared pizza is moved to the storage position (manipulator base rotation is not foreseen).

A2.1.2 WORKSTATION FEATURES AND KITCHEN GENERAL ARRANGEMENT

- The workstation must be wide enough to allow the execution of robot tasks, both in the assembled and single unit configuration, without interferences;
- a free corridor for human personnel assistance in the preparation of the workstation must be left in between the workstation and the cart.

A2.1.3 LINKS LENGTH

- The gripper of the robotic arm must reach the more distant operating point; worst case is with **L3** vertical;
- the robotic arm must not have Links interferences when operating at the closest point; worst case is with **L3** horizontal.

A2.1.4 STABILITY (VERTICAL AND LATERAL DESIGN)

- the robotic arm must be free from overturning if the gripper reaches the more distant operating point with **L3** vertical, worst case.

A2.2 ROBOT LONGITUDINAL DESIGN

One of the main parameters influencing the geometric design of both robot and relevant workstation is the dimension of the available robot components.

In this feasibility study the dimensions of the components have been fixed by capturing them from the robotics visualization toolbox.

The adopted robot components dimensions are reported in **Figure A2.2-1** for the single robot unit. They allow to define the overall longitudinal size (**X** axis) of the robotic arm **Wa**. This quote is a constrain for the overall length of the cart body **X** axis dimension **Cx**, which is equivalent to the minimum distance between the gripping points of the two assembled robots.

The **X** axis dimension of the cart is also relevant for the overall workstation extension along the **X** axis to avoid interferences between the two robots in specific cases of pizza preparation. This point will be discussed later, when the workstation lay out design is described. On the contrary the **Y** axis cart dimension is important for the design against overturning during movements.

From **Figure A2.2-1** it is possible to derive the minimum overall **Wa** dimension of the robot arm, by taking into consideration also the filled pizza movement towards the rear table. In fact, during this movement the pizza shovel of 160 mm radius will pass close to the second link from the bottom (**L2**). Then the center of the gripper must be at least 160 mm from the outer surface of the **L2**, or (**a** + **b** + **c** + **d**) must be at a minimum (120 + 160 +110 + 130) = 520 mm.

In order to have a little margin in the robot design the value of **b** has been taken as 170 mm and the cart length of 550 mm.

The pizza shovel, has been shaped like a disk of 320 mm diameter, assuming a standard pizza diameter of 300 mm.

The extension of the wooden rolling surface of the roll pin is linked to the pizza diameter. However, in this design the longer value of 530 mm has been used to limit the flexibility of the internal shaft of the special rotative roll pin to be adopted.

As a summary, the robot parameters defined in this chapter are showed below:

- cart length (**X** axis dimension) = 550 mm
- distance between the two pick up points of the roll pin = 550 mm
- roll pin wooden rolling surface extension = 530 mm
- manipulator revolution joint diameter (2**a**) = 240 mm
- manipulator revolution joint extension (2**c**) = 260 mm
- manipulator links diameter (2**d**) = 220 mm
- gap between joint and link = 4 mm
- distance of the end effector gripper point from **L2** axis (**b** + **c**) = 280 mm

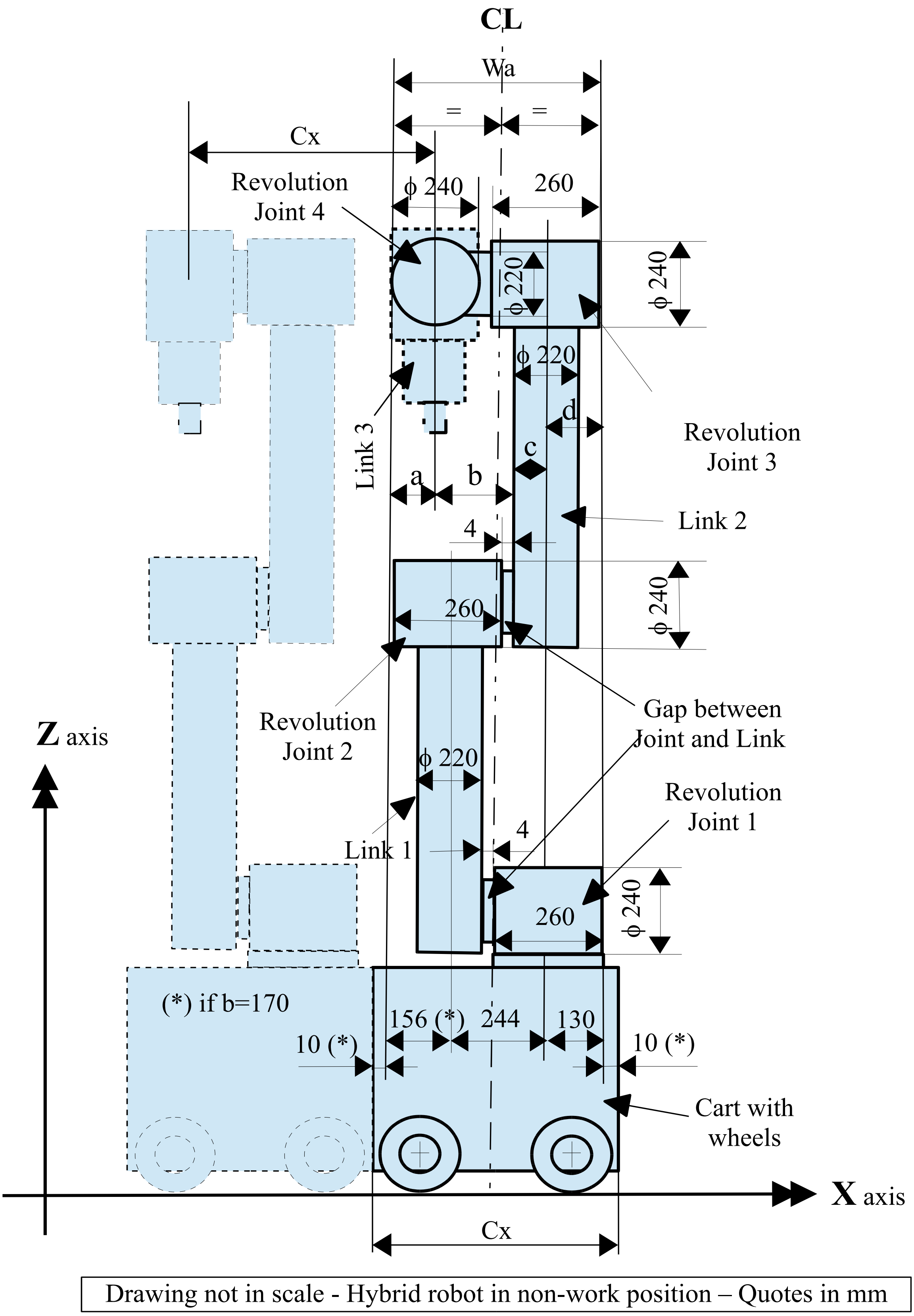


Figure A2.2-1 - Robot components dimensions in mm.

A2.3 ROBOT WORKSTATION FEATURES AND KITCHEN ARRANGEMENT

In the following there are reported some considerations done for the definition of the workstation and kitchen arrangement using the currently identified architecture of the hybrid robot. However, as outlined in body of the thesis, the operational and performance study for this robot has not been continued due to its big overall dimensions, occupying large kitchen space.

A2.3.1 WORKSTATION LAY OUT

The basic idea has been a robot reproducing as much as possible the way of working of a human pizzaiolo. Consequently, the pizza maker work environment has been identified as follows:

- a workstation where there are specific locations:
  - for the pizza dough partitions allocation, for the roll pin allocation and for the flour container allocation: these locations are unique because in the sequence of robot tasks they will be used only when the robot is in the assembled configuration;
  - for pizza dough partition roll out operation: this location is duplicated even if it is used by the two robot units in assembled configuration, because it will be also used for pizza preparation;
  - for pizza preparation, for tomato sauce dispenser and ladle allocation, for condiment containers allocation, for condiments spreading tool allocation: these locations are duplicated because the two robot units when disassembled will proceed in parallel and

simultaneously in the execution of the pizza preparation tasks for each own pizza;

- a table for placing the already prepared pizzas;
- an oven location.

In comparison with the real sequence of operations of a human pizzaiolo, this feasibility study has left to the human intervention its final condiment with salt, origan, garlic and olive oil, other than the pizza placing in the oven and its cooking.

The pizza maker workstation has been assumed to be placed against a wall. Taking into consideration the identified tools geometry the workstation overall derived dimensions are 2100 mm **X** axis length, 1000 mm **Y** axis depth and 750 mm **Z** axis height at the level of pizza preparation. The condiment containers are at two levels of nominal height of 848 mm and 973 mm to avoid occasional interferences of the robotic arm with tools placed ahead of them. Moreover, the first row of containers axis is placed at 544 mm from the front edge of the workstation and the second row of containers axis at 874 mm.

The reason for the raised levels of condiment containers is to maintain the possibility for the manipulator final link with gripper to pick up them arriving in horizontal position. In fact, being necessary the container overturning above the pizza, to allow condiments fall, the horizontal link position guarantees that the gripper will be out of the condiment falling path. The same applies to the tomato sauce ladle. On the contrary the requirement is not necessary for the pizza doughs trays because the presence of flour between the tray and the dough will allow the dough drop down with a smaller tray rotation.

Two areas have been identified, both for pizza doughs roll out and for pizza preparation. The first activity has been assumed to be accomplished by the two robots in assembled configuration, the second activity to be performed by each robot in parallel and in an independent way.

Nr. 8 types of condiments, allowing the preparation of at least nr. 6 pizza tastes, have been identified:

- mozzarella cheese,
- aubergines,
- zucchini,
- peppers,
- wurstels,
- sausages,
- mushrooms,
- ham.

Therefore, two sets of nr. 8 containers with relevant locations have been foreseen. The two sets have been sufficiently spaced so that the handle of the last one of set number 2 (the left one looking at the work table, i.e. the area reserved to Robot 2 operativity) is distant more than 550 mm from the handle of the first container of set number 1 (the right one looking at the work table, i.e. the area reserved to Robot 1 operativity) in order to avoid interferences between the two robot arms in case of contemporarily use of these containers. Practically the above distance has resulted to be 1010 mm, nominally.

A2.3.2 WORKSTATION SPECIAL FEATURES

Some special features have been identified for the correct operability of the Robots and to guarantee an almost circular shaped pizza.

A2.3.2.1 ***Rotating mechanism at pizza dough roll out location***

As already mentioned, for the currently defined robot configuration the use of the roll pin requires the availability of a rotating mechanism at pizza roll out location to be sure to realize an almost circular shaped pizza.

Therefore at both pizza roll out locations the pizza shovel, which is shaped like a disc of 320 mm diameter, will rest over a sort of record player activated by the release of a button situated in the roll pin accommodation place, when the roll pin is picked up for use.

In addition, when the roll pin applies pressure on the pizza shovel the motor below will be stopped and put in standby; when the roll pin does not apply pressure, the motor will rotate one time the pizza shovel by 45°, always in the same direction. Therefore, once completed the sequence of roll out actions, the pizza dough will result rolled out in all directions with a high probability to achieve an almost circular shaped pizza. The mechanism will be disabled when the roll pin will return on its allocation place.

The pizza shovel rotating mechanism will be accommodated into a recess of the workstation (12 mm in depth and 324 mm of diameter) in order to allow the pizza dough roll out at the same level of the workstation surface.

Figure A2.3.2.1-1 gives a representation of this mechanism where the workstation top surface has been removed.

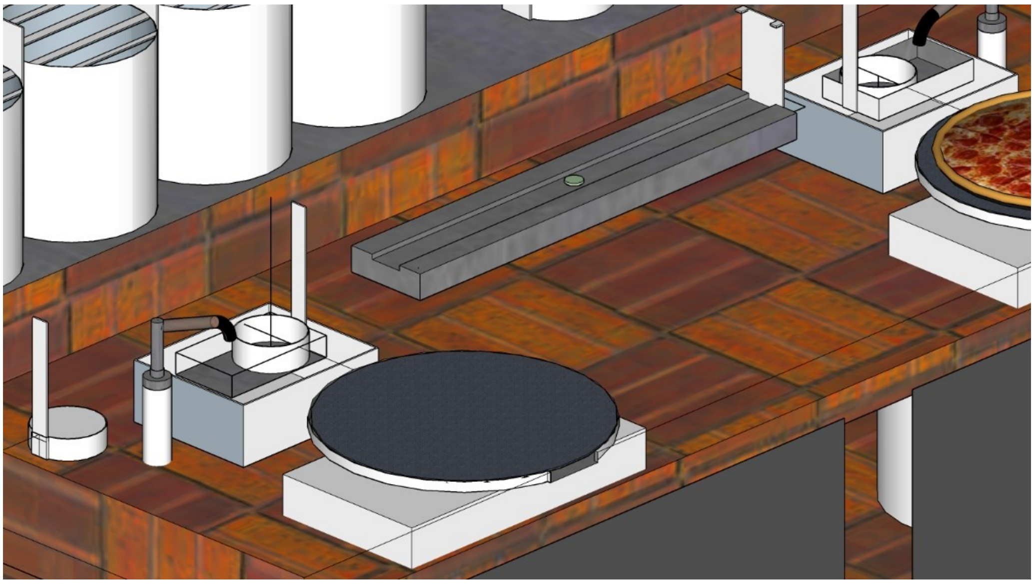


Figure A2.3.2.1-1 – Pizza shovel rotating mechanism, roll pin and tomato sauce dispenser accommodation. The workstation top surface has been removed.

A2.3.2.2 Tomato sauce dispenser

Regarding the tomato sauce, in order to be sure to use always the same quantity of sauce, it has been foreseen a dispenser that will be activated one time when a button will be pushed by the ladle. The robot has to pick up the ladle, move it against the push button, wait for tomato sauce supply, move back the ladle to have it far away from the dispenser obstruction and rise up the ladle to complete the list of tasks related to the use of this tool. A special allocation with a recess of 25 mm has been foreseen for the tomato sauce ladle. The container of sauce dispenser will be allocated below the work table surface (see **Figure A2.3.2.1-1**).

A2.3.2.3 Smart location for tools

The location on the work station of any tool is realized with a recess of 2 mm with respect to the work station surface, enlarged by 2 mm in diameter and provided with an indentation to accommodate the special featured handle of the tools to avoid human wrong positioning of them during the work station preparation. A special feature, as described in the previous **Section A2.3.2.2**, has been arranged for the tomato sauce ladle. **Figure A2.3.2.3-1** gives a representation of the smart location for tools feature.

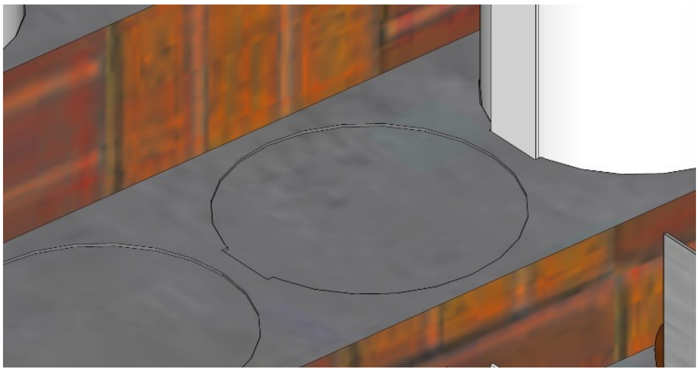


Figure A2.3.2.3-1 - Smart location for tools.

A2.3.3 PIZZA MAKER ROBOT ALLOCATION

The bodies of pizza maker robot carts are to be placed at a convenient lateral distance (**Y** axis) from the workstation to preserve easy transit to the assistant personnel during the workstation preparation phase. Of course, this distance is to be contained as much as possible to limit the robot Links extension. Here a distance value of 550 mm of the carts body from the workstation has been used.

The table where the already prepared pizzas are to be stored has been placed in front of the workstation and behind the pizza maker robots at a distance from the carts body of 180 mm. This distance is enough to allow robot arms movements without interferences and is not cause of other design constraints.

The overall dimensions for the pizzas storage table, according to the pizza shovel diameter and the number of 6 pizzas to be stored, will result 2400 mm **X** axis length, 400 mm **Y** axis depth and 750 mm **Z** axis height. The dedicated personnel for pizzas cooking will operate on the other side of this table.
The oven has been placed on the right side of the workstation.

The schematic arrangement of the pizza maker robot workstation and the overall kitchen arrangement is given in **Figure A2.3.3-1**, realized with the tool **SKETCHUP**.

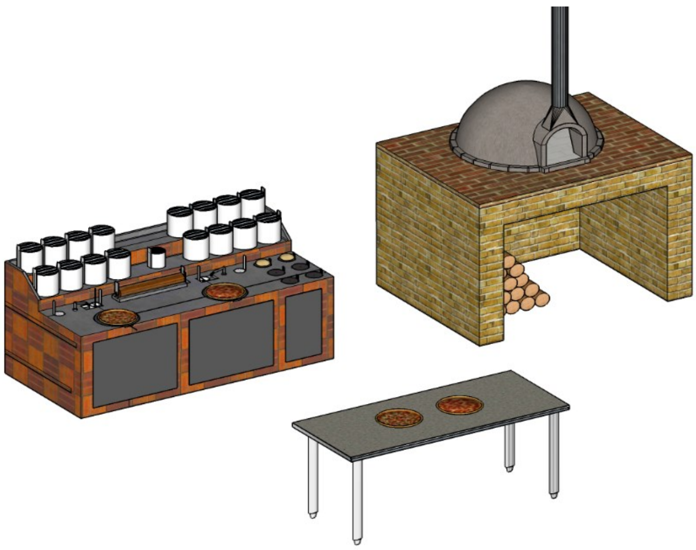


Figure A2.3.3-1 - Schematic arrangement of the pizza maker robot workstation and overall kitchen arrangement realised with the tool **SKETCHUP**.

As a summary, the workstation geometry and the overall environment disposition quotes derived in this chapter are showed below:

- workstation length (**X** axis dimension) = 2100 mm
- workstation depth (**Y** axis dimension) = 1000 mm
- workstation height at pizza roll out and preparation level (**Z** axis dimension) = 750 mm
- workstation height at first level of condiments containers (**Z** axis dimension) = 850 mm
- workstation height at second level of condiments containers (**Z** axis dimension) = 975 mm
- first row of containers axis distance from the workstation front edge = 544 mm
- second row of containers axis distance from the workstation front edge = 874 mm
- pizza diameter = 300 mm
- pizza shovel diameter = 320 mm
- tools locations featured with a recess on the workstation surface and with an indentation for proper accommodation of tools
- pizza shovel rotating mechanisms for uniform pizza dough roll out rotating steps = 45°
- cart body distance from the workstation (**Y** axis direction) = 550 mm
- cart body distance from the table for the storage of the already prepared pizzas= 180 mm
- table for the storage of the already prepared pizzas length (**X** axis dimension) = 2400 mm
- table for the storage of the already prepared pizzas depth (**Y** axis dimension) = 400 mm
- table for the storage of the already prepared pizzas height (**Z** axis dimension) = 750 mm

A2.4 LINKS LENGTH

To fix the lengths of the three robot links the following considerations from the schematic view in **Figure A2.4-1** have been done.

- The distance of Joint 1 (**J1**) axis from the workstation must be contained in order to minimize the length of Link 1 (**L1**);
- the height of **J1** axis influences the total height of the robot arm; i.e. a higher position of **J1** will result in a higher value of the sum of lengths **L1** plus **L2**;
- the Cart body width must be contained in order to reduce the overall area occupied by the robot during its operation and to minimize the length of **L1**;
- the sum of **L1** and **L2** lengths must have a value to allow the achievement of the more distant operating point **P2** for the worst case of **L3** vertical, with **J2** axis higher than **P2** height plus **L3** length, to avoid robotic arm interferences with the workstation lay out;
- there must be no interference between **L1** and **L2** when the closest operating point **P1** is achieved with **L3** horizontal.

Once the **J1** axis position has been fixed and **L1**, **L2**, **L3** lengths have been defined, the stability of the robot to overturning around **X** axis must be verified.

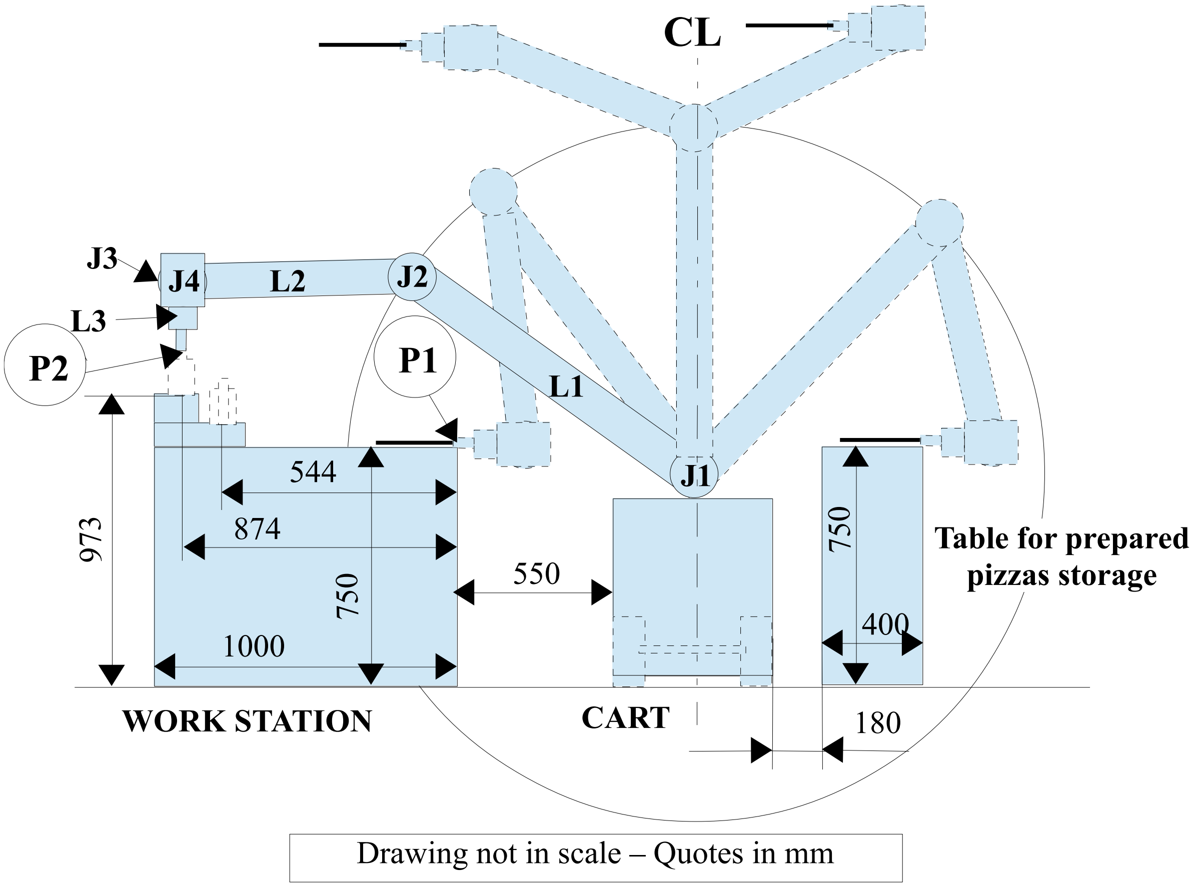


Figure A2.4-1 – Schematic view of the working area arrangement and robotic arm movements.

Assuming:

- height of **J1** axis = 600 mm
- distance of **J1** axis from the workstation = 900 mm
- width of cart body = 700 mm
- height of **P1** = 750 mm
- height of **P2** = 1193 mm
- length of **L3** = 300 mm

and referring to **Figure A2.4-2** we can also assume **L1** = 1200 mm, obtaining **a** = 801,593 mm. Now **L2** must be greater than 1774 – 801,593 = 972,41 mm.

Here **L2** = 980 mm has been assumed and the verification that there is no interference between **L1** and **L3** for the worst-case operating point **P1** has been performed. The calculation gives γ = 27,92° and is reported in the same **Figure A2.4-2**.

Being γ_{min} = 17,029°, as can be seen from **Figure A2.4-3**, the criteria of no interference between **L1** and **L3** is verified.

As a summary the additional robot dimensions and overall environment disposition quotes derived in this Section are showed below:

- length of **L1** = 1200 mm
- length of **L2** = 980 mm
- length of **L3** = 300 mm
- height of **J1** axis = 600 mm
- distance of **J1** axis from the workstation = 900 mm
- cart width (**Y** axis) 700 mm
- height of **P1** = 750 mm
- height of **P2** = 1193 mm

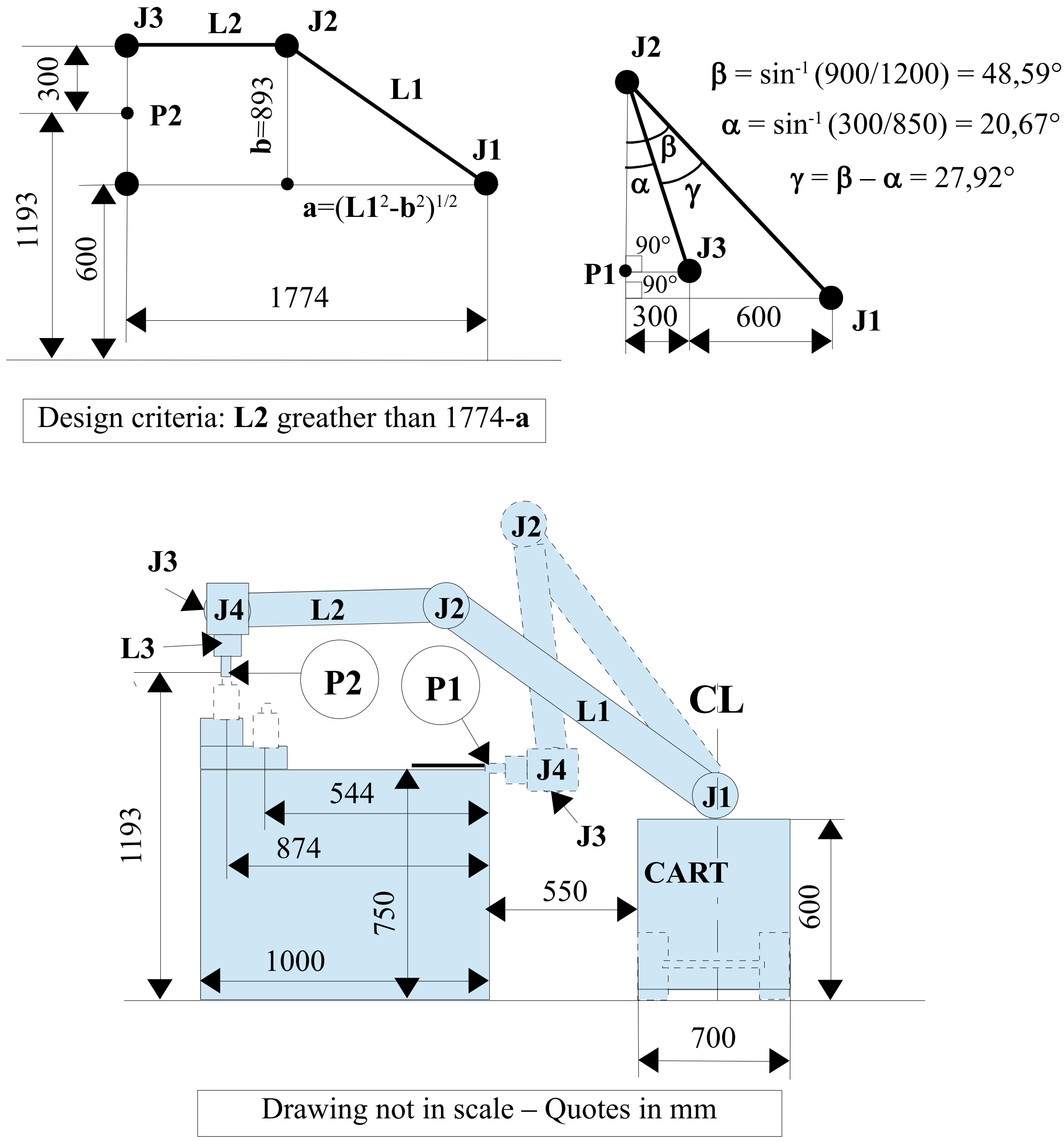


Figure A2.4-2 – Schematic representation of design worst case gripper operating points.

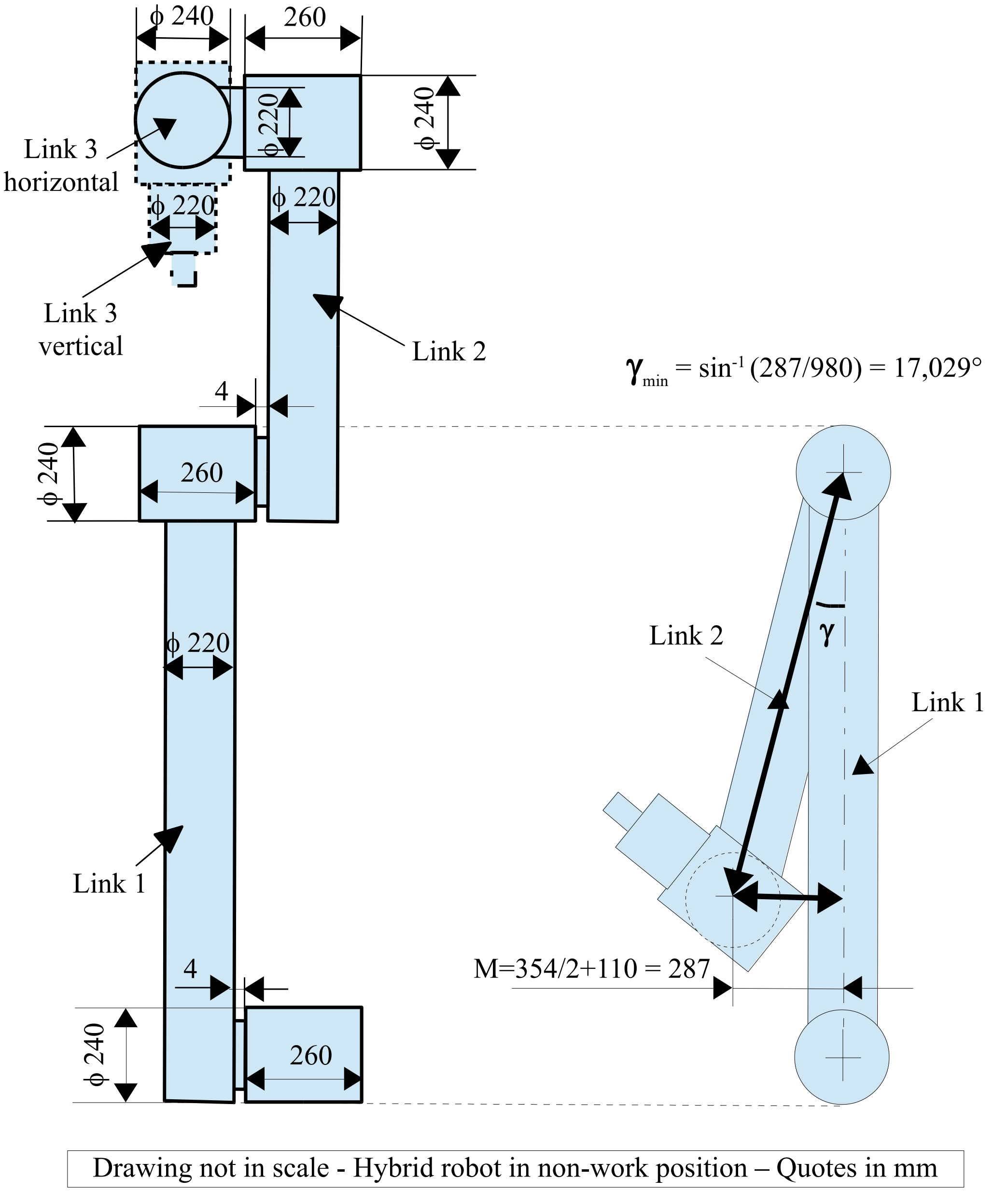


Figure A2.4-3 – Schematic view of contact angle between Link 1 and Link 3.

A2.5 STABILITY CONSIDERATIONS

To complete the design geometry, it has been verified that the robot architecture is free from overturning during its operation.

To perform this analysis the robot masses have been quantified.

Referring to **Figure A2.5-1** it is assumed that the robot may be schematically represented by concentrated masses in the middle of each Joint. Each Joint mass includes half mass of any Link concurring to that Joint.

Considering an aluminum and plastic structure, the following masses were used for the analysis:

- **M1** = 50 kg
- **M2** = 12 kg
- **M3** = 10 kg
- **M4** = 8 kg
- **M5** = 10 kg
- **M6** = 6 kg

M6 is the maximum workload, which never exceeds 6 kg.

In fact, the pizza shovel is a stainless-steel disk of 320 mm diameter and 2 mm thickness. Its weight is:

$$\pi * 1{,}60^2 * 0{,}02 * 7{,}85 = 1{,}26 \text{ kg},$$

being 7,85 kg/dm^3 the stainless-steel specific weight.

The pizza weight is normally not more than 0,4 kg. Therefore, the shovel plus pizza weight is less than 2 kg.

The special roll pin, having a stainless-steel bar in the middle has a weight of less than 3,5 kg and is used by the two robot units.

Its weight details are:

- body in dried beech wood (specific weight 0,73 kg/dm^3)
  $\pi * (0{,}4^2 – 0{,}11^2) * 5{,}3 * 0{,}73 = 1{,}8$ kg
- low friction plastic material tube (specific weight 2,2 kg/dm^3)
  $\pi * (0{,}11^2 – 0{,}10^2) * 5{,}3 * 2{,}2 = 0{,}078$ kg
- stainless steel shaft (specific weight 7,85 kg/dm^3)
  $\pi * (0{,}1^2) * 5{,}48 * 7{,}85 = 1{,}31$ kg
- nr. 2 stainless steel handles (specific weight 7,85 kg/dm^3)
  $2 * (0{,}02 * 0{,}4 \text{ x } 1{,}15) * 7{,}85 = 0{,}144$ kg

The heaviest loads are the containers filled with condiments. Considering the container structure in stainless steel composed by a cylinder of 0,5 mm thickness and a height of 200 mm, a disc base of 180 mm diameter and 0,5 mm thickness, a rectangular handle 40 x 240 x 2 mm, and assuming a specific weight for the heaviest ingredient of 0,9 kg/dm^3 the resultant weight is:

$$[\pi * (0{,}9^2) * 0{,}005 + \pi * 1{,}8 * 2 * 0{,}005 + 0{,}4 * 2{,}4 * 0{,}02] * 7{,}85 +$$
$$+ \pi * (0{,}9^2) * 2 * 0{,}9 = 5{,}27 \text{ kg}$$

If few grams of the grid above the container are added, the total weight does not exceed 6 kg.

Worst case for stability proof is the robotic arm fully extended, even if this is not a working condition. At the gripper point the workload of **M6** = 6 kg has been concentrated.

From the mass moments balance referring to the cart wheelbase center line **WbCL** in the **Y-Z** plane gives (see **Figure A2.5-2**):

$$\mathbf{M6} * 2480 + (\mathbf{M5} + \mathbf{M4}) * 2180 + \mathbf{M3} * 1200 + \mathbf{M2} * 0 + \mathbf{M1} * 0 = \mathbf{Mt} * \mathbf{d}$$

having assumed the mass of cart centered on the wheelbase (**Wb**). By substituting the mass values, it is obtained:

d = 688,75 mm for **M1** = 50 kg

or

d = 268,785 mm for **M1** = 200 kg

Also, the height **h** of **Mt** in the robot fully extended condition can be calculated:

$$(\mathbf{M6} + \mathbf{M5} + \mathbf{M4} + \mathbf{M3} + \mathbf{M2}) * 600 + \mathbf{M1} * 200 = \mathbf{Mt} * \mathbf{h}$$

i.e., for **M1** = 50 kg: **h** = 392 mm

In **Figure A2.5-1** it is also showed the hybrid robot center of gravity height **Hrcgz** in the non-work configuration and the longitudinal position **Sc** (**X** axis) of the cart mass **M1** to center on the Centre Line the overall hybrid robot CG.

$$\mathbf{M5} * 2780 + \mathbf{M4} * 2780 + \mathbf{M2} * 600 + \mathbf{M1} * 200 = \mathbf{Mt} * \mathbf{Hrcgz}$$

i.e., now **Mt** = 90 kg: **Hrcgz** = 747,11 mm

and

M5 * 145 + **M3** * 109 – **M1** * **Sc** – **M2** * 135 – **M4** * 135 = 0

i.e.: **Sc** = -3,2 mm

To avoid overturning the cart wheelbase must be at least the double of **d**. Practically, from the above calculation, a very large or a very heavy cart should be realized. Moreover, it is not convenient to move the cart center of gravity far away from the wheelbase center line because the robotic arm will operate also on the other side for pizza storage.

To contain the width of the cart it was necessary to foresee the application of a balance mass. In **Figure A2.5-3** it is introduced a balance mass at the extremity of **L1** with a center of gravity height **MBcg** at a distance of 300 mm from **J1** axis. The accommodation of the balance mass requires a cart design modification to create a recovery area for it.

Now the robot stability can be verified using the mass moments balance referred to the cart wheelbase center line **WbCL** in the **Y-Z** plane (see **Figure A2.5-4**):

M6 * 2480 + (**M5** + **M4**) * 2180 + **M3** * 1200 + **M2** * 0 + **M1** * 0 -
MB * 300 = **Mt** * **d**

Using **MB** = 70 kg the total mass will be **Mt** = 166 kg, and **d** = 271,81 mm.

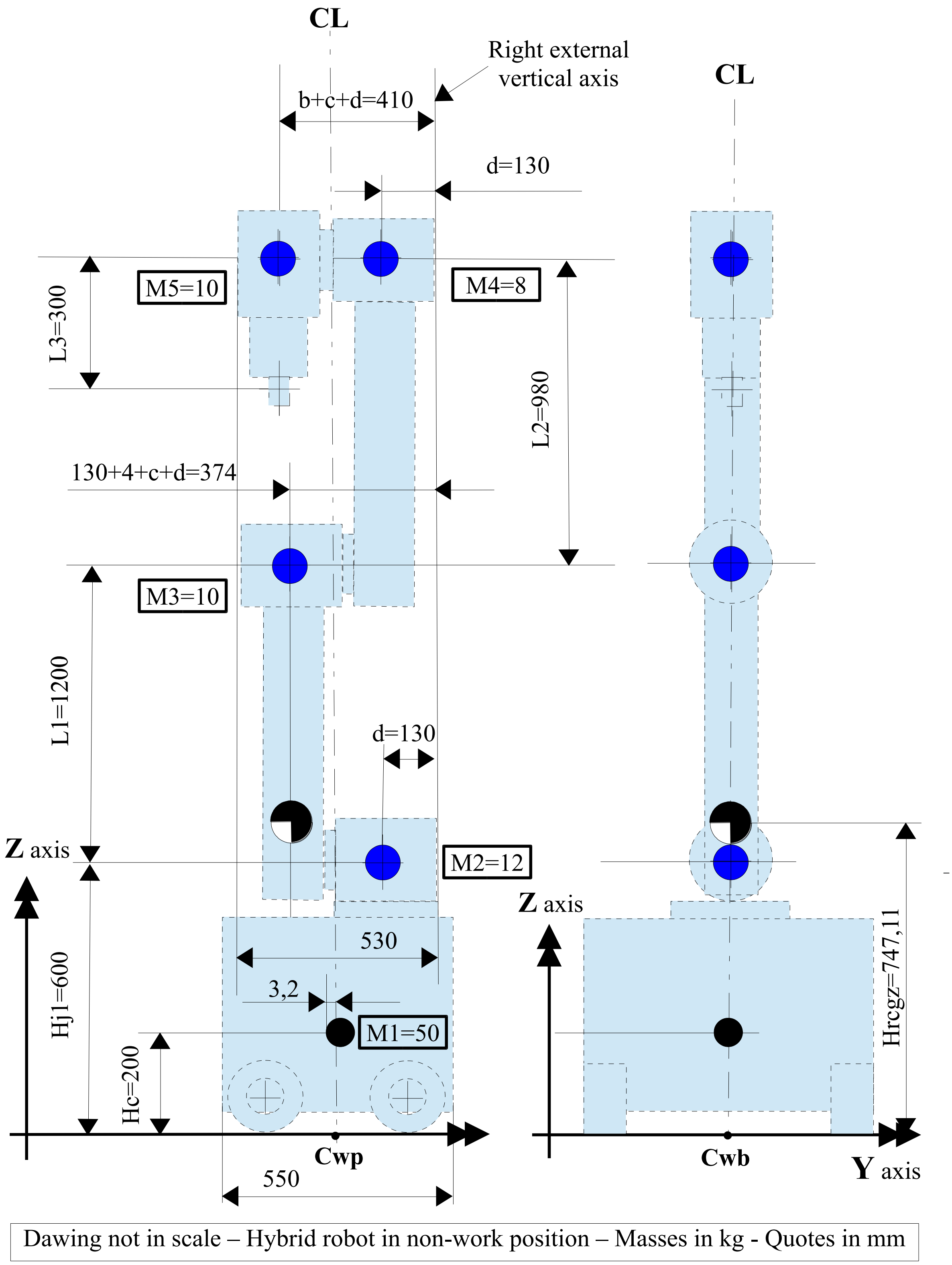


Figure A2.5-1 – Schematic representation of the hybrid robot masses before optimization.

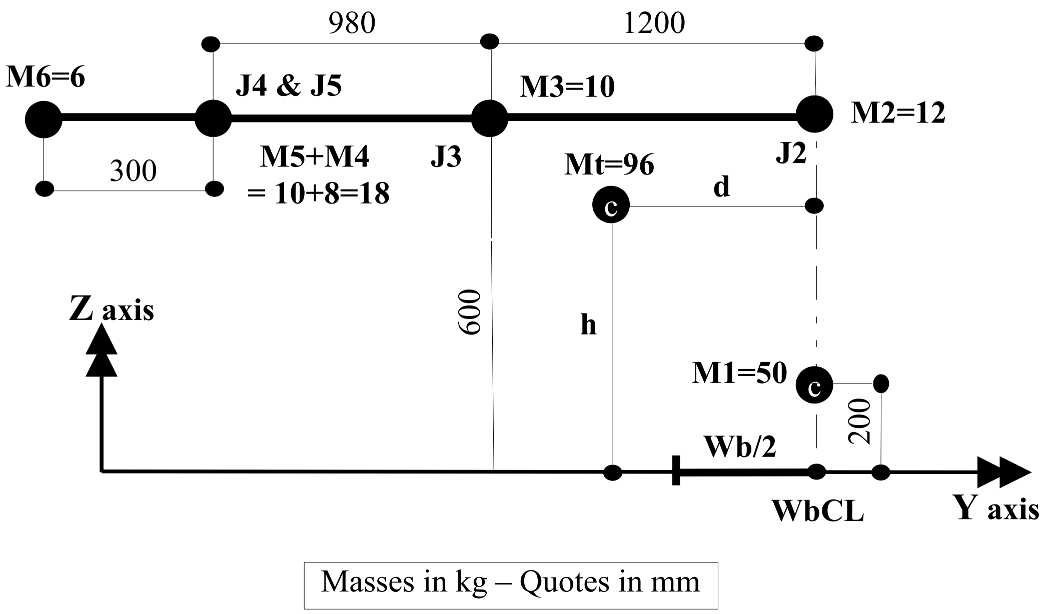


Figure A2.5-2 – Schematic representation for stability analysis with no balance mass.

Similarly, the height **h** of **Mt** will result:

(**M6** + **M5** + **M4** + **M3** + **M2**) * 600 + **M1** * 200 + **MB** * 600 = **Mt** * **h**

or:

h = 479,52 mm

In **Figure A2.5-3** it is also showed the hybrid robot center of gravity height **Hrcgz** in the non-work configuration and the longitudinal position **Sc** (**X** axis) of the cart mass **M1** to center on the Centre Line the overall hybrid robot CG.

M5 * 2780 + **M4** * 2780 + **M2** * 600 + **MB** * 300 + **M1** * 200 = **Mt** * **Hrcgz**

i.e., now **Mt** = 160 kg **Hrcgz** = 551,5 mm and

$$\mathbf{M5} * 145 + \mathbf{M3} * 109 + \mathbf{MB} * 109 - \mathbf{M1} * \mathbf{Sc} - \mathbf{M2} * 135 - \mathbf{M4} * 135 = 0$$

i.e.: **Sc** = 149,4 mm

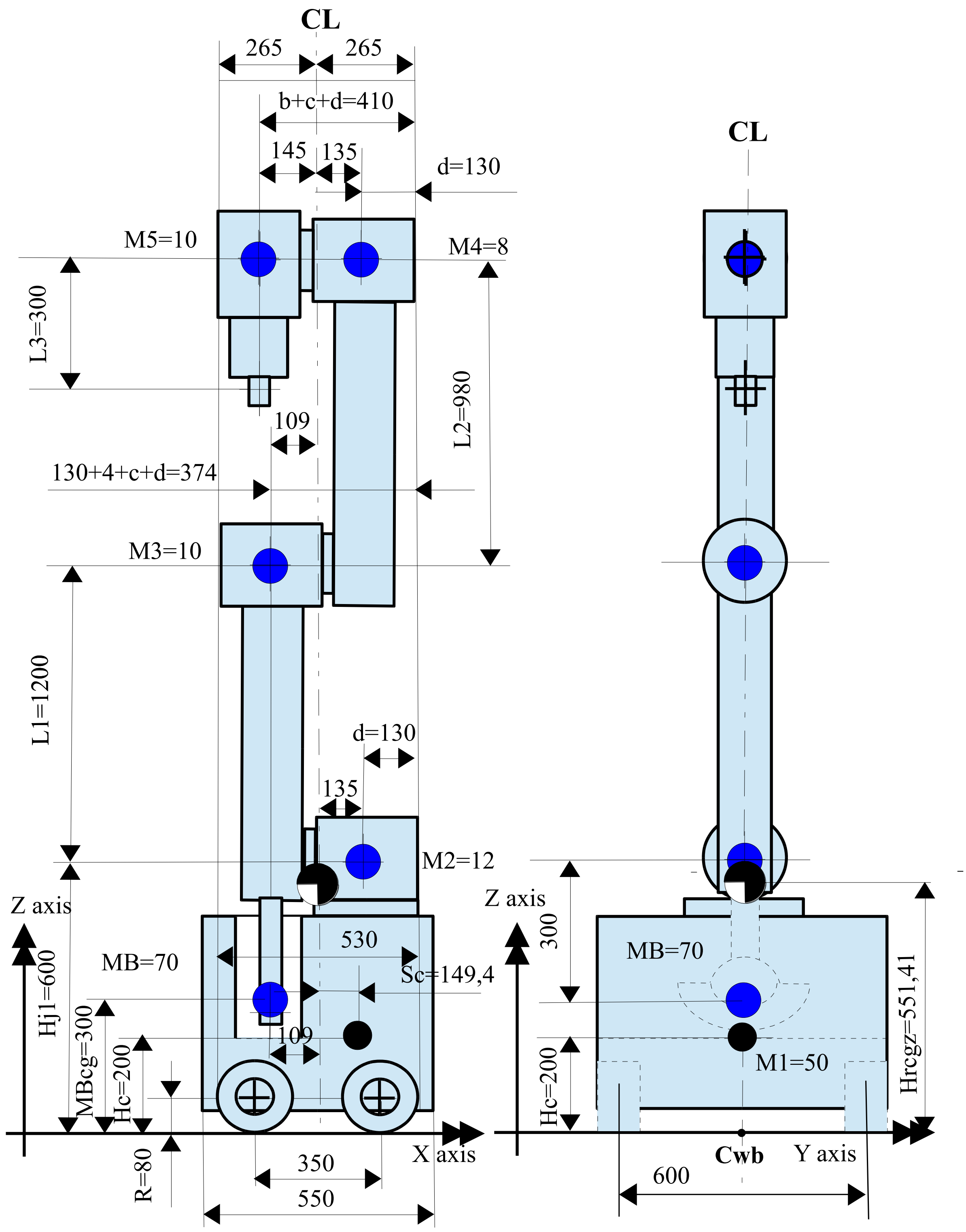
Finally, the last hybrid robot design parameters can be defined.

In fact, the cart wheelbase must be more than 2 x 269 = 538 mm.

The cart body width was already assumed to be 700 mm; therefore, wheels 100 mm wide and a conservative value of 600 mm for the cart wheelbase can be adopted. As far as wheel diameter is concerned it is preferable to adopt small radius wheels in order to control higher values of revolution for small displacements of the cart. The assumed wheel diameter was 160 mm and the number of wheels 4.

As a summary the final robot dimensions derived in this chapter are showed below:

- cart wheelbase **Wb** = 600 mm
- number of cart wheels = 4
- cart wheels diameter = 160 mm
- cart wheels width = 100 mm
- balance mass **MB** = 70 kg
- cart mass **M1** = 50 kg
- robotic arm mass (**M2 + M3 + M4 + M5**) = 40 kg
- hybrid robot weight = 160 kg
- balance mass arm length = 300 mm



Dawing not in scale – Hybrid robot in non-work position – Masses in kg - Quotes in mm

Figure A2.5-3– Schematic representation of the hybrid robot masses optimized with a balance mass.

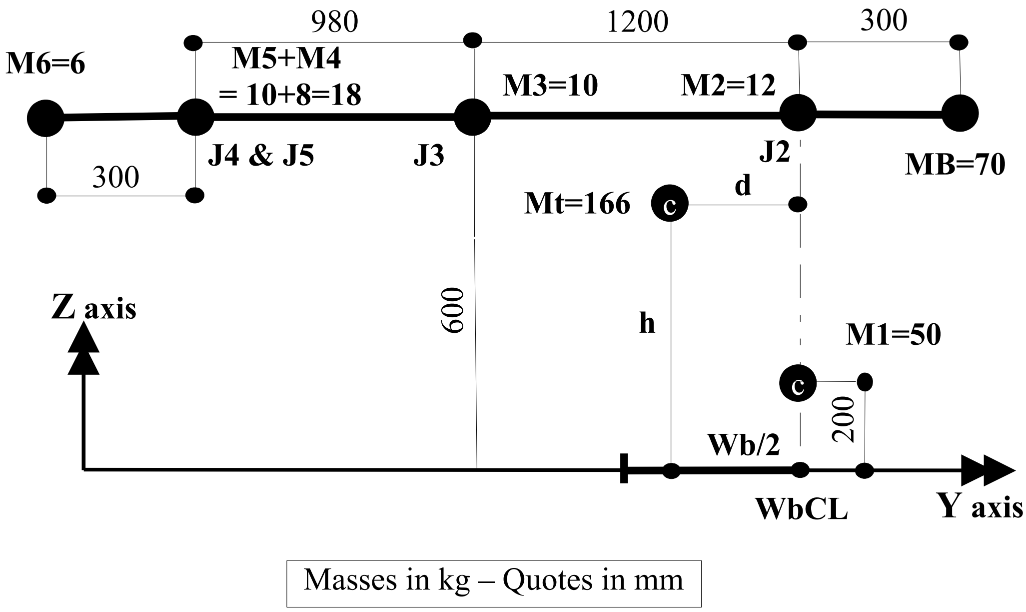


Figure A2.5-4 – Schematic representation for stability analysis with balance mass.

A3 FEASIBILITY STUDY ROBOT MATHEMATICAL MODEL

To carry out the development of the mathematical model of the hybrid two robots layout a first simplification has been made by carrying out the study only for the kinematics motion of a single cart.

For the preliminary study, as already mentioned before, the simple robot model is composed by a prismatic joint (which represents the movement on a straight line, for positive and negative motion with respect to the initial base position) followed by four revolute joints (that compose the effective robotic arm).

A3.1 SIMPLE MODEL – FORWARD KINEMATICS

The model used is a three massless links robot schematically reported in **Figure A3.1-1**; the obtained Denavit-Hartenberg parameters are reported in **Table A3.1-1.**

In **Figure A3.1-2** there is a plot of the robot generated by the robotic toolbox with the above-mentioned DH parameters.

In order to obtain the homogeneous transformation matrix representing the end effector position with respect to the coordinate system of the base, the composition of the various matrix that link a generic link to its previous one has been done giving the rotation and translation matrixes in **Equation A3.1-1**.

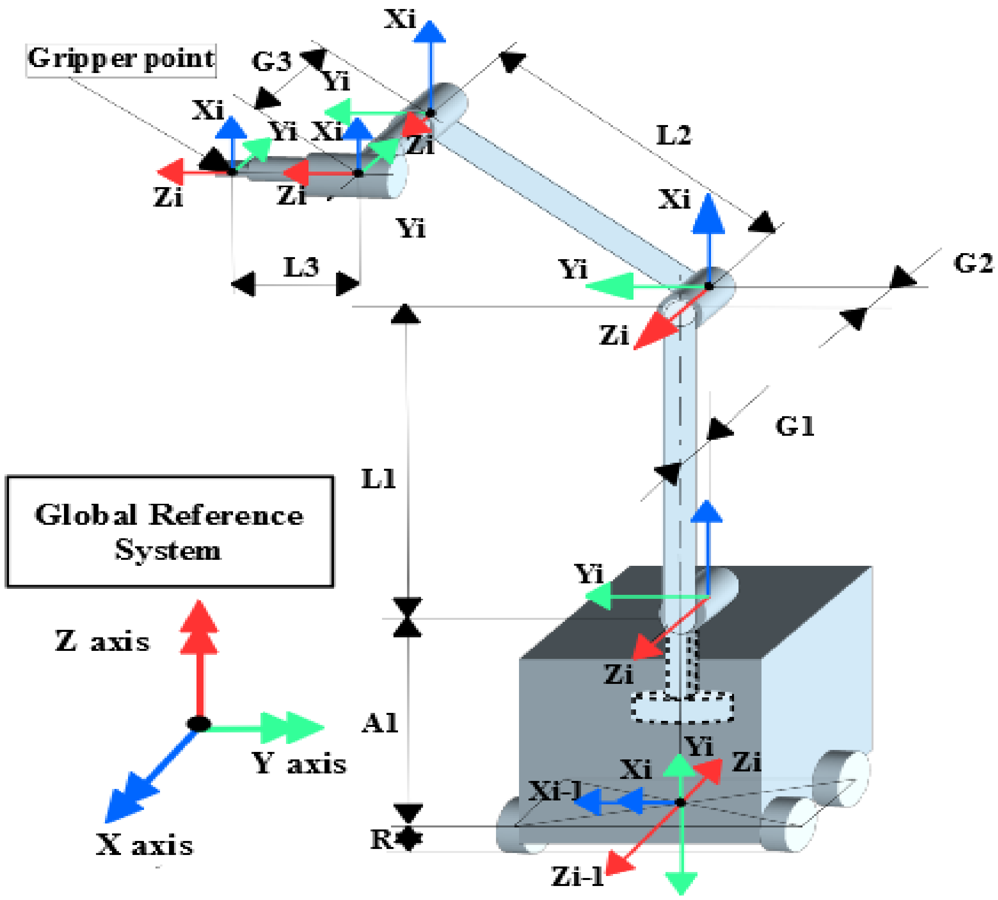


Figure A3.1-1 - Physical model sketch for the simpler robot module.

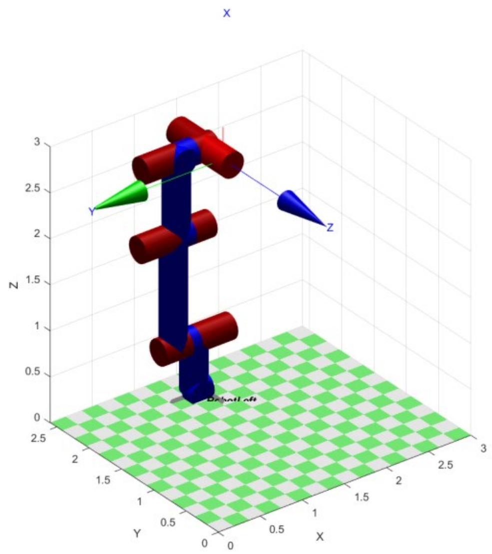


Figure A3.1-2 - A representation of the simpler model robot using Robotic Toolbox by Peter Corke.

θ *[rad]*	d *[m]*	a *[m]*	α *[rad]*
0	q1	0	π
π/2	q2	A1	π
q3	-G1	L1	0
q4	G2	L2	0
q5	G3	0	-π/2
q6	L3	0	0

Table A3.1-1 - DH parameters obtained from the robotic model.

$$\boldsymbol{R_{gripper}^{base}} = \begin{bmatrix} \sin(q_3+q_4+q_5)*\cos(q_6) & -\sin(q_3+q_4+q_5)*\sin(q_6) & \cos(q_3+q_4+q_5) \\ -\cos(q_3+q_4+q_5)*\cos(q_6) & \cos(q_3+q_4+q_5)*\sin(q_6) & \sin(q_3+q_4+q_5) \\ -\sin(q_6) & -\cos(q_6) & 0 \end{bmatrix}$$

$$\boldsymbol{t_{gripper}^{base}} = \begin{bmatrix} L_1*\sin(q_3)+L_2*\sin(q_3+q_4)+L_3*\cos(q_3+q_4+q_5) \\ -L_1*\cos(q_3)-L_2*\cos(q_3+q_4)+L_3*\sin(q_3+q_4+q_5)-A_1 \\ G_2-G_1+G_3+q_1-q_2 \end{bmatrix}$$

Equation A3.1-1 – Rotation and translation matrixes using DH parameters.

However, the feasibility study has been carried out with respect to a global reference system having the origin at the rear bottom corner of the workstation. Therefore, the **Equation A3.1-1** has to be transformed in order to obtain the homogeneous transformation matrix that represents the gripper position in the global reference system (**Equation A3.1-2**).

$$T_{gripper}^{global} = T_{base}^{global} * T_{gripper}^{base} = T\left(\begin{bmatrix} x \\ y \\ z \end{bmatrix}\right) * R_z\left(-\frac{\pi}{2}\right) * R_x\left(-\frac{\pi}{2}\right) * T_{gripper}^{base}$$

$$= \begin{bmatrix} 0 & 0 & 1 & x \\ -1 & 0 & 0 & y \\ 0 & -1 & 0 & z \\ 0 & 0 & 0 & 1 \end{bmatrix} * T_{gripper}^{base}$$

Equation A3.1-2 – Transformation to get the homogeneous matrix in the global reference system from the base system. x, y depend on which robot is considered, z corresponds to R

The overall homogeneous transformation matrix that represents the gripper movements with respect to the global reference system is given by composition of rotation and translation of **Equation A3.1-3** as a result of calculation with **Equation A3.1-2**.

$$R_{gripper}^{global} = \begin{bmatrix} -\sin(q_6) & -\cos(q_6) & 0 \\ -\sin(q_3 + q_4 + q_5) * \cos(q_6) & \sin(q_3 + q_4 + q_5) * \sin(q_6) & -\cos(q_3 + q_4 + q_5) \\ \cos(q_3 + q_4 + q_5) * \cos(q_6) & -\cos(q_3 + q_4 + q_5) * \sin(q_6) & -\sin(q_3 + q_4 + q_5) \end{bmatrix}$$

$$t_{gripper}^{global} = \begin{bmatrix} x + G_2 - G_1 + G_3 + q_1 - q_2 \\ y - L_1 * \sin(q_3) - L_2 * \sin(q_3 + q_4) - L_3 * \cos(q_3 + q_4 + q_5) \\ z + A_1 + L_1 * \cos(q_3) + L_2 * \cos(q_3 + q_4) - L_3 * \sin(q_3 + q_4 + q_5) \end{bmatrix}$$

Equation A3.1-3 – The rotation and translation transformation matrixes of gripper represented in the global reference system.

The matrixes in **Equation A3.1-3** are used to study the forward kinematics for the proposed model of the robot during the accomplishment of a defined list of tasks to be performed by each individual simpler robot.

A3.2 INTERACTION BETWEEN SIMPLE MODELS

The above model is valid for only one robot-cart. Since the interaction between two copies of it is of interest a model has been developed using the Robotic Toolbox by Peter Corke (see **Figure A3.2-1**). It is composed with generic geometric shapes but preserves the DH parameters in **Table A3.1-1**, hence the **Equation A3.1-1** can be still applied. Using this toolbox, the study of the two carts can be carried on.

A3.3 INVERSE KINEMATICS

The study of the inverse kinematics has also been carried out starting from **Equation A3.1-3** and examining rotations and translations separately.

The rotation matrix is the composition of various rotations that include joint coordinates **q3**, **q4**, **q5**, **q6**. Due to this the rotation matrix given from **Equation A3.1-3** has been decomposed in order to get at least one known Cardan angles triplet (refer to **Equation A3.3-1**).

$$R_{gripper}^{global} = R_6^{global} * R_{gripper}^6 = R_6^{global} * R_z(q_6)$$

$$= \begin{bmatrix} 0 & -1 & 0 \\ -\sin(q_3+q_4+q_5) & 0 & \cos(q_3+q_4+q_5) \\ \cos(q_3+q_4+q_5) & 0 & -\sin(q_3+q_4+q_5) \end{bmatrix} * \begin{bmatrix} \cos(q_6) & -\sin(q_6) & 0 \\ \sin(q_6) & \cos(q_6) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

$$R_{gripper}^{global} = R_3^{global} * R_5^3 * R_6^5 * R_z(q_6)$$

$$= R_z(-\pi) * R_y\left(-\frac{\pi}{2}\right) * R_z(q_3+q_4+q_5) * R_x\left(-\frac{\pi}{2}\right) * R_z(q_6)$$

$$R_y^{-1}\left(-\frac{\pi}{2}\right) * R_z^{-1}(-\pi) * R_{gripper}^{global}$$

$$= R_z(q_3+q_4+q_5) * R_x\left(-\frac{\pi}{2}\right) * R_z(q_6)$$

$$= R_z(\varphi) * R_x(\theta) * R_z(\gamma)$$

$$\begin{Bmatrix} \varphi = q_3+q_4+q_5 \\ \theta = -\dfrac{\pi}{2} \\ \gamma = q_6 \end{Bmatrix}$$

Equation A3.3-1 – The joints variables **q3**, **q4**, **q5**, **q6** in relation to cardan angles given by rotations around **Z**, **X**, **Z** axis.

The **Equation A3.3-1** shows how to get the joint coordinates **q3**, **q4**, **q5**, **q6** from a generic rotation matrix given that θ is always equal to -π/2 otherwise the rotation is never obtainable from the given robot configuration.

Once given the translation vector, it is possible to get the joint variables **q1**, **q2**, **q3**, **q4**.

$$t_{gripper}^{global} = \begin{bmatrix} x + G_2 - G_1 + G_3 + q_1 - q_2 \\ y - L_1 * \sin(q_3) - L_2 * \sin(q_3 + q_4) - L_3 * \cos(q_3 + q_4 + q_5) \\ z + A_1 + L_1 * \cos(q_3) + L_2 * \cos(q_3 + q_4) - L_3 * \sin(q_3 + q_4 + q_5) \end{bmatrix} = \begin{bmatrix} t_x \\ t_y \\ t_z \end{bmatrix}$$

$$t_x = x + G_2 - G_1 + G_3 + q_1 - q_2$$
$$\rightarrow q_1 - q_2 = t_x - x - G_2 + G_1 - G_3 = t_x - x_0$$
$$\rightarrow \left\{ \begin{matrix} \left\{ \begin{matrix} q_1 = t_x - x_0 \\ q_2 = 0 \end{matrix} \right\} t_x \geq x_0 \\ \left\{ \begin{matrix} q_1 = 0 \\ q_2 = t_x - x_0 \end{matrix} \right\} t_x < x_0 \end{matrix} \right\}$$

$$t_y = y - L_1 * \sin(q_3) - L_2 * \sin(q_3 + q_4) - L_3 * \cos(q_3 + q_4 + q_5)$$
$$= y - L_1 * \sin(q_3) - L_2 * \sin(q_3 + q_4) - L_3 * \cos(\varphi)$$
$$\rightarrow -t_y + y - L_3 * \cos(\varphi) = L_1 * \sin(q_3) + L_2 * \sin(q_3 + q_4) = \alpha$$

$$t_z = z + A_1 + L_1 * \cos(q_3) + L_2 * \cos(q_3 + q_4) - L_3 * \sin(q_3 + q_4 + q_5)$$
$$= z + A_1 + L_1 * \cos(q_3) + L_2 * \cos(q_3 + q_4) - L_3 * \sin(\varphi)$$
$$\rightarrow t_z - z - A_1 + L_3 * \sin(\varphi) = L_1 * \cos(q_3) + L_2 * \cos(q_3 + q_4) = \beta$$

These equations express the relation on **q1** and **q2** that, due to the idea of them acting like a prismatic joint on opposite directions, it is better to modify one or the other in the proper direction.

Also, a relation on **q3** and **q4** is obtained and gives the system:

$$\left\{ \begin{matrix} \alpha = L_1 * \sin(q_3) + L_2 * \sin(q_3 + q_4) \\ \beta = L_1 * \cos(q_3) + L_2 * \cos(q_3 + q_4) \end{matrix} \right\}$$

Using this equations system with proper mathematical operations the following results are obtained:

$$\alpha^2 + \beta^2 = L_2^2 + L_1^2 + 2 * L_1 * L_2 * \cos(q_4)$$

$$\rightarrow \cos(q_4) = \frac{[(\alpha^2 + \beta^2) - (L_1^2 + L_2^2)]}{(2 * L_1 * L_2)}$$

$$\rightarrow q_4 = \pm \cos^{-1}\left(\frac{[(\alpha^2 + \beta^2) - (L_1^2 + L_2^2)]}{(2 * L_1 * L_2)}\right)$$

$$\begin{bmatrix} \alpha & -\beta \\ \beta & \alpha \end{bmatrix} * \begin{bmatrix} \cos(q_3) \\ \sin(q_3) \end{bmatrix} = \begin{bmatrix} L_2 * \sin(q_4) \\ L_2 * \cos(q_4) + L_1 \end{bmatrix}$$

$$\rightarrow \begin{Bmatrix} \sin(q_3) = \dfrac{[\alpha * L_1 + \alpha * L_2 * \cos(q_4) - \beta * L_2 * \sin(q_4)]}{(\alpha^2 + \beta^2)} \\ \cos(q_3) = \dfrac{[\beta * L_1 + \beta * L_2 * \cos(q_4) + \alpha * L_2 * \sin(q_4)]}{(\alpha^2 + \beta^2)} \end{Bmatrix}$$

$$\rightarrow q_3 = \tan^{-1}\left(\frac{[\alpha * L_1 + \alpha * L_2 * \cos(q_4) - \beta * L_2 * \sin(q_4)]}{[\beta * L_1 + \beta * L_2 * \cos(q_4) + \alpha * L_2 * \sin(q_4)]}\right)$$

$$\varphi = q_3 + q_4 + q_5 \rightarrow q_5 = \varphi - (q_3 + q_4)$$

Solving the equation, a value for joints **q3**, **q4**, **q5** is obtained. It is noticeable that the robot is redundant with respect to joint **q4**, i.e. the robot can reach a given point both in elbow-up and elbow-down configuration.

APPENDIX B

OPTIMIZED WORKSTATION MODULES DESIGN DETAILS

B1 OPTIMIZED WORKSTATION DETAILS

The optimised workstation has been defined with a modular concept. In detail there is a module dedicated to the activity of pizza dough roll out and another one dedicated to the pizza preparation (filling with condiments).

B1.1 MODULE 1 (PIZZA PREPARATION MODULE)

On the pizza preparation module there are:

- the pizza preparation location;
- nr. 8 containers for nr. 8 different condiment types;
- the condiments spreading tool;
- the tomato sauce ladle with an automatic sauce dispenser and the relevant accommodation;
- a shovel;
- the origan container;
- the salt container;
- the garlic container;
- the olive oil container.

B1.1.1 PIZZA PREPARATION LOCATION

The location for pizza preparation is a flat area of more than 400 x 400 mm, where the pizza will be filled with condiments.

The center of the location on the work table top surface, identified with the number **L1**, is at the following coordinates (see also **Figure B1.1.1-1**):

$X_1 = 500$ mm

$Y_1 = 670$ mm

$Z_1 = 750$ mm

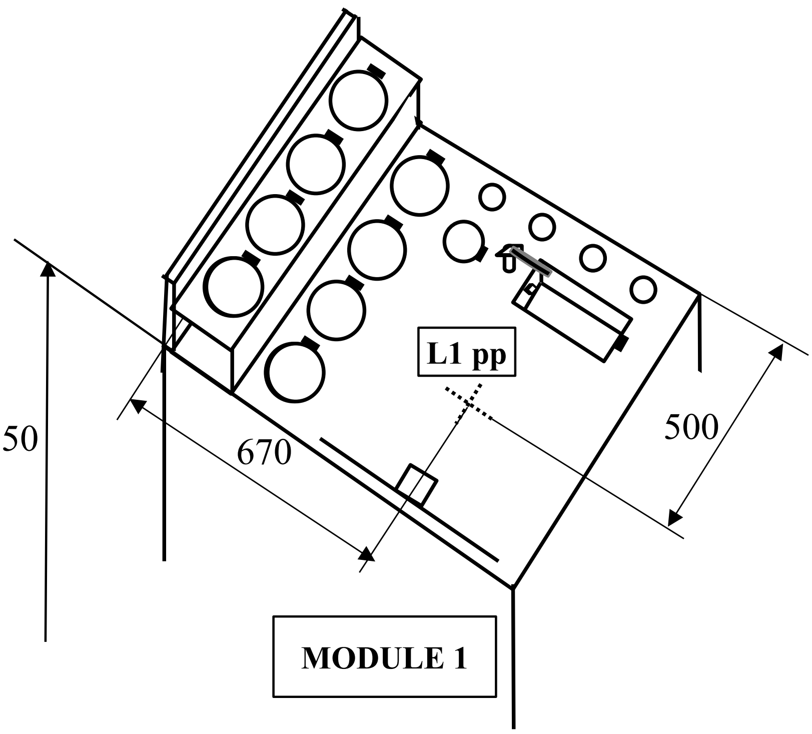


Figure B1.1.1 -1 – Pizza preparation location.

B1.1.2 PIZZA SHOVEL 1

The pizza shovel 1 is placed in a vertical slit on the front left part of the module. It is featured as a stainless-steel material flat panel of 320 x 320 mm and 1 mm thickness with a handle angled by 45° to the vertical made by a part of the same panel and reinforced on both sides by two stainless steel plates of dimensions 40 x 50 x 2 mm. The calculated shovel weight is 0,9 kg (stainless steel specific weight = 7,85 kg/dm^3). The slit has dimensions of 3 x 324 mm at work table top surface and has a depth of 325 mm. The shovel material has been preferred to be in stainless steel in order to benefit of its flexibility, avoiding deformations.

The center of the slit on the work table top surface, identified with the number **L2**, is at the following coordinates (see also **Figure B1.1.2-1**):

$X_2 = 775$ mm

$Y_2 = 670$ mm

$Z_2 = 750$ mm

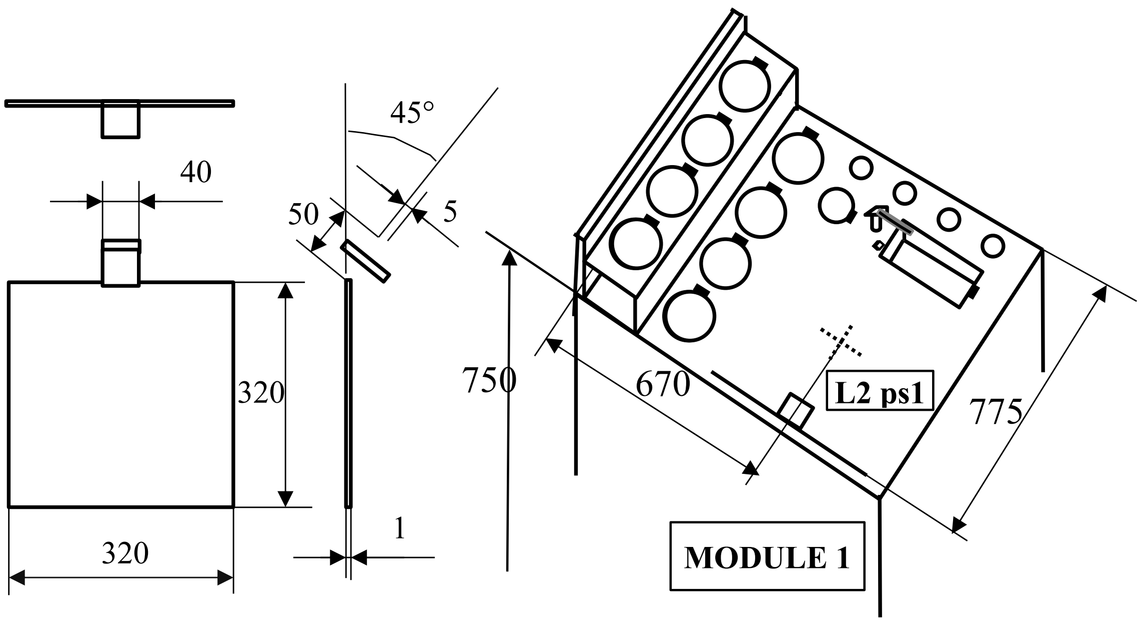


Figure B1.1.2-1 – Pizza shovel 1 geometry and relevant location.

The pizza shovel 1 pick-up point, identified with the code **ps1**, where the end effector has to arrive angled by 45° to the vertical with the gripper fingers open, is at the following coordinates (see also **Figure B1.1.2-2**):

$X_{ps1} = 775 - 40 \text{ x } \sin 45° = 747$ mm

$Y_{ps1} = 670$ mm

$Z_{ps1} = 750 + 40 \text{ x } \cos 45° = 778$ mm

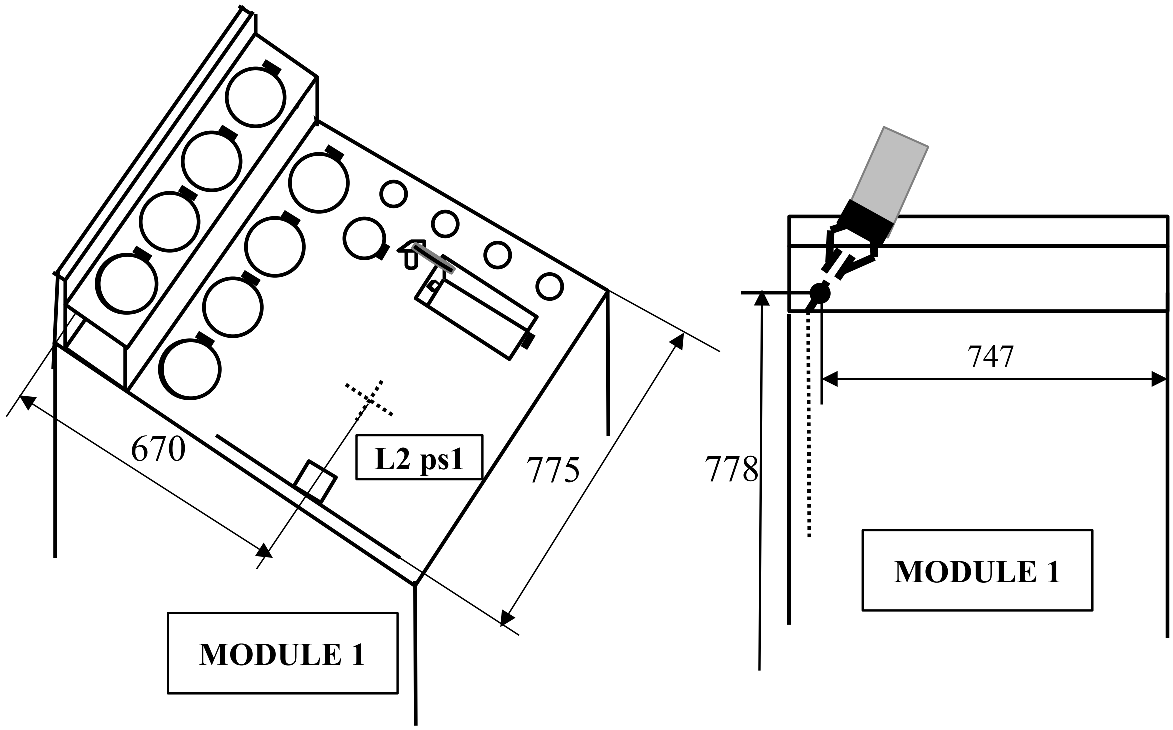


Figure B1.1.2-2 – Pizza shovel 1 pick-up point and assumed gripper position.

B1.1.3 CONDIMENT CONTAINERS

There are two rows of condiment containers, with the first row starting from the wall, which is raised by 100 mm. The reason for this is to maintain the possibility for the final manipulator link, with gripper, to pick up the containers

maintaining a horizontal position, perpendicular to the wall. Therefore, it must be free from interferences with the second row of condiment containers.
As already mentioned in the feasibility study, the pizza preparation process requires the need to overturn the condiment containers above the pizza, to allow the condiment falling down. Only with the final manipulator arm (Wrist 3) horizontal it is guaranteed to maintain during the rotation the gripper out of the falling path of the condiment.

The same criteria apply to the tomato sauce ladle, the flour, origan, salt, garlic and olive oil containers.

On the contrary the requirement is not necessary for the pizza dough trays because of the presence of flour between the tray and the dough, which will allow the dough partition to drop down with a smaller tray rotation. However, a shaker movement is foreseen to be performed by the manipulator to force the falling down of any condiment and the pizza itself when transferred from one location to another.

Condiment containers are in stainless steel material with a cylindrical shape. The external diameter is 160 mm, the height 180 mm and the thickness is 0,5 mm. The base is a disc of 0,5 mm thickness and 159 mm diameter. On the top there is a sort of grid to regulate the quantity of condiment falling down on the pizza. Finally, there is a simple flat bar handle of dimensions 2 x 30 x 210 mm starting from the base, which is also used for correct positioning of the container on the workstation. The calculated weight of each container is approximately 0,55 kg (stainless steel specific weight = 7,85 kg/dm^3). The maximum weight of the inside condiment (assuming a specific weight = 0,8 kg/dm^3) is approximately 2,8 kg.

The accommodation site of each container is a recess of 2 mm depth and 162 mm diameter with an indentation of 2 x 32 mm on the right side for proper positioning of the tool.

The centers of all the locations at the recess level, identified with the numbers from **L3** to **L10**, have the following coordinates (see also **Figure B1.1.3-1**):

X_3 = 683 mm	X_4 = 494 mm	X_5 = 305 mm	X_6 = 116 mm
Y_3 = 116 mm	Y_4 = 116 mm	Y_5 = 116 mm	Y_6 = 116 mm
Z_3 = 848 mm	Z_4 = 848 mm	Z_5 = 848 mm	Z_6 = 848 mm

X_7 = 683 mm	X_8 = 494 mm	X_9 = 305 mm	X_{10} = 116 mm
Y_7 = 328 mm	Y_8 = 328 mm	Y_9 = 328 mm	Y_{10} = 328 mm
Z_7 = 748 mm	Z_8 = 748 mm	Z_9 = 748 mm	Z_{10} = 748 mm

The containers pick up points, identified with the codes from **cc1** to **cc8**, where the end effector has to arrive horizontal and perpendicular to the front wall with the gripper fingers open in a plane parallel to **X-Y** are at the following coordinates, (see also **Figure B1.1.3-2**):

X_{cc1} = 602 mm	X_{cc2} = 413 mm	X_{cc3} = 224 mm	X_{cc4} = 35 mm
Y_{cc1}= 116 mm	Y_{cc2} = 116 mm	Y_{cc3} = 116 mm	Y_{cc4} = 116 mm
Z_{cc1} = 1048 mm	Z_{cc2} = 1048 mm	Z_{cc3} = 1048 mm	Z_{cc4} = 1048 mm

X_{cc5} = 602 mm	X_{cc6} = 413 mm	X_{cc7} = 224 mm	X_{cc8} = 35 mm
Y_{cc5} = 328 mm	Y_{cc6} = 328 mm	Y_{cc7} = 328 mm	Y_{cc8} = 328 mm
Z_{cc5} = 948 mm	Z_{cc6} = 948 mm	Z_{cc7} = 948 mm	Z_{cc8} = 948 mm

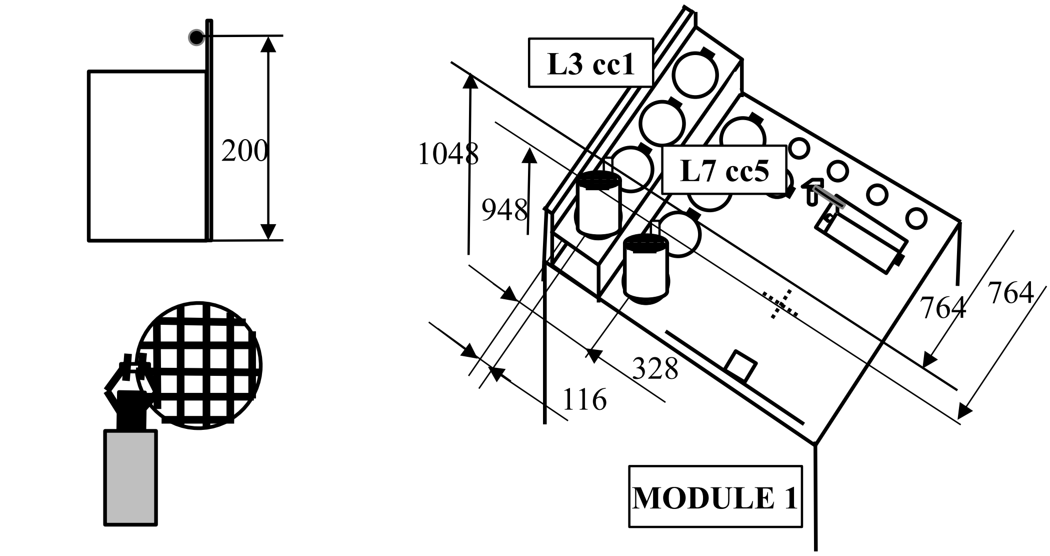


Figure B1.1.3-1 – Condiment containers geometry and relevant locations.

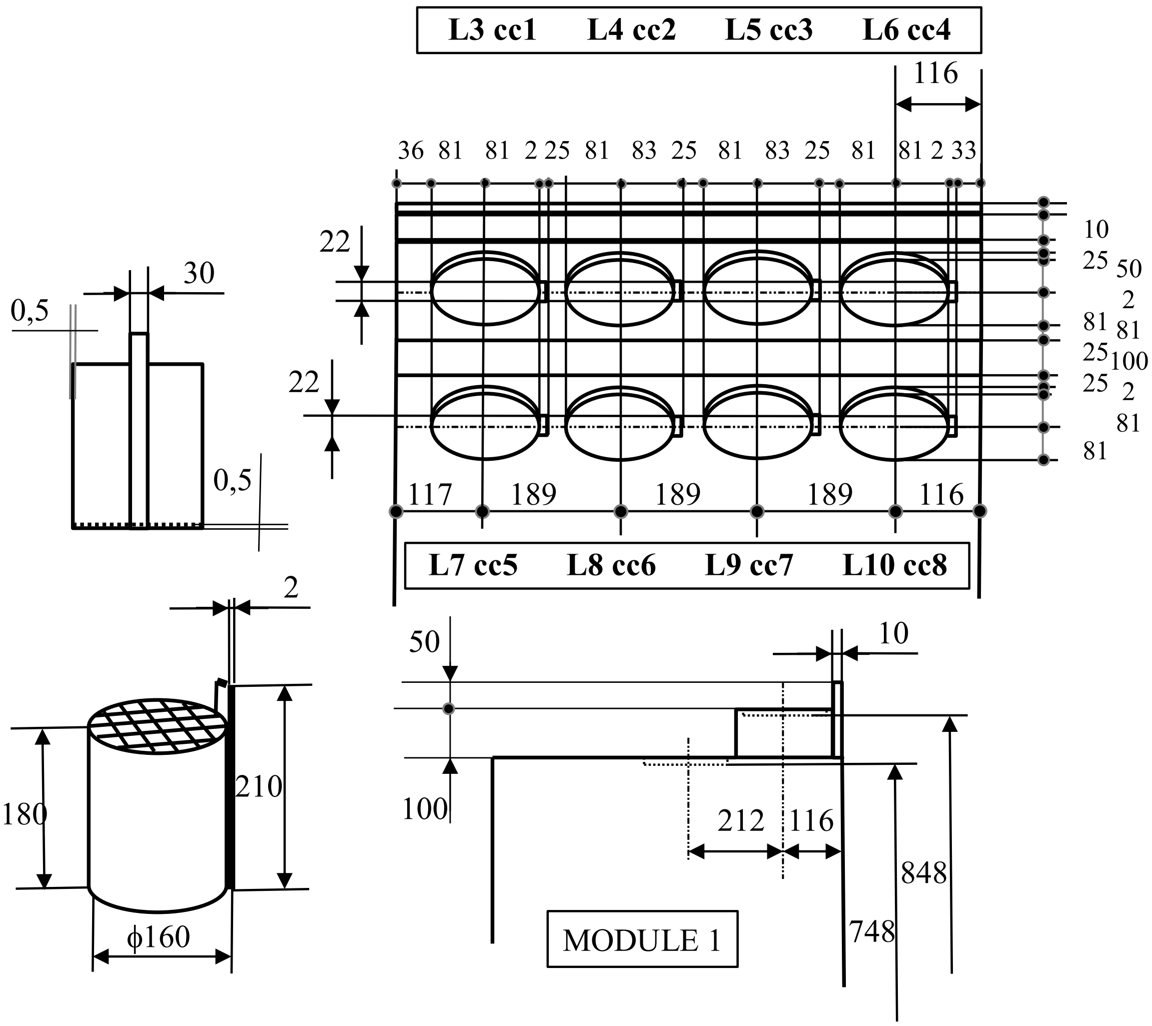


Figure B1.1.3-2 – Condiment containers pick up point and assumed gripper position.

B1.1.4 TOMATO SAUCE DISPENSER AND LADLE

To be sure to use always the same quantity of tomato sauce, it has been foreseen an automatic sauce dispenser that will be activated one time when a button is pushed by the ladle. The robot has to pick up the ladle, move it against the push button, wait for tomato sauce supply, move back the ladle to have it far away from the dispenser obstruction and rise up the ladle to continue the completion of the list of tasks related to the use of this tool.

The tomato sauce ladle is used both to pour sauce on the pizza and to spread the poured sauce over the pizza.

The tool is in stainless steel material and is featured as showed in **Figure B1.1.4-1**. The bowl is circular with the external diameter of 80 mm, lateral and bottom thickness of 1 mm, height of 30 mm. Finally, the tool has a simple flat bar handle of dimensions 2 x 20 x 80 mm starting from the bottom of the bowl. The calculated ladle weight is 0,22 kg (stainless steel specific weight = 7,85 kg/dm^3).

The accommodation site is a rectangular recess of 25 mm depth, 82 mm width and 140 mm length. The site extends in forward direction and has an indentation of 2 x 22 mm for proper positioning of the tool on the front face. The recess has a grid on the bottom and below the workstation top table there is a tray to collect the residual sauce remaining on the bottom of the ladle.

On the opposite side of the ladle accommodation and inside the recess there is a button, which allows, when pushed, the supply of a fixed quantity of sauce by the dispenser (see **Figure B1.1.4-1**). The ladle has to be moved nominally by 60 mm towards the button to activate the sauce dispenser. The sauce container and the automatic mechanism are allocated below the workstation top table.

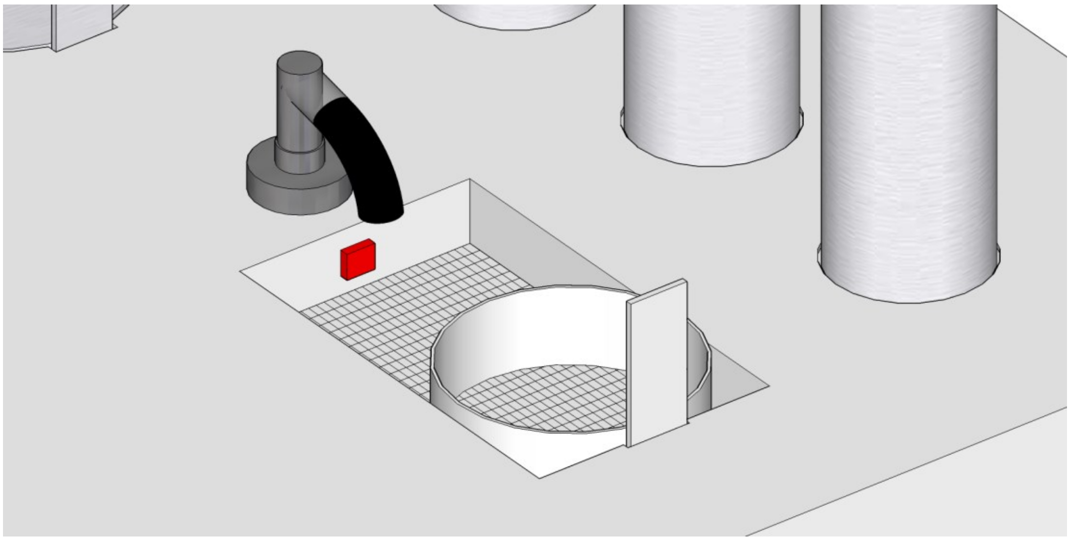


Figure B1.1.4-1 – detail of the tomato sauce ladle accommodation site.

The geometric center at recess level of the ladle accommodation site, identified with the number **L11**, is positioned at the following coordinates (see also **Figure B1.1.4-2**):

X_{11} = 215 mm

Y_{11} = 790 mm

Z_{11} = 725 mm

The recess for sauce ladle extends:

from X = 174 mm to X = 256 mm

from Y = 720 mm to Y = 860 mm

Z bottom = 725 mm

The indentation is towards the front edge of the Module 1.

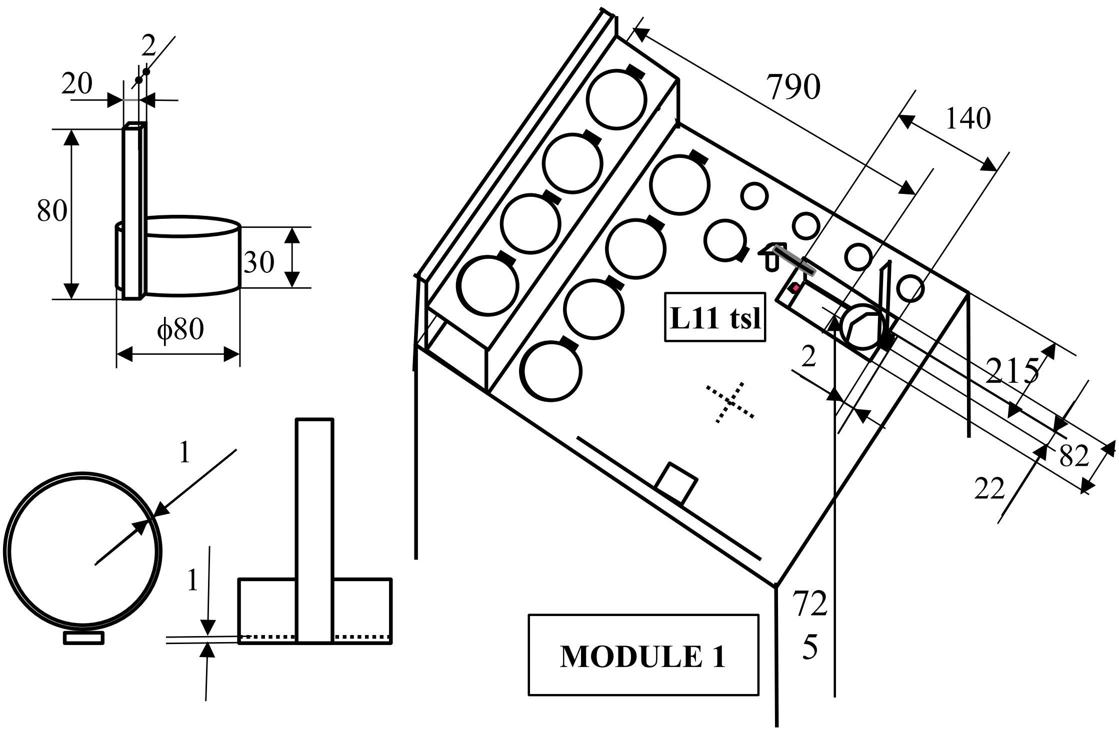


Figure B1.1.4-2 – Geometric details of tomato sauce ladle tool and its accommodation site.

The tomato ladle pick up point, identified with the code **tsl**, where the end effector has to arrive horizontal and parallel to the front wall with the gripper fingers open in a plane parallel to **X-Y**, is at the following coordinates (see also **Figure B1.1.4-3**):

$X_{tsl} = 215$ mm

$Y_{tsl} = 861$ mm

$Z_{tsl} = 795$ mm

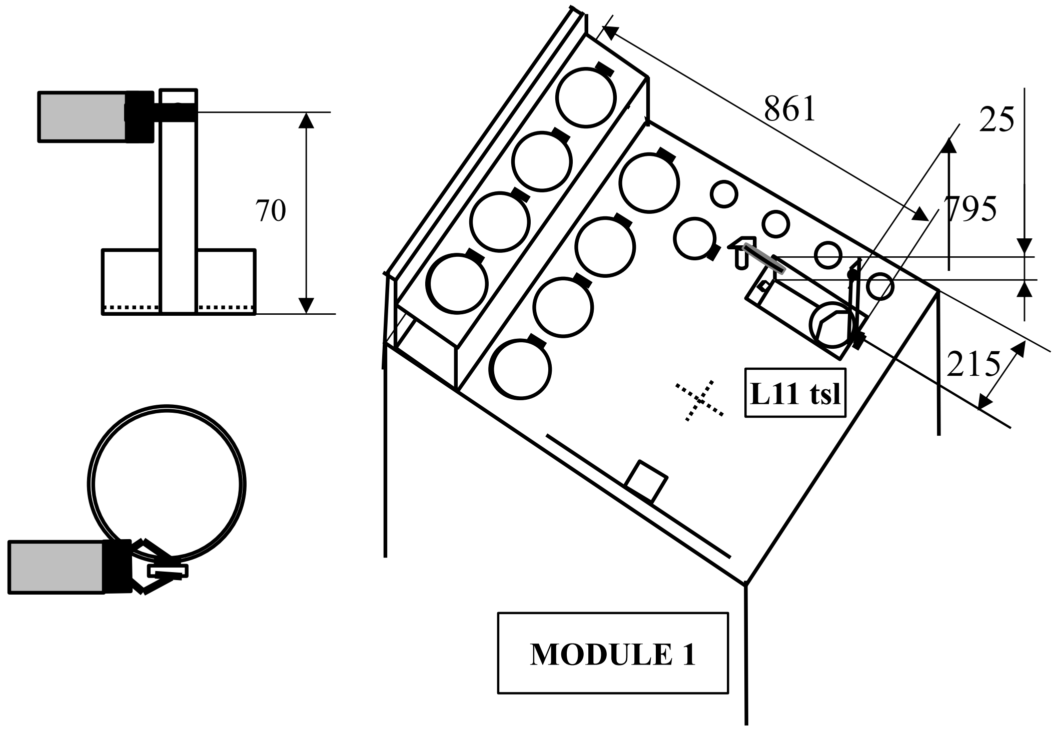


Figure B1.1.4-3 – Tomato sauce ladle pick up point and assumed gripper position.

B1.1.5 TOOL TO SPREAD CONDIMENTS

When the condiments are poured on the pizza, they may remain accumulated somewhere. For this reason, a tool is provided to spread the condiments for an even distribution of them over the pizza.

The tool is in stainless steel material and is featured as showed in **Figure B1.1.5-1**. In detail there is a circular plate of 80 mm diameter and 5 mm thickness, which is provided on the bottom with two circumferential series of teeth spaced 45° (nr. 4 plus nr. 8) at a radius distance from the center of 16 mm (nr. 4 teeth) and 33 mm (nr. 8 teeth). The height of the teeth is 20 mm, the diameter is 4 mm. Also, this tool has a simple flat bar handle of dimensions 2 x

20 x 60 mm starting from the bottom of the circular plate. The calculated weight of this tool is 0,24 kg (stainless steel specific weight = 7,85 kg/dm^3).

The accommodation site is a recess of 25 mm depth and 82 mm diameter with an indentation of 2 x 22 mm on the forward part for proper positioning of the tool. Its geometric center at recess level, identified with the number **L12**, is positioned at the following coordinates (see also **Figure B1.1.5-1**):

X_{12} = 215 mm

Y_{12} = 552 mm

Z_{12} = 725 mm

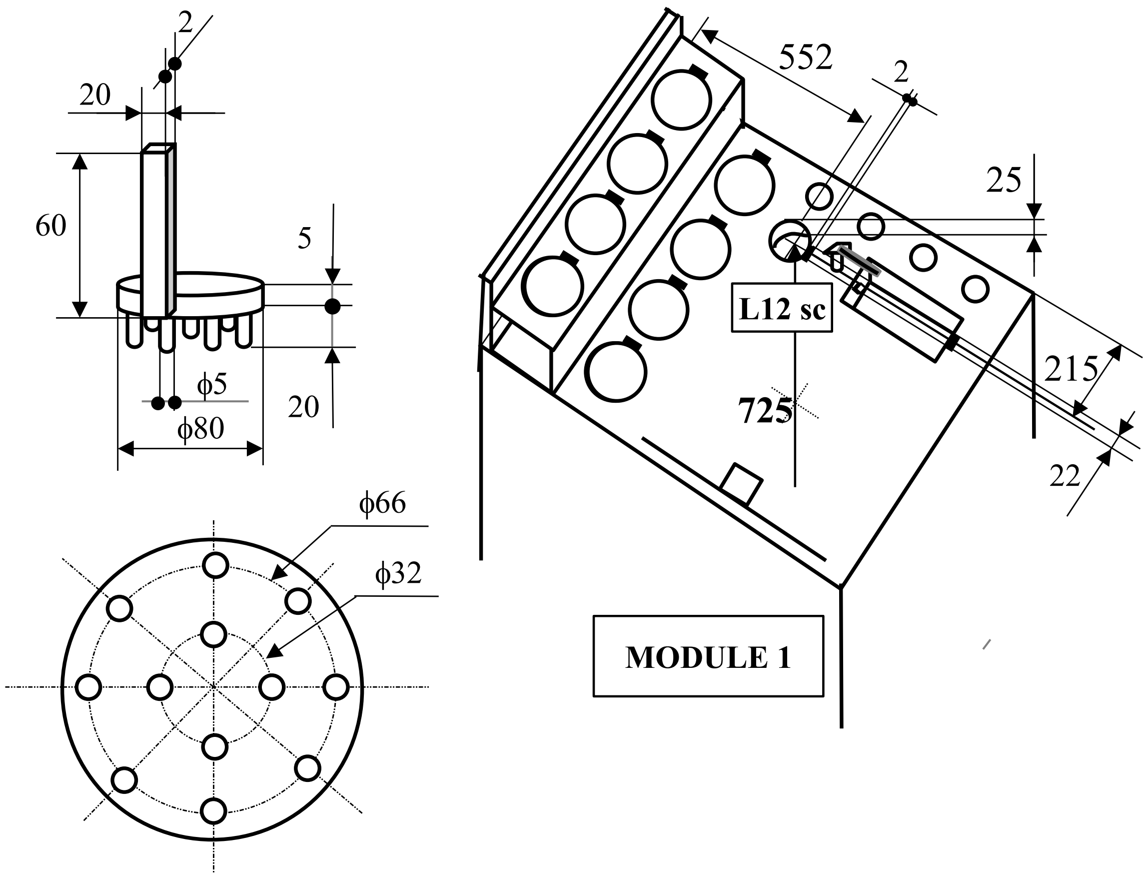


Figure B1.1.5-1 – Geometric details of condiments spreading tool and its accommodation site.

The condiments spreading tool pick up point, identified with the code **cs**, where the end effector has to arrive horizontal and parallel to the front wall with the gripper fingers open in a plane parallel to **X-Y** is at the following coordinates (see also **Figure B1.1.5-2**):

$X_{cst} = 215$ mm

$Y_{cst} = 593$ mm

$Z_{cst} = 795$ mm

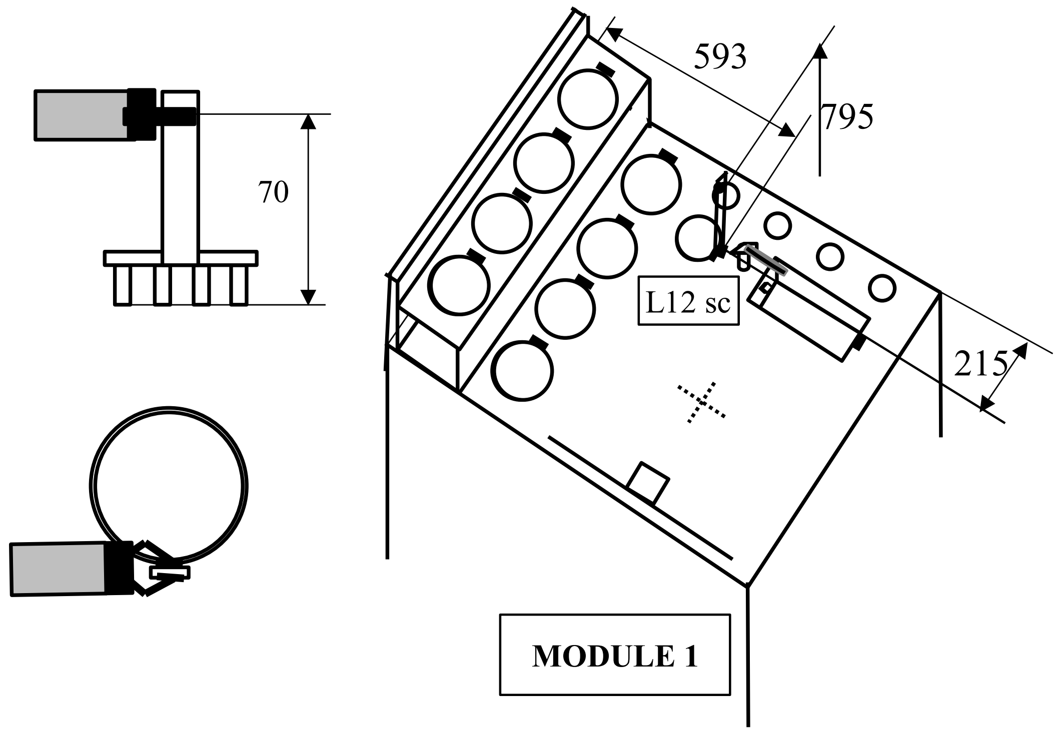


Figure B1.1.5-2 – Condiments spreading tool pick up point and assumed gripper position.

B1.1.6 ORIGAN CONTAINER

The origan container is in stainless steel material and is featured as showed in **Figure B1.1.6-1**. In detail it is of cylindrical shape with the external diameter of

50 mm, the height is 120 mm and the thickness is 0,5 mm. The base is a disc of 0,5 mm thickness and 49 mm diameter. On the top there is a grid to regulate the quantity of origan falling down on the pizza. The calculated weight of the container is approximately 0,1 kg (stainless steel specific weight = 7,85 kg/dm^3). The accommodation site is a recess of 2 mm depth and 52 mm diameter. Its geometric center at recess level, identified with the number **L13**, is positioned at the following coordinates (see also **Figure B1.1.6-1**):

X_{13} = 100 mm

Y_{13} = 552 mm

Z_{13} = 748 mm

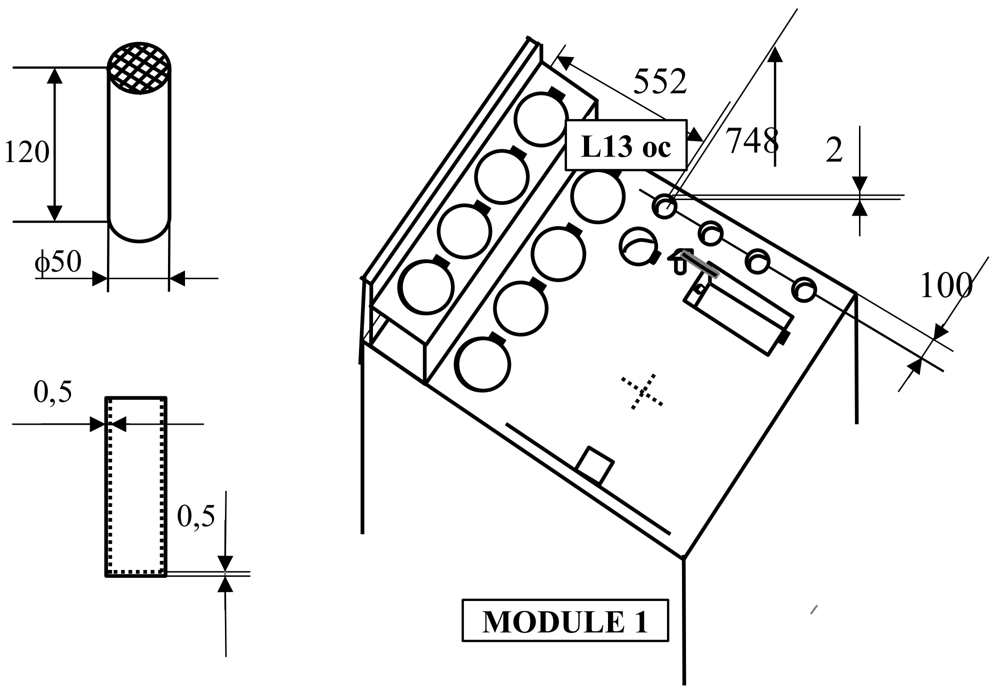


Figure B1.1.6-1 – Geometric details of origan container and its accommodation site.

The origan container pick up point, identified with the code **oc**, where the end effector has to arrive horizontal from the external right side and parallel to the front wall with the gripper fingers fully open in a plane parallel to **X-Y** is at the following coordinates (see also **Figure B1.1.6-2**). In this case the gripper will pick up directly the container:

$X_{oc} = 100$ mm
$Y_{oc} = 552$ mm
$Z_{oc} = 808$ mm

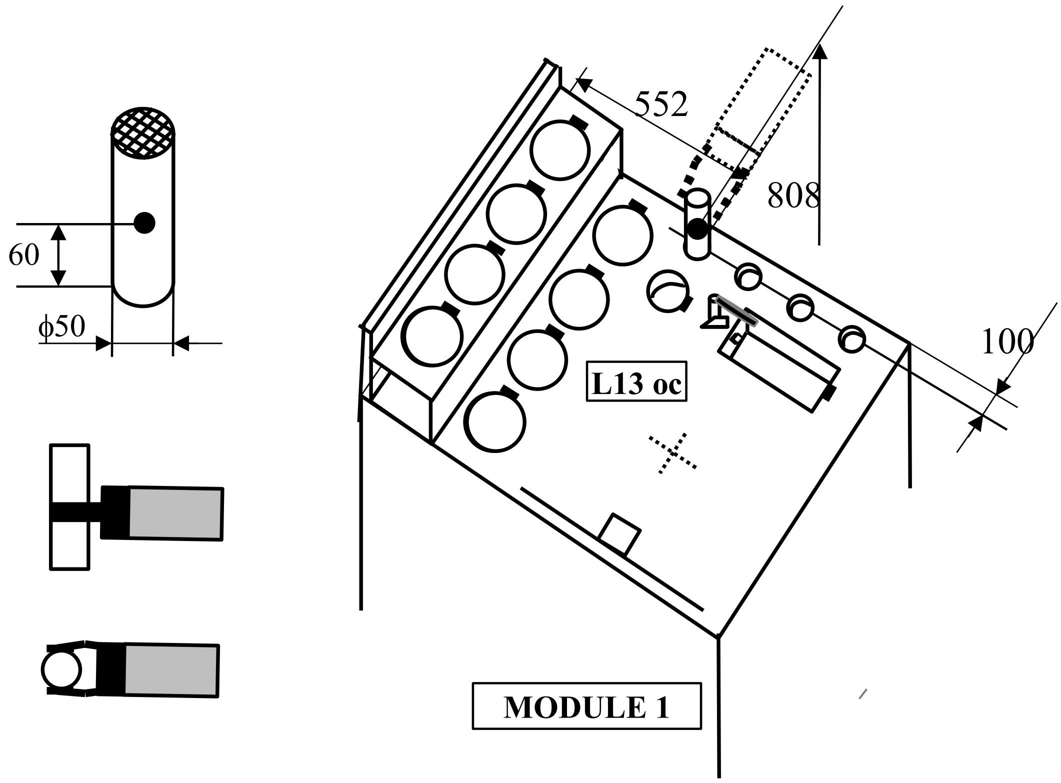


Figure B1.1.6-2 – Origan container pick up point and assumed gripper position.

B1.1.7 SALT CONTAINER

The salt container is in stainless steel material and is featured as showed in **Figure B1.1.7-1**. In detail it is of cylindrical shape with the external diameter of 50 mm, the height is 120 mm and the thickness is 0,5 mm. The base is a disc of

0,5 mm thickness and 49 mm diameter. On the top there is a grid to regulate the quantity of salt falling down on the pizza. The calculated weight of the container is approximately 0,1 kg (stainless steel specific weight = 7,85 kg/dm^3).

The accommodation site is a recess of 2 mm depth and 52 mm diameter. Its geometric center at recess level, identified with the number **L14**, is positioned at the following coordinates (see also **Figure B1.1.7-1**):

X_{14} = 100 mm
Y_{14} = 644 mm
Z_{14} = 748 mm

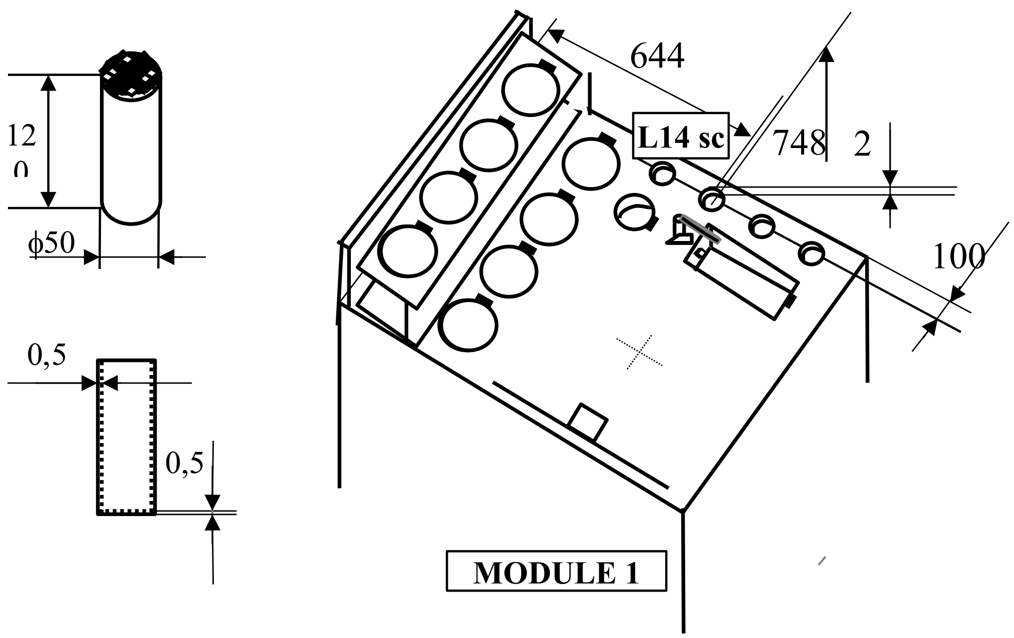


Figure B1.1.7-1 – Geometric details of salt container and of its accommodation site.

The salt container pick up point, identified with the code **sc**, where the end effector has to arrive horizontal from the external right side and parallel to the front wall with the gripper fingers fully open in a plane parallel to **X-Y** is at the following coordinates (see also **Figure B1.1.7-2**). In this case the gripper will pick up directly the container:

$X_{sc} = 100$ mm

$Y_{sc} = 644$ mm

$Z_{sc} = 808$ mm

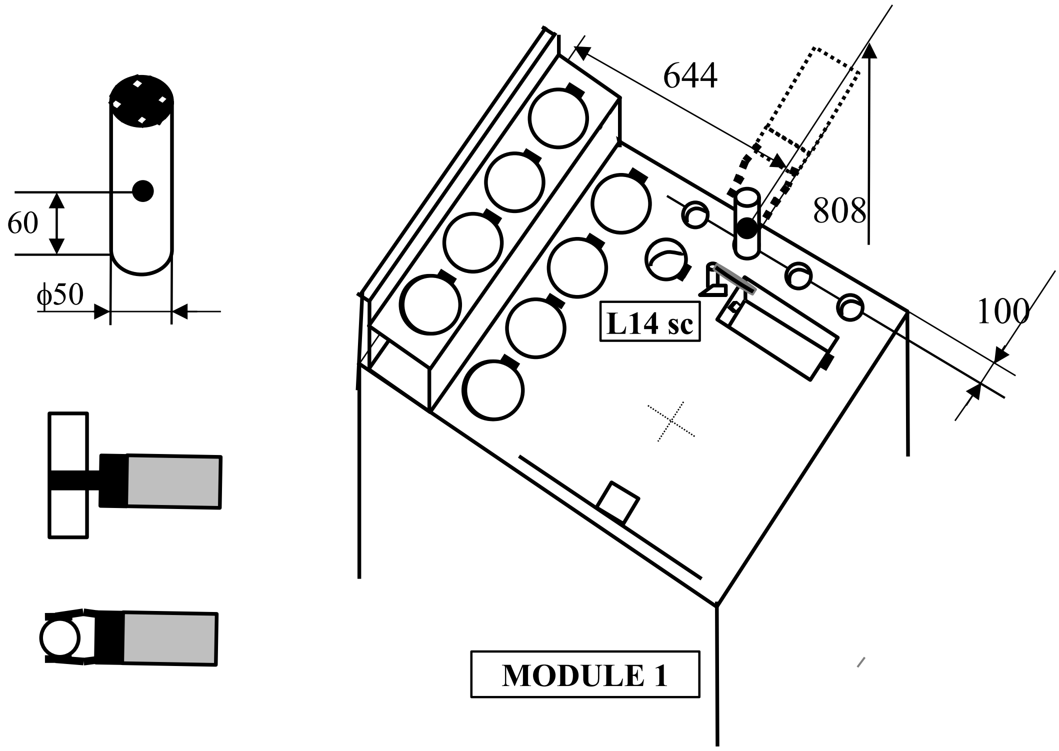


Figure B1.1.7-2 – Salt container pick up point and assumed gripper position.

B1.1.8 GARLIC CONTAINER

The garlic container is in stainless steel material and is featured as showed in **Figure B1.1.8-1**. In detail it is of cylindrical shape with the external diameter of 50 mm, the height is 120 mm and the thickness is 0,5 mm. The base is a disc of

0,5 mm thickness and 49 mm diameter. On the top there is a grid to regulate the quantity of garlic falling down on the pizza. The calculated weight of the container is approximately 0,1 kg (stainless steel specific weight = 7,85 kg/dm^3). The accommodation site is a recess of 2 mm depth and 52 mm diameter. Its geometric center at recess level, identified with the number **L15**, is positioned at the following coordinates (see also **Figure B1.1.8-1**):

X_{15} = 100 mm

Y_{15} = 736 mm

Z_{15} = 748 mm

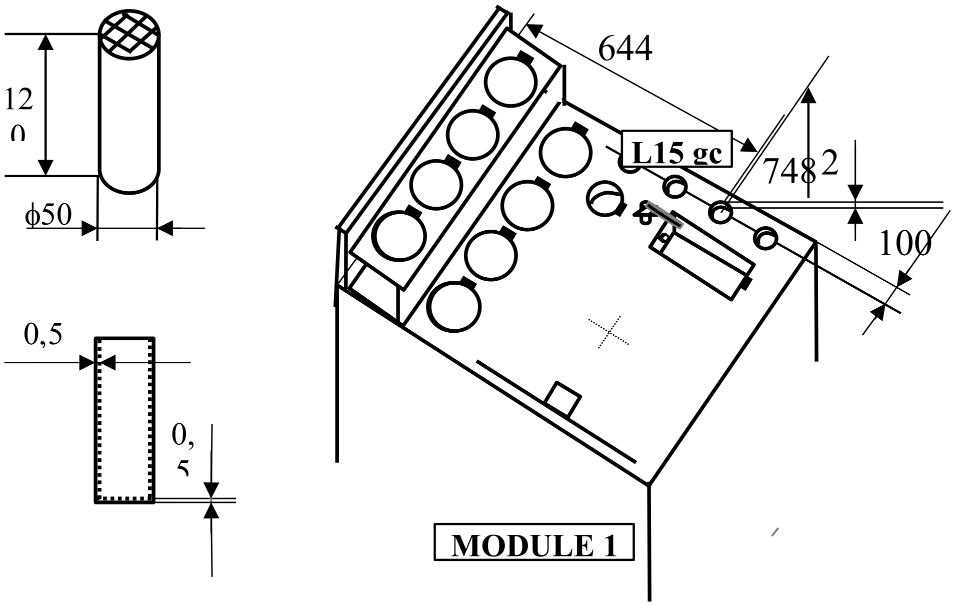


Figure B1.1.8-1 – Geometric details of garlic container and of its accommodation site.

The garlic container pick up point, identified with the code **gc**, where the end effector has to arrive horizontal from the external right side and parallel to the front wall with the gripper fingers fully open in a plane parallel to **X-Y** is at the following coordinates (see also **Figure B1.1.8-2**). In this case the gripper will pick up directly the container:

$X_{gc} = 100$ mm

$Y_{gc} = 736$ mm

$Z_{cc} = 808$ mm

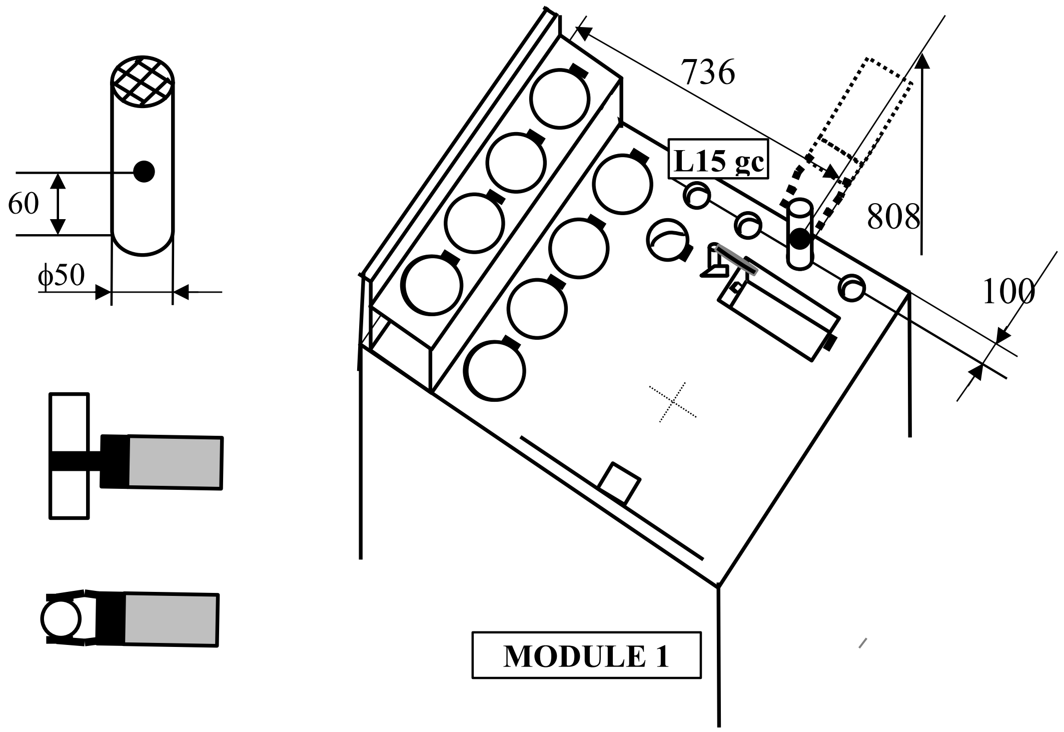


Figure B1.1.8-2 – Garlic container pick up point and assumed gripper position.

B1.1.9 OLIVE OIL CONTAINER

The olive oil container is in stainless steel material and is featured as showed in **Figure B1.1.9-1**. In detail it is of cylindrical shape with the external diameter of 50 mm, the height is 120 mm and the thickness is 0,5 mm. The base is a disc of 0,5 mm thickness and 49 mm diameter. On the top there is a typical conic nozzle 20 mm height to regulate the quantity of oil falling down on the pizza. The calculated weight of the container is approximately 0,1 kg (stainless steel specific weight = 7,85 kg/dm^3).

The accommodation site is a recess of 2 mm depth and 52 mm diameter. Its geometric center at recess level, identified with the number **L16**, is positioned at the following coordinates (see also **Figure B1.1.9-1**):

$X_{16} = 100$ mm

$Y_{16} = 828$ mm

$Z_{16} = 748$ mm

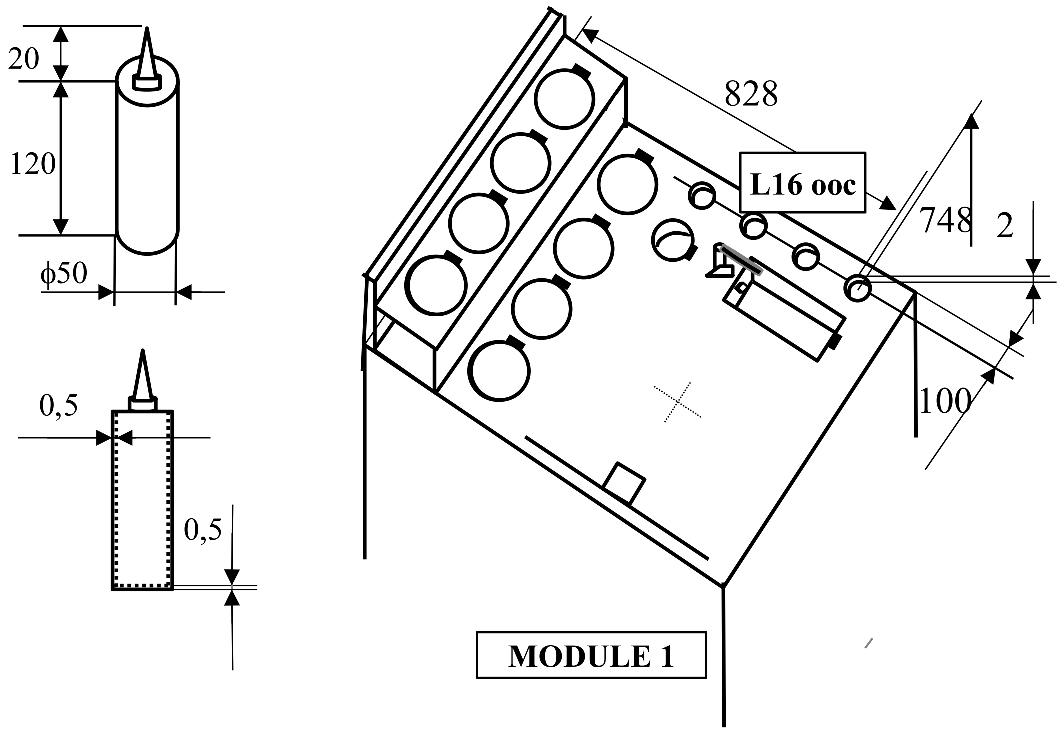


Figure B1.1.9-1 – Geometric details of olive oil container and its accommodation site.

The olive oil container pick up point, identified with the code **ooc**, where the end effector has to arrive horizontal from the external right side and parallel to the front wall with the gripper fingers fully open in a plane parallel to **X-Y** is at the following coordinates (see also **Figure B1.1.9-2**). In this case the gripper will pick up directly the container:

$X_{ooc} = 100$ mm

$Y_{ooc} = 828$ mm

$Z_{ooc} = 808$ mm

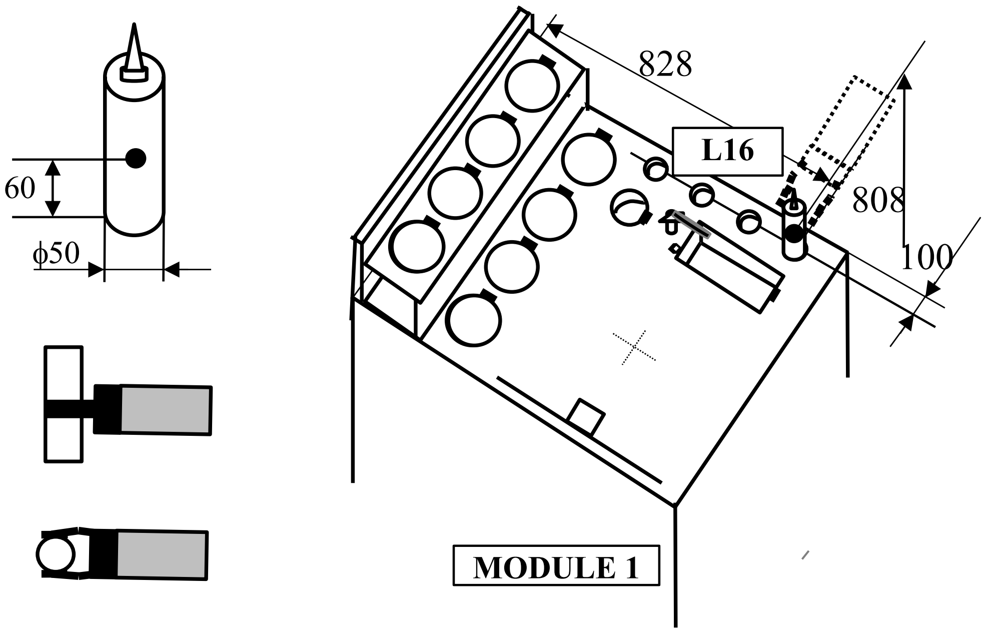


Figure B1.1.9-2 – Olive oil container pick up point and assumed gripper position.

B1.2 MODULE 2 (PIZZA DOUGH ROLL OUT MODULE)

On the pizza roll out module there are:

- the pizza dough roll out location;
- the roll pin;
- the flour container;
- nr. 10 pizza doughs partitions above the relative trays;
- a shovel.

B1.2.1 PIZZA DOUGH ROLL OUT LOCATION

The location for pizza dough roll out is a flat area of more than 470 x 470 mm, where the pizza dough partition will be rolled out by the use of the roll pin.

The center of the location on the workstation top surface, identified with the number **L17**, is at the following coordinates (see also **Figure B1.2.1-1**):

$X_{17} = 1200$ mm

$Y_{17} = 670$ mm

$Z_{17} = 750$ mm

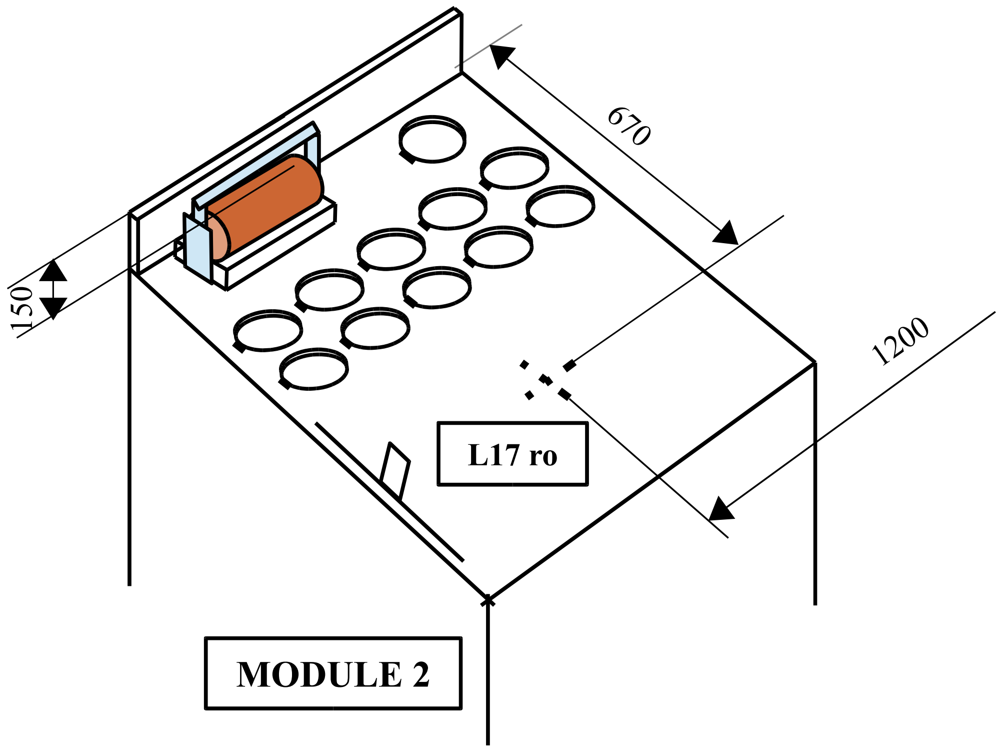


Figure B1.2.1-1 – Pizza dough roll out location.

B1.2.2 PIZZA SHOVEL 2

The pizza shovel 2 is placed in a vertical slit on the front left part of the module. It is featured as a stainless-steel material flat panel of 320 x 320 mm and 1 mm thickness with a handle angled by 45° to the vertical made by a part of the same panel and reinforced on both sides by two stainless steel plates of dimensions 40 x 50 x 2 mm. The calculated shovel weight is 0,9 kg (stainless steel specific weight = 7,85 kg/dm^3). The slit has dimensions of 3 x 324 mm at work table top surface and has a depth of 325 mm. The shovel material has been preferred to be in stainless steel to benefit of its flexibility, avoiding deformations.

The center of the slit, identified with the number **L18**, on the work table top surface is at the following coordinates (see also **Figure B1.2.2-1**):

X_{18} = 1575 mm

Y_{18} = 670 mm

Z_{18} = 750 mm

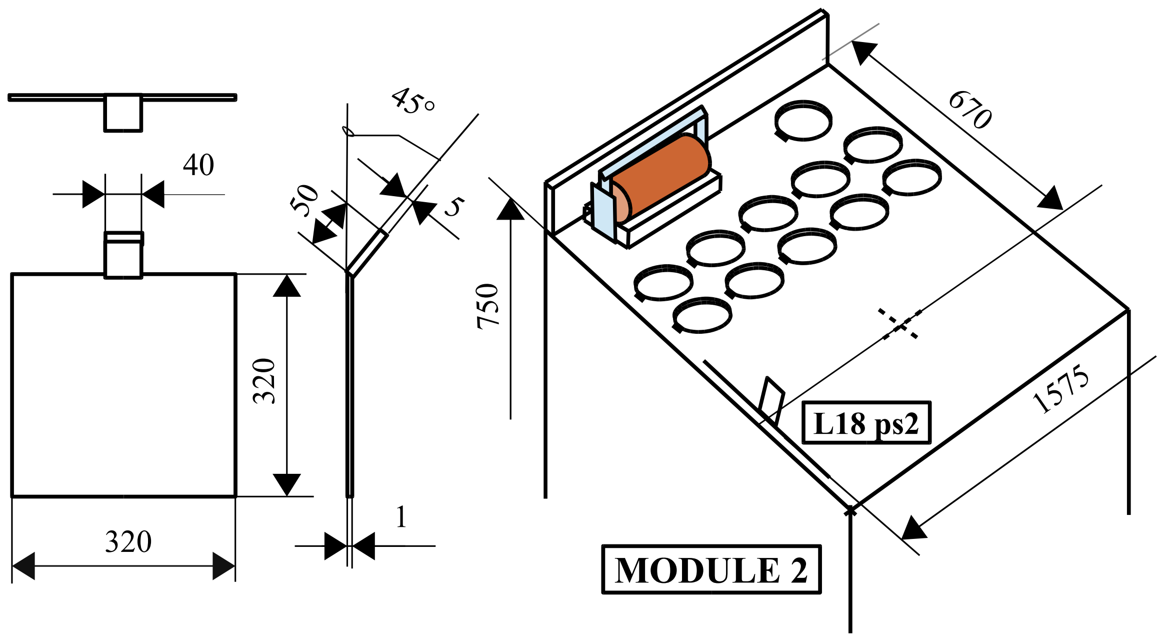


Figure B1.2.2-1 – Pizza shovel geometry and relevant location.

The pizza shovel 2 pick-up point, identified with the code **ps2**, where the end effector has to arrive angled by 45° to the vertical with the gripper fingers open is at the following coordinates (see also **Figure B1.2.2-2**):

$X_{ps2} = 1575 - 40 \text{ x } \sin 45° = 1547 \text{ mm}$

$Y_{ps2} = 670 \text{ mm}$

$Z_{ps2} = 750 + 40 \text{ x } \cos 45° = 778 \text{ mm}$

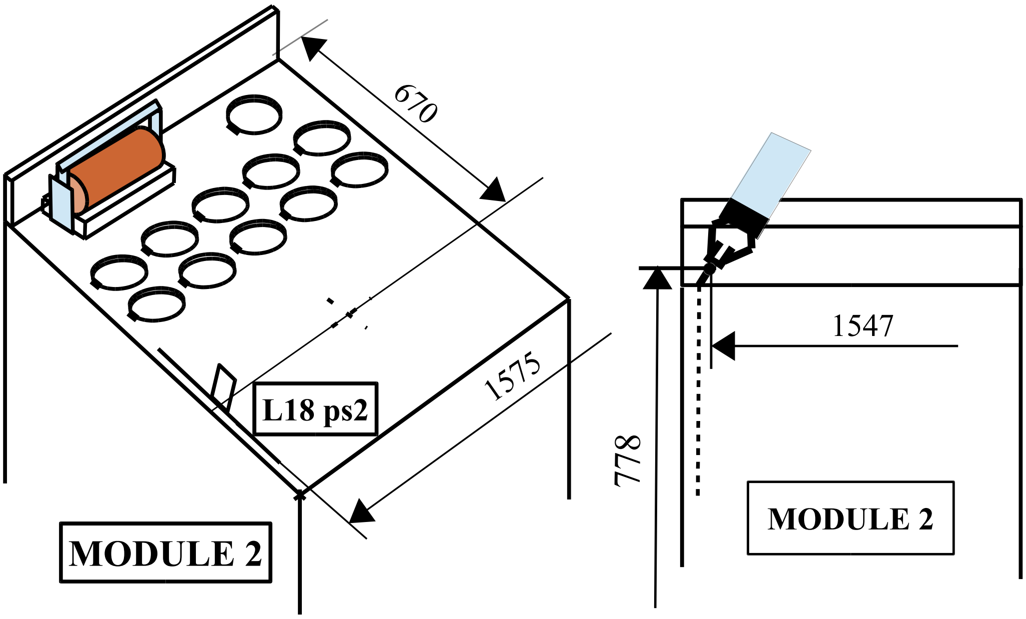


Figure B1.2.2-2 – Pizza shovel 2 pick-up point and assumed gripper position.

B1.2.3 ROLL PIN TOOL

The roll pin has a dried beech wood rolling part and an internal stainless-steel shaft rotating inside a tube of low friction material, like polytetrafluoroethylene. The shaft is welded at both extremities to a continuous C shape stainless-steel flat bar, which has in the middle a gripping point allowing the use of the roll pin by the robot.

The roll pin geometry is shown in **Figure B1.2.3-1**. The wooden rolling part has a length of 320 mm, an external diameter of 80 mm and a hollow of 22 mm diameter for the full roll pin length. The stainless-steel shaft has a diameter of 20 mm and a length of 336 mm. The stainless-steel flat bar has total dimensions of 3 x 40 x 472 mm, a "C" shape and is provided with a wing of dimensions 3 x 40 x 40 mm, which represents the pick-up point. The calculated weight of the assembly is 2,45 kg with the following details:

- dried beech wood (specific weight 0,73 kg/dm^3) = 1,09 kg
- low friction material tube (specific weight 2,2 kg/dm^3) = 0,05 kg
- stainless steel shaft (specific weight 7,85 kg/dm^3) = 0,83 kg
- stainless steel flat bar handle (specific weight 7,85 kg/dm^3) = 0,48 kg

The accommodation site is a rectangular support with a recess in the middle and extending along the full length of the support. On the left side of the support it is fixed a sort of fork where the flat bar of the roll pin acting as a handle has to be properly accommodated to prevent its falling down. The geometry of the roll pin base plus the fork is as follows (see also **Figure B1.2.3-1**):

length = 350 mm
height = 30 mm
width = 100 mm
recess depth = 6 mm
recess width = 40 mm
recess length = 350 mm
fork height = 90 mm
fork thickness = 2 mm
fork external width = 60 mm

fork internal width = 42 mm

teeth length = 10 mm

teeth width = 9 mm

Therefore, the roll pin pick-up sequence is:

- catch the pick-up point
- move the roll pin 15 mm on the right
- raise up the roll pin.

Similarly, the roll pin repositioning will require a left movement for the handle engagement.

The geometric center of the base support at recess level, identified with the number **L19**, is at the following coordinates (see also **Figure B1.2.3-1**):

X_{19} = 1278 mm

Y_{19} = 60 mm

Z_{19} = 774 mm

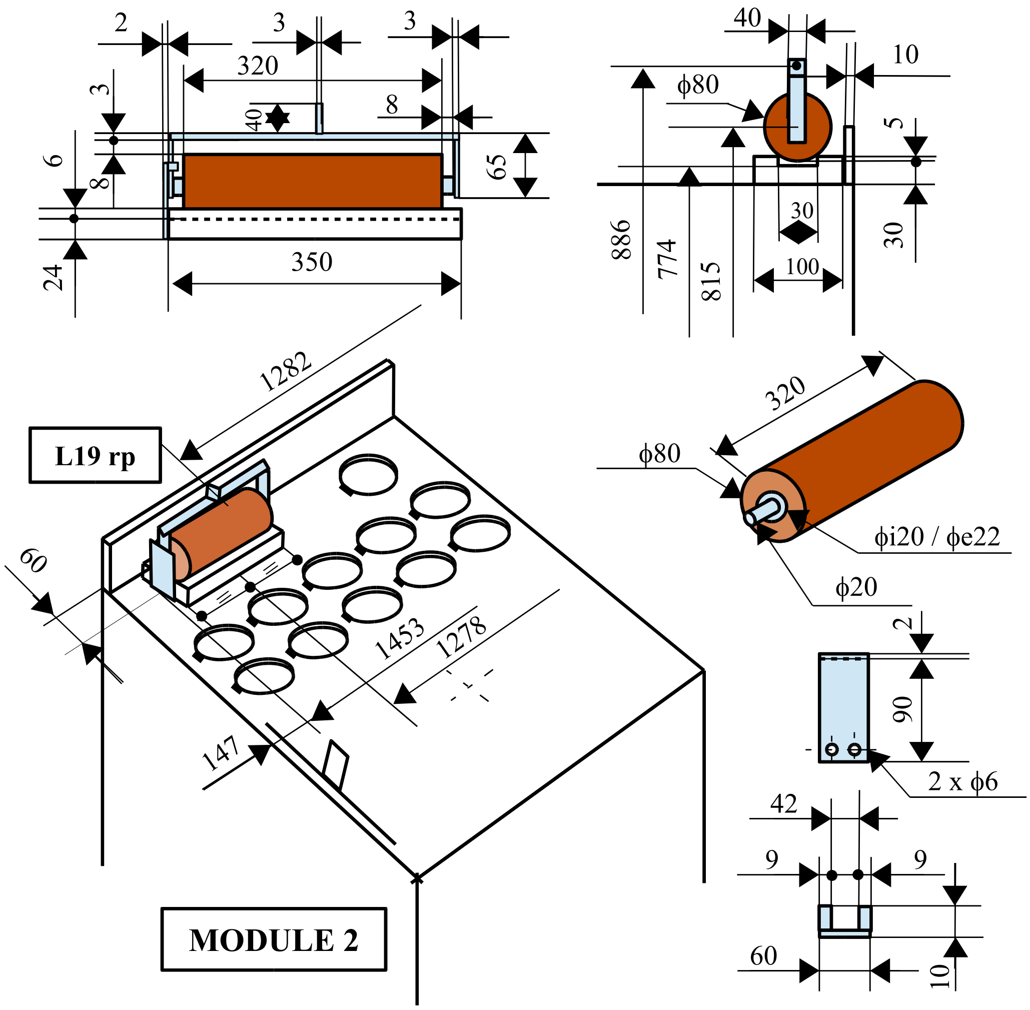


Figure B1.2.3-1 – Geometric details of roll pin and relevant accommodation.

The roll pin pick-up point, identified with the code **rp**, where the end effector has to arrive vertical with the gripper fingers open in a plane parallel to **X-Z** is at the following coordinates (see also **Figure B1.2.3-2**):

$X_{rp} = 1282$ mm

$Y_{rp} = 60$ mm

$Z_{rp} = 886$ mm

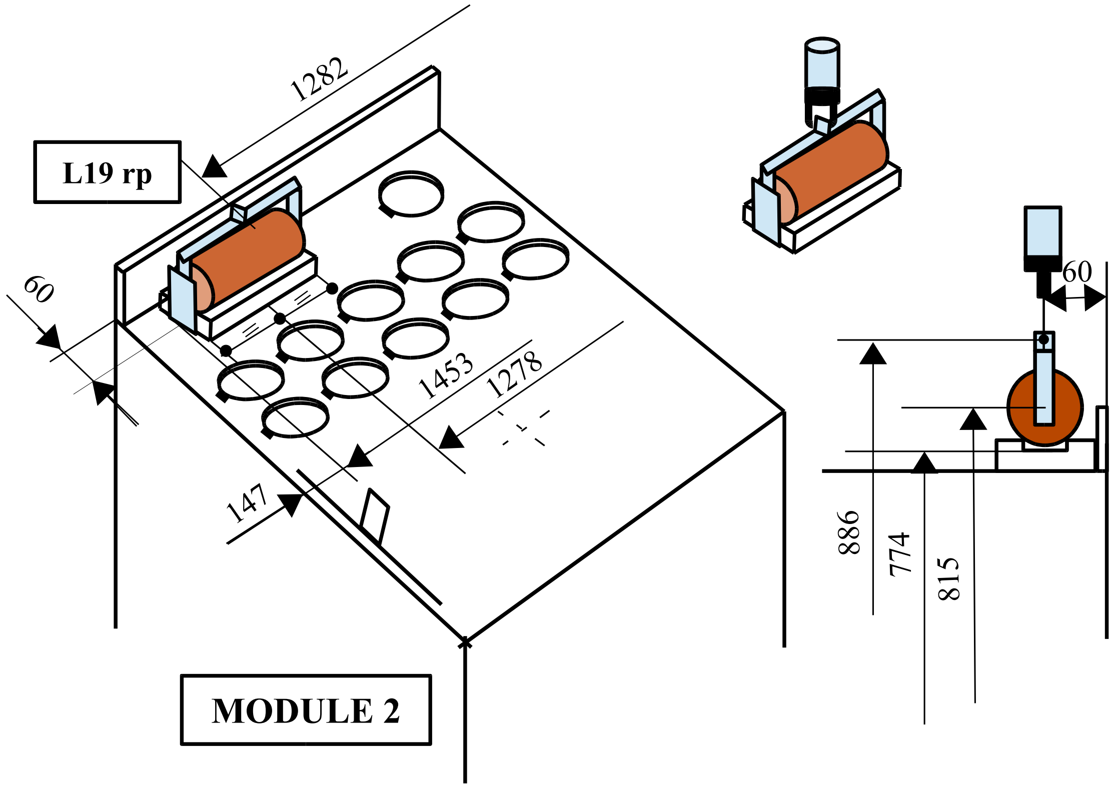


Figure B1.2.3-2 – Roll pin pick up points and assumed gripper position.

B1.2.4 FLOUR CONTAINER

The flour container is in stainless steel material and is featured as showed in **Figure B1.2.4-1**. In detail it is of cylindrical shape with the external diameter of 100 mm, the height is 160 mm and the thickness is 0,5 mm. The base is a disc of 0,5 mm thickness and 99 mm diameter. On the top there is a narrow mesh grid for fine distribution of the flour. Also, this tool has a simple flat bar handle of dimensions 2 x 20 x 190 mm starting from the bottom of the container. The calculated weight of the container is approximately 0,3 kg (stainless steel specific weight = 7,85 kg/dm^3).

The accommodation site is a recess of 2 mm depth and 102 mm diameter with an indentation of dimensions 2 x 22 mm on the left side for proper positioning on the work table during the preparation phase. The geometric center of the recess, identified with the number **L20**, is positioned at the following coordinates (see also **Figure B1.2.4-1**):

X_{20} = 950 mm

Y_{20} = 81 mm

Z_{20} = 748 mm

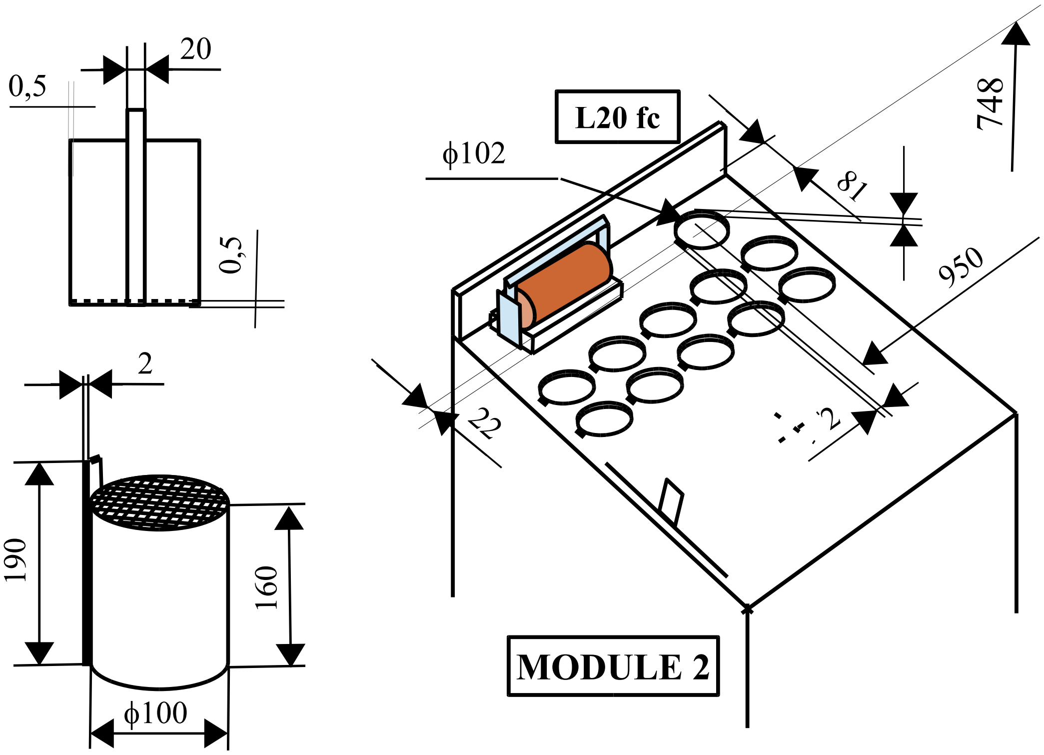


Figure B1.2.4-1 – Geometric details of flour container and its accommodation site.

The flour container pick up point, identified with the code **fc**, where the end effector has to arrive horizontal and perpendicular to the front wall with the gripper fingers open in a plane parallel to **X-Y** is at the following coordinates (see also **Figure B1.2.4-2**):

$X_{fc} = 1001$ mm

$Y_{fc} = 81$ mm

$Z_{fc} = 928$ mm

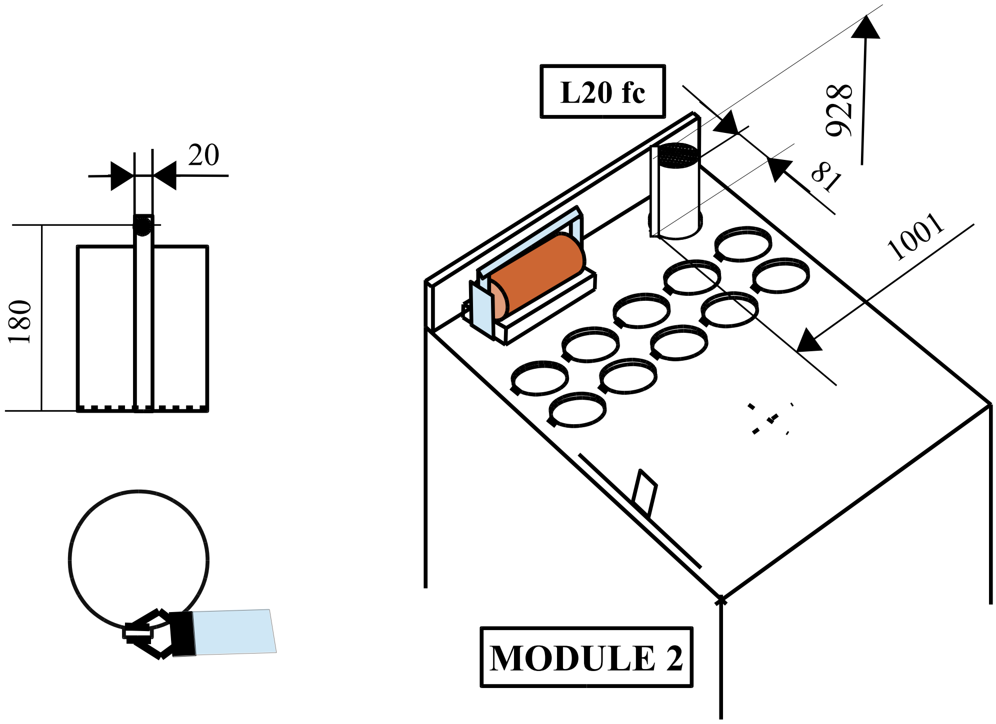


Figure B1.2.4-2 – Flour container pick up point and assumed gripper position.

B1.2.5 PIZZA DOUGH PARTITIONS TRAYS

There are nr. 10 locations for the positioning of a dough partition tray in each location. The trays are in aluminum material and are featured like a disc with a simple flat bar handle starting from the bottom of the disc. Their geometry is as follows (see also **Figure B1.2.5-1**):

diameter = 120 mm

thickness = 2 mm

handle = 2 x 20 x h42 mm

The calculated weight of the tray is approximately 0,07 kg (aluminum specific weight = 2,7 kg/dm^3).

The accommodation site is a recess of 2 mm depth and 122 mm diameter with an indentation of 2 x 22 mm on the left for proper positioning of the tool.

The geometric centers of the locations at recess level, identified with the numbers from **L21** to **L30**, are at the following coordinates (see also **Figure B1.2.5-1**):

X_{21} = 1489 mm	X_{22} = 1345 mm	X_{23} = 1201 mm	X_{24} = 1057 mm
Y_{21} = 217 mm	Y_{22} = 217 mm	Y_{23} = 217 mm	Y_{24} = 217 mm
Z_{21} = 748 mm	Z_{22} = 748 mm	Z_{23} = 748 mm	Z_{24} = 748 mm
X_{25} = 913 mm	X_{26} = 1489 mm	X_{27} = 1345 mm	X_{28} = 1201 mm
Y_{25} = 217 mm	Y_{26} = 359 mm	Y_{27} = 359 mm	Y_{28} = 359 mm
Z_{25} = 748 mm	Z_{26} = 748 mm	Z_{27} = 748 mm	Z_{28} = 748 mm
X_{29} = 1057 mm	X_{30}= 913 mm		
Y_{29} = 359 mm	Y_{30} = 359 mm		
Z_{29} = 748 mm	Z_{30} = 748 mm		

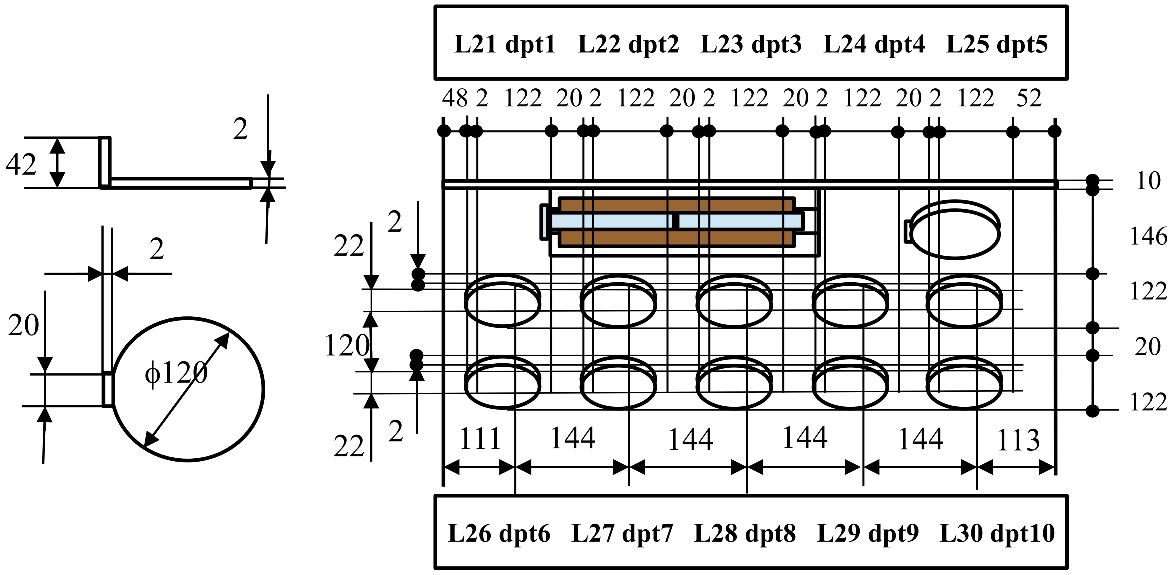


Figure B1.2.5-1 – Geometric details of pizza dough partition trays and relevant locations.

The dough partition trays pick up points, identified with the code from **dpt1** to **dpt10**, where the end effector has to arrive vertical to the work table top surface with the gripper fingers open and parallel to a plane **X-Z** are at the following coordinates (see also **Figure B1.2.5-2**):

$X_{dpt1} = 1550$ mm $X_{dpt2} = 1406$ mm $X_{dpt3} = 1262$ mm $X_{dpt4} = 1118$ mm

$Y_{dpt1} = 217$ mm $Y_{dpt2} = 217$ mm $Y_{dpt3} = 217$ mm $Y_{dpt4} = 217$ mm

$Z_{dpt1} = 780$ mm $Z_{dpt2} = 780$ mm $Z_{dpt3} = 780$ mm $Z_{dpt4} = 780$ mm

$X_{dpt5} = 974$ mm $X_{dpt6} = 1550$ mm $X_{dpt7} = 1406$ mm $X_{dpt8} = 1262$ mm

$Y_{dpt5} = 217$ mm $Y_{dpt6} = 359$ mm $Y_{dpt7} = 359$ mm $Y_{dpt8} = 359$ mm

$Z_{dpt5} = 780$ mm $Z_{dpt6} = 780$ mm $Z_{dpt7} = 780$ mm $Z_{dpt8} = 780$ mm

$X_{dpt9} = 1118$ mm $X_{dpt10}= 974$ mm

$Y_{dpt9} = 359$ mm $Y_{dpt10} = 359$ mm

$Z_{dpt9} = 780$ mm $Z_{dpt10} = 780$ mm

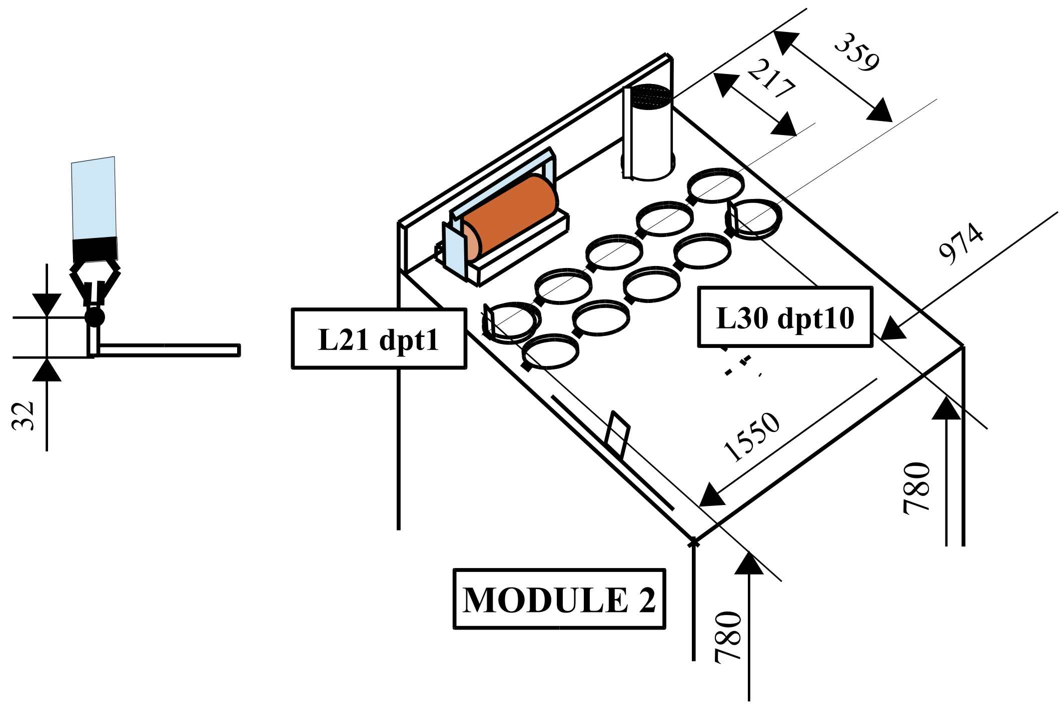


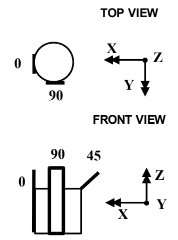
Figure B1.2.5-2 – Dough partition trays pick up points and assumed gripper position.

APPENDIX C

GRIPPING POINT TASK PATHS FOR CONFIGURATION NR. 1

TOOLS LOCATION AND PICK UP POINT COORDINATES

Location	X [mm]	Y [mm]	Z [mm]	Pick up point	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [deg]	
Base Robot 1 at rest	-400	1220	767								
C1GPR1 at rest	-257	1384	938								Gripping point Robot 1
Base Robot 1 at work	400	1220	767								
Base Robot 2 at rest	1200	1220	767								
C1GPR2 at rest	1057	1056	938								Gripping point Robot 2
Robot 1 Base change	1200	1380	767								
C1GPR2 at rest with changed Base	1057	1216	938								
C1PST1	500	1920	750								Pizza Storage 1
C1PST2	100	1920	750								Pizza Storage 2
C1PST3	-300	1920	750								Pizza Storage 3
Location 1	500	670	750	pp	500	670	750				Roll out location Module 1
Location 2	775	670	750	**ps1**	747	670	778	0	45	0	Pizza shovel 1
Location 3	683	116	848	**cc1**	602	116	1048	0	0	0	Cond cont 1 Mozzarella
Location 4	494	116	848	**cc2**	413	116	1048	0	0	0	Cond cont 1 Aubergin
Location 5	305	116	848	**cc3**	224	116	1048	0	0	0	Cond cont 1 Zucchini
Location 6	116	116	848	**cc4**	35	116	1048	0	0	0	Cond cont 1 Peppers
Location 7	683	328	748	**cc5**	602	328	948	0	0	0	Cond cont 1 Wurstels
Location 8	494	328	748	**cc6**	413	328	948	0	0	0	Cond cont 1 Sausages
Location 9	305	328	748	**cc7**	224	328	948	0	0	0	Cond cont 1 Mushrooms
Location 10	116	328	748	**cc8**	35	328	948	0	0	0	Cond cont 1 Ham
Location 11	215	790	725	**tsl**	215	861	795	0	0	90	Tomato sauce ladle
Location 12	215	552	725	**cs**	215	593	795	0	0	90	Condiment spreading tool
Location 13	100	552	748	**oc**	100	552	808				Origan container
Location 14	100	644	748	**sc**	100	644	808				Salt container
Location 15	100	736	748	**gc**	100	736	808				Garlic container
Location 16	100	828	748	**ooc**	100	828	808				Olive oil container
Location 17	1200	670	750	**ro**	1200	670	750				Pizza prep loc Module 2
Location 18	1575	670	750	**ps2**	1547	670	778	0	45	0	Pizza shovel 2
Location 19	1278	60	774	**rp**	1282	60	886	0	0	0	Roll pin
Location 20	950	81	748	**fc**	1001	81	928	0	0	0	Flour container
Location 21	1489	217	748	**dpt1**	1550	217	780	0	0	0	Dought partition tray 1
Location 22	1345	217	748	**dpt2**	1406	217	780	0	0	0	Dought partition tray 2
Location 23	1201	217	748	**dpt3**	1262	217	780	0	0	0	Dought partition tray 3
Location 24	1057	217	748	**dpt4**	1118	217	780	0	0	0	Dought partition tray 4
Location 25	913	217	748	**dpt5**	974	217	780	0	0	0	Dought partition tray 5
Location 26	1489	359	748	**dpt6**	1550	359	780	0	0	0	Dought partition tray 6
Location 27	1345	359	748	**dpt7**	1406	359	780	0	0	0	Dought partition tray 7
Location 28	1201	359	748	**dpt8**	1262	359	780	0	0	0	Dought partition tray 8
Location 29	1057	359	748	**dpt9**	1118	359	780	0	0	0	Dought partition tray 9
Location 30	913	359	748	**dpt10**	974	359	780	0	0	0	Dought partition tray 10



ROBOT 2

C1R2T1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set **8**
	before to start check if a request to go at rest position arrives from R1										
at pos fc	1001	81	928	90	90	180	2	1	3	0	
pick up fc	1001	81	928	90	90	180	2	1	3	1	
raise up 100	1001	81	1028	90	90	180	2	1	3	1	
over Loc 17	1200	670	960	90	90	180	2	1	3	1	
flour spread	1220	705	960	90	90	240	2	1	3	1	
“	1242	712	960	90	90	300	2	1	3	1	
“	1287	720	960	90	90	360	2	1	3	1	
“	1300	670	960	90	90	90	2	1	3	1	
“	1287	620	960	90	90	180	2	1	3	1	
“	1271	599	960	90	90	240	2	1	3	1	
“	1250	583	960	90	90	300	2	1	3	1	
“	1200	570	960	90	90	360	2	1	3	1	
“	1150	583	960	90	90	60	2	1	3	1	
“	1129	599	960	90	90	120	2	1	3	1	
“	1113	620	960	90	90	180	2	1	3	1	
“	1100	670	960	90	90	240	2	1	3	1	
“	1113	720	960	90	90	360	2	1	3	1	
“	1129	741	960	90	90	60	2	1	3	1	
“	1150	757	960	90	90	120	2	1	3	1	
“	1200	770	960	90	90	180	2	1	3	1	
above pos fc	1001	81	1028	90	90	180	2	1	3	1	
leave fc	1001	81	928	90	90	180	2	1	3	1	
open gripper	1001	81	928	90	90	180	2	1	3	0	
raise up 100	1001	81	1028	90	90	180	2	1	3	0	
			continue with next task								

C1R2T2–dpt1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
	before to start check if a request to go at rest position arrives from R1										
at pos dpt1	1550	217	780	180	0	90	1	2	3	0	
pick up dpt1	1550	217	780	180	0	90	1	2	3	1	
raise up 100	1550	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt1	1550	217	880	180	0	90	1	2	3	1	
leave dpt1	1550	217	780	180	0	90	1	2	3	1	
open gripper	1550	217	780	180	0	90	1	2	3	0	
raise up 100	1550	217	880	180	0	90	1	2	3	0	
	continue with next task										

C1R2T2–dpt2	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
	before to start check if a request to go at rest position arrives from R1										
at pos dpt2	1406	217	780	180	0	90	1	2	3	0	
pick up dpt2	1406	217	780	180	0	90	1	2	3	1	
raise up 100	1406	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt2	1406	217	880	180	0	90	1	2	3	1	
leave dpt2	1406	217	780	180	0	90	1	2	3	1	
open gripper	1406	217	780	180	0	90	1	2	3	0	
raise up 100	1406	217	880	180	0	90	1	2	3	0	
	continue with next task										

C1R2T2–dpt3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
	before to start check if a request to go at rest position arrives from R1										
at pos dpt3	1262	217	780	180	0	90	1	2	3	0	
pick up dpt3	1262	217	780	180	0	90	1	2	3	1	
raise up 100	1262	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt3	1262	217	880	180	0	90	1	2	3	1	
leave dpt3	1262	217	780	180	0	90	1	2	3	1	
open gripper	1262	217	780	180	0	90	1	2	3	0	
raise up 100	1262	217	880	180	0	90	1	2	3	0	
	continue with next task										

C1R2T2–dpt4	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
	before to start check if a request to go at rest position arrives from R1										
at pos dpt4	1118	217	780	180	0	90	1	2	3	0	
pick up dpt4	1118	217	780	180	0	90	1	2	3	1	
raise up 100	1118	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt4	1118	217	880	180	0	90	1	2	3	1	
leave dpt4	1118	217	780	180	0	90	1	2	3	1	
open gripper	1118	217	780	180	0	90	1	2	3	0	
raise up 100	1118	217	880	180	0	90	1	2	3	0	
	continue with next task										

C1R2T2–dpt5	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											6
before to start check if a request to go at rest position arrives from R1											
at pos dpt5	974	217	780	180	0	90	1	2	3	0	
pick up dpt5	974	217	780	180	0	90	1	2	3	1	
raise up 100	974	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt5	974	217	880	180	0	90	1	2	3	1	
leave dpt5	974	217	780	180	0	90	1	2	3	1	
open gripper	974	217	780	180	0	90	1	2	3	0	
raise up 100	974	217	880	180	0	90	1	2	3	0	
continue with next task											

C1R2T2–dpt6	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											6
before to start check if a request to go at rest position arrives from R1											
at pos dpt6	1550	359	780	180	0	90	1	2	3	0	
pick up dpt6	1550	359	780	180	0	90	1	2	3	1	
raise up 100	1550	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt6	1550	359	880	180	0	90	1	2	3	1	
leave dpt6	1550	359	780	180	0	90	1	2	3	1	
open gripper	1550	359	780	180	0	90	1	2	3	0	
raise up 100	1550	359	880	180	0	90	1	2	3	0	
continue with next task											

C1R2T2–dpt7	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											6
before to start check if a request to go at rest position arrives from R1											
at pos dpt7	1406	359	780	180	0	90	1	2	3	0	
pick up dpt7	1406	359	780	180	0	90	1	2	3	1	
raise up 100	1406	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt7	1406	359	880	180	0	90	1	2	3	1	
leave dpt7	1406	359	780	180	0	90	1	2	3	1	
open gripper	1406	359	780	180	0	90	1	2	3	0	
raise up 100	1406	359	880	180	0	90	1	2	3	0	
continue with next task											

C1R2T2–dpt8	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											6
before to start check if a request to go at rest position arrives from R1											
at pos dpt8	1262	359	780	180	0	90	1	2	3	0	
pick up dpt8	1262	359	780	180	0	90	1	2	3	1	
raise up 100	1262	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt8	1262	359	880	180	0	90	1	2	3	1	
leave dpt8	1262	359	780	180	0	90	1	2	3	1	
open gripper	1262	359	780	180	0	90	1	2	3	0	
raise up 100	1262	359	880	180	0	90	1	2	3	0	
continue with next task											

C1R2T2–dpt9	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											6
	before to start check if a request to go at rest position arrives from R1										
at pos dpt9	1118	359	780	180	0	90	1	2	3	0	
pick up dpt9	1118	359	780	180	0	90	1	2	3	1	
raise up 100	1118	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt9	1118	359	880	180	0	90	1	2	3	1	
leave dpt9	1118	359	780	180	0	90	1	2	3	1	
open gripper	1118	359	780	180	0	90	1	2	3	0	
raise up 100	1118	359	880	180	0	90	1	2	3	0	
	continue with next task										

C1R2T2–dpt10	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											6
	before to start check if a request to go at rest position arrives from R1										
at pos dpt10	974	359	780	180	0	90	1	2	3	0	
pick up dpt10	974	359	780	180	0	90	1	2	3	1	
raise up 100	974	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt10	974	359	880	180	0	90	1	2	3	1	
leave dpt10	974	359	780	180	0	90	1	2	3	1	
open gripper	974	359	780	180	0	90	1	2	3	0	
raise up 100	974	359	880	180	0	90	1	2	3	0	
	continue with next task										

C1R2T3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos rp	1282	60	886	180	0	90	1	2	3	0	
pick up rp	1282	60	886	180	0	90	1	2	3	1	
rp release	1267	60	886	180	0	90	1	2	3	1	
raise up	1267	60	986	180	0	90	1	2	3	1	
CART back 160	1267	220	986	180	0	90	1	2	3	1	CART movement ONLY
R2 Base reference change	1267	220	986	180	0	90	1	2	3	1	R2 Base refer change
above Loc 17	1200	670	986	180	0	90	1	2	3	1	
down h40 (bottom of roll pin)	1200	670	901	180	0	90	1	2	3	1	
N 80 h36 CART	1200	590	897	180	0	90	1	2	3	1	CART movement ONLY
S 160 h36 CART	1200	750	897	180	0	90	1	2	3	1	CART movement ONLY
CART to centre	1200	670	897	180	0	90	1	2	3	1	CART movement ONLY
turn by 90°	1200	670	897	180	0	180	1	2	3	1	
E 80 h32 CART	1120	670	893	180	0	180	1	2	3	1	CART movement ONLY
W 160 h32 CART	1280	670	893	180	0	180	1	2	3	1	CART movement ONLY
CART to centre	1200	670	893	180	0	180	1	2	3	1	CART movement ONLY
turn by -45°	1200	670	893	180	0	135	1	2	3	1	
NE 120 h28 CART	1115	585	889	180	0	135	1	2	3	1	CART movement ONLY
SW 240 h28 CART	1285	755	889	180	0	135	1	2	3	1	CART movement ONLY
CART to centre	1200	670	889	180	0	135	1	2	3	1	CART movement ONLY
turn by -90°	1200	670	889	180	0	45	1	2	3	1	
NW 120 h24 CART	1285	585	885	180	0	45	1	2	3	1	CART movement ONLY
SE 240 h24 CART	1115	755	885	180	0	45	1	2	3	1	CART movement ONLY
CART to centre	1200	670	885	180	0	45	1	2	3	1	CART movement ONLY
turn by 45°	1200	670	885	180	0	90	1	2	3	1	
N 160 h20 CART	1200	510	881	180	0	90	1	2	3	1	CART movement ONLY
S 320 h20 CART	1200	830	881	180	0	90	1	2	3	1	CART movement ONLY
CART to centre	1200	670	881	180	0	90	1	2	3	1	CART movement ONLY
turn by 90°	1200	670	881	180	0	180	1	2	3	1	
E 160 h16 CART	1040	670	877	180	0	180	1	2	3	1	CART movement ONLY
W 320 h16 CART	1360	670	877	180	0	180	1	2	3	1	CART movement ONLY
CART to centre	1200	670	877	180	0	180	1	2	3	1	CART movement ONLY
turn by -45°	1200	670	877	180	0	135	1	2	3	1	
NE 160 h12 CART	1087	557	873	180	0	135	1	2	3	1	CART movement ONLY
SW 320 h12 CART	1313	783	873	180	0	135	1	2	3	1	CART movement ONLY
CART to centre	1200	670	873	180	0	135	1	2	3	1	CART movement ONLY
turn by -90°	1200	670	873	180	0	45	1	2	3	1	
NW 160 h8 CART	1313	557	869	180	0	45	1	2	3	1	CART movement ONLY
SE 320 h8 CART	1087	783	869	180	0	45	1	2	3	1	CART movement ONLY
CART to centre	1200	670	869	180	0	45	1	2	3	1	CART movement ONLY
turn by 45°	1200	670	869	180	0	90	1	2	3	1	
N 160 h7 CART	1200	510	868	180	0	90	1	2	3	1	CART movement ONLY
S 320 h7 CART	1200	830	868	180	0	90	1	2	3	1	CART movement ONLY
CART to centre	1200	670	868	180	0	90	1	2	3	1	CART movement ONLY
turn by 90°	1200	670	868	180	0	180	1	2	3	1	
E 160 h6 CART	1040	670	867	180	0	180	1	2	3	1	CART movement ONLY
W 320 h6 CART	1360	670	867	180	0	180	1	2	3	1	CART movement ONLY
CART to centre	1200	670	867	180	0	180	1	2	3	1	CART movement ONLY
turn by -45°	1200	670	867	180	0	135	1	2	3	1	
NE 160 h5 CART	1087	557	866	180	0	135	1	2	3	1	CART movement ONLY
SW 320 h5 CART	1313	783	866	180	0	135	1	2	3	1	CART movement ONLY
CART to centre	1200	670	866	180	0	135	1	2	3	1	CART movement ONLY
turn by -90°	1200	670	866	180	0	45	1	2	3	1	
NW 160 h4 CART	1313	557	865	180	0	45	1	2	3	1	CART movement ONLY
SE 320 h4 CART	1087	783	865	180	0	45	1	2	3	1	CART movement ONLY
CART to centre	1200	670	865	180	0	45	1	2	3	1	CART movement ONLY
turn by 45°	1200	670	865	180	0	90	1	2	3	1	
raise up	1200	670	986	180	0	90	1	2	3	1	
CART forward 160	1200	510	865	180	0	90	1	2	3	1	CART movement ONLY
R2 Base reference change	1200	510	865	180	0	90	1	2	3	1	R2 Base refer change
back to pos rp	1267	60	986	180	0	90	1	2	3	1	
down to Loc 19	1267	60	886	180	0	90	1	2	3	1	
engaging	1282	60	886	180	0	90	1	2	3	1	
open gripper	1282	60	886	180	0	90	1	2	3	0	
raise up 100	1282	60	986	180	0	90	1	2	3	0	
continue with next task											

C1R2T4	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
send request to R1											
70 & -30° Northwise of ps2	1547	600	778	180	45	90	1	2	3	0	
at pos ps2	1547	670	778	180	45	90	1	2	3	0	
pick up ps2	1547	670	778	180	45	90	1	2	3	1	
raise 340	1547	670	1118	180	45	90	1	2	3	1	
rotation 90°	1547	670	1118	180	-45	90	1	2	3	1	
GP h28 & 508 Westwise Loc 17	1708	670	778	180	-45	90	1	2	3	1	
pick up pizza move CART 320 Eastwise	1388	670	778	180	-45	90	1	2	3	1	**CART movement ONLY**
stby for R1 conf & R1 800 East	1388	670	778	180	-45	90	1	2	3	1	
raise up h104	1388	670	867	180	-45	90	1	2	3	1	
move to L1 CART 719 Eastwise	669	670	867	180	-45	90	1	2	3	1	**CART movement ONLY**
rotation -15°	669	670	867	180	-30	90	1	2	3	1	
move 20 Westwise (shake)	689	670	867	180	-30	90	1	2	3	1	
move 20 Eastwise (shake)	669	670	867	180	-30	90	1	2	3	1	
Rotation 15°	669	670	867	180	-45	90	1	2	3	1	
move CART 1039 Westwise	1708	670	867	180	-45	90	1	2	3	1	**CART movement ONLY**
up to 1116 and right to 1560	1547	670	1118	180	-45	90	1	2	3	1	
Rotation -90°	1547	670	1118	180	45	90	1	2	3	1	
down to Loc 18	1547	670	778	180	45	90	1	2	3	1	
send finish info to R1	1547	670	778	180	45	90	1	2	3	1	
open gripper	1547	670	778	180	45	90	1	2	3	0	
disingage	1547	600	778	180	45	90	1	2	3	0	
raise 100	1547	600	878	180	45	90	1	2	3	0	
continue with next task or stop at rest if dpti = dpt10											

ROBOT 1

C1R1T1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
before to start check if a request to remain at rest position arrives from R2											
after R2 confirmation											
at pos tsl	215	861	795	0	-90	0	2	1	3	0	
pick up tsl	215	861	795	0	-90	0	2	1	3	1	
move forward 60	215	801	795	0	-90	0	2	1	3	1	
wait 3 sec to collect souce	215	801	795	0	-90	0	2	1	3	1	souce from dispenser
move backward 40	215	821	795	0	-90	0	2	1	3	1	
raise by 145	215	821	940	0	-90	0	2	1	3	1	
W2 rotation +90	450	586	940	90	-90	0	2	1	3	1	
over Loc 1 centre	500	670	940	90	-90	0	2	1	3	1	
W3 rotation +90	500	670	940	90	-90	-90	2	1	3	1	
W3 rotation +180	500	670	940	90	-90	-180	2	1	3	1	
W3 rotation +270	500	670	940	90	-90	-270	2	1	3	1	
W3 rotation +360	500	670	940	90	-90	-360	2	1	3	1	
move down by 115	500	670	825	90	-90	0	2	1	3	1	
spread tomato sauce	510	687	825	90	-90	0	2	1	3	1	
“	528	698	825	90	-90	0	2	1	3	1	
“	540	670	825	90	-90	0	2	1	3	1	
“	528	642	825	90	-90	0	2	1	3	1	
“	500	630	825	90	-90	0	2	1	3	1	
“	472	642	825	90	-90	0	2	1	3	1	
“	460	670	825	90	-90	0	2	1	3	1	
“	448	700	825	90	-90	0	2	1	3	1	
“	450	757	825	90	-90	0	2	1	3	1	
“	500	780	825	90	-90	0	2	1	3	1	
“	555	765	825	90	-90	0	2	1	3	1	
“	595	725	825	90	-90	0	2	1	3	1	
“	610	670	825	90	-90	0	2	1	3	1	
“	595	615	825	90	-90	0	2	1	3	1	
“	555	575	825	90	-90	0	2	1	3	1	
“	500	560	825	90	-90	0	2	1	3	1	
“	445	575	825	90	-90	0	2	1	3	1	
“	405	615	825	90	-90	0	2	1	3	1	
“	390	670	825	90	-90	0	2	1	3	1	
“	422	715	825	90	-90	0	2	1	3	1	
“	465	690	825	90	-90	0	2	1	3	1	
“	500	670	825	90	-90	0	2	1	3	1	
raise up by 100	500	670	925	90	-90	0	2	1	3	1	
above pos tsl	215	861	925	0	-90	0	2	1	3	1	
W2 rotation -90	215	861	925	0	-90	0	2	1	3	1	
leave tsl	215	861	795	0	-90	0	2	1	3	1	
open gripper	215	861	795	0	-90	0	2	1	3	0	
raise up 100	215	861	895	0	-90	0	2	1	3	0	
continue with next task											

C1R1T2-cc1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
			to be always completed								
at pos cc1	602	116	1048	90	90	180	2	1	3	0	
pick up cc1	602	116	1048	90	90	180	2	1	3	1	
raise up 100	602	116	1148	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc1	602	116	1148	90	90	180	2	1	3	1	
leave cc1	602	116	1048	90	90	180	2	1	3	1	
open gripper	602	116	1048	90	90	180	2	1	3	0	
raise up 100	602	116	1148	90	90	180	2	1	3	0	
			continue with next task								

C1R1T2-cc2	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
			to be always completed								
at pos cc2	413	116	1048	90	90	180	2	1	3	0	
pick up cc2	413	116	1048	90	90	180	2	1	3	1	
raise up 100	413	116	1148	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc2	413	116	1148	90	90	180	2	1	3	1	
leave cc2	413	116	1048	90	90	180	2	1	3	1	
open gripper	413	116	1048	90	90	180	2	1	3	0	
raise up 100	413	116	1148	90	90	180	2	1	3	0	
			continue with next task								

C1R1T2-cc3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
			to be always completed								
at pos cc3	224	116	1048	90	90	180	2	1	3	0	
pick up cc3	224	116	1048	90	90	180	2	1	3	1	
raise up 100	224	116	1148	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc3	224	116	1148	90	90	180	2	1	3	1	
leave cc3	224	116	1048	90	90	180	2	1	3	1	
open gripper	224	116	1048	90	90	180	2	1	3	0	
raise up 100	224	116	1148	90	90	180	2	1	3	0	
			continue with next task								

C1R1T2-cc4	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											1
		to be always completed									
at pos cc4	35	116	1048	90	90	180	2	1	3	0	
pick up cc4	35	116	1048	90	90	180	2	1	3	1	
raise up 100	35	116	1148	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc4	35	116	1148	90	90	180	2	1	3	1	
leave cc4	35	116	1048	90	90	180	2	1	3	1	
open gripper	35	116	1048	90	90	180	2	1	3	0	
raise up 100	35	116	1148	90	90	180	2	1	3	0	
		continue with next task									

C1R1T2-cc5	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											1
		to be always completed									
at pos cc5	602	328	948	90	90	180	2	1	3	0	
pick up cc5	602	328	948	90	90	180	2	1	3	1	
raise up 100	602	328	1048	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc5	602	328	1048	90	90	180	2	1	3	1	
leave cc5	602	328	948	90	90	180	2	1	3	1	
open gripper	602	328	948	90	90	180	2	1	3	0	
raise up 100	602	328	1048	90	90	180	2	1	3	0	
		continue with next task									

C1R1T2-cc6	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											1
		to be always completed									
at pos cc6	413	328	948	90	90	180	2	1	3	0	
pick up cc6	413	328	948	90	90	180	2	1	3	1	
raise up 100	413	328	1048	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc6	413	328	1048	90	90	180	2	1	3	1	
leave cc6	413	328	948	90	90	180	2	1	3	1	
open gripper	413	328	948	90	90	180	2	1	3	0	
raise up 100	413	328	1048	90	90	180	2	1	3	0	
		continue with next task									

C1R1T2-cc7	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
			to be always completed								
at pos cc7	224	328	948	90	90	180	2	1	3	0	
pick up cc7	224	328	948	90	90	180	2	1	3	1	
raise up 100	224	328	1048	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc7	224	328	1048	90	90	180	2	1	3	1	
leave cc7	224	328	948	90	90	180	2	1	3	1	
open gripper	224	328	948	90	90	180	2	1	3	0	
raise up 100	224	328	1048	90	90	180	2	1	3	0	
			continue with next task								

C1R1T2-cc8	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
			to be always completed								
at pos cc8	35	328	948	90	90	180	2	1	3	0	
pick up cc8	35	328	948	90	90	180	2	1	3	1	
raise up 100	35	328	1048	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc8	35	328	1048	90	90	180	2	1	3	1	
leave cc8	35	328	948	90	90	180	2	1	3	1	
open gripper	35	328	948	90	90	180	2	1	3	0	
raise up 100	35	328	1048	90	90	180	2	1	3	0	
			continue with next task								

C1R1T3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
		to be always completed									
at pos cs	215	593	795	0	-90	0	2	1	3	0	
pick up cs	215	593	795	0	-90	0	2	1	3	1	
raise up 100	215	593	895	0	-90	0	2	1	3	1	
W2 rotation +90	450	358	895	90	-90	0	2	1	3	1	
over Loc 1 centre	500	670	895	90	-90	0	2	1	3	1	
move down by 65	500	670	830	90	-90	0	2	1	3	1	
spread condiments	510	687	830	90	-90	0	2	1	3	1	
“	528	698	830	90	-90	0	2	1	3	1	
“	540	670	830	90	-90	0	2	1	3	1	
“	528	642	830	90	-90	0	2	1	3	1	
“	500	630	830	90	-90	0	2	1	3	1	
“	472	642	830	90	-90	0	2	1	3	1	
“	460	670	830	90	-90	0	2	1	3	1	
“	448	700	830	90	-90	0	2	1	3	1	
“	450	757	830	90	-90	0	2	1	3	1	
“	500	780	830	90	-90	0	2	1	3	1	
“	555	765	830	90	-90	0	2	1	3	1	
“	595	725	830	90	-90	0	2	1	3	1	
“	610	670	830	90	-90	0	2	1	3	1	
“	595	615	830	90	-90	0	2	1	3	1	
“	555	575	830	90	-90	0	2	1	3	1	
“	500	560	830	90	-90	0	2	1	3	1	
“	445	575	830	90	-90	0	2	1	3	1	
“	405	615	830	90	-90	0	2	1	3	1	
“	390	670	830	90	-90	0	2	1	3	1	
“	422	715	830	90	-90	0	2	1	3	1	
“	500	690	830	90	-90	0	2	1	3	1	
“	465	670	830	90	-90	0	2	1	3	1	
raise up by 65	465	670	895	90	-90	0	2	1	3	1	
back to 100 above pos cs	215	593	895	0	-90	0	2	1	3	1	
W2 rotation -90	215	593	895	0	-90	0	2	1	3	1	
leave cs	215	593	795	0	-90	0	2	1	3	1	
open gripper	215	593	795	0	-90	0	2	1	3	0	
raise up 100	215	593	895	0	-90	0	2	1	3	0	
		continue with next task									

C1R1T4-oc	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
		to be always completed									
above h950, 400 Westwise oc	500	552	950	90	90	90	1	2	3	0	
move CART 400 Eastwise	100	552	950	90	90	90	1	2	3	0	
at pos oc	100	552	808	90	90	90	1	2	3	0	
pick up oc	100	552	808	90	90	90	1	2	3	1	
raise up 142	100	552	950	90	90	90	1	2	3	1	
move CART 400 Westwise	500	552	950	90	90	90	1	2	3	1	
GP 80W-80N from L1 centre & h100	580	590	880	90	90	90	1	2	3	1	
rotate -135°	580	590	880	90	90	-45	1	2	3	1	
shaking +20 up	580	590	900	90	90	-45	1	2	3	1	
shaking -20 down	580	590	880	90	90	-45	1	2	3	1	
move 160 Eastwise	420	590	880	90	90	-45	1	2	3	1	
shaking +20 up	420	590	900	90	90	-45	1	2	3	1	
shaking -20 down	420	590	880	90	90	-45	1	2	3	1	
move 160 Southwise	420	750	880	90	90	-45	1	2	3	1	
shaking +20 up	420	750	900	90	90	-45	1	2	3	1	
shaking -20 down	420	750	880	90	90	-45	1	2	3	1	
move 160 Westwise	580	750	880	90	90	-45	1	2	3	1	
shaking +20 up	580	750	900	90	90	-45	1	2	3	1	
shaking -20 down	580	750	880	90	90	-45	1	2	3	1	
rotate +135°	580	750	880	90	90	90	1	2	3	1	
raise up 70, 400 Westwise oc	500	552	950	90	90	90	1	2	3	1	
move CART 400 Eastwise	100	552	950	90	90	90	1	2	3	1	
leave oc	100	552	808	90	90	90	1	2	3	1	
open gripper	100	552	808	90	90	90	1	2	3	0	
raise up 142	100	552	950	90	90	90	1	2	3	0	
move CART 400 Westwise	500	552	950	90	90	90	1	2	3	0	
		continue with next task									

C1R1T4-sc	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
to be completed if after start the stand by request arrives from R1											
above h950, 400 Westwise sc	500	644	950	90	90	90	1	2	3	0	
move CART 400 Eastwise	100	644	950	90	90	90	1	2	3	0	
at pos sc	100	644	808	90	90	90	1	2	3	0	
pick up sc	100	644	808	90	90	90	1	2	3	1	
raise up 142	100	644	950	90	90	90	1	2	3	1	
move CART 400 Westwise	500	644	950	90	90	90	1	2	3	1	
GP 80W-80N from L1 centre & h100	580	590	880	90	90	90	1	2	3	1	
rotate -135°	580	590	880	90	90	-45	1	2	3	1	
shaking +20 up	580	590	900	90	90	-45	1	2	3	1	
shaking -20 down	580	590	880	90	90	-45	1	2	3	1	
move 160 Eastwise	420	590	880	90	90	-45	1	2	3	1	
shaking +20 up	420	590	900	90	90	-45	1	2	3	1	
shaking -20 down	420	590	880	90	90	-45	1	2	3	1	
move 160 Southwise	420	750	880	90	90	-45	1	2	3	1	
shaking +20 up	420	750	900	90	90	-45	1	2	3	1	
shaking -20 down	420	750	880	90	90	-45	1	2	3	1	
move 160 Westwise	580	750	880	90	90	-45	1	2	3	1	
shaking +20 up	580	750	900	90	90	-45	1	2	3	1	
shaking -20 down	580	750	880	90	90	-45	1	2	3	1	
rotate +135°	580	750	880	90	90	90	1	2	3	1	
raise up 70, 400 Westwise sc	500	644	950	90	90	90	1	2	3	1	
move CART 400 Eastwise	100	644	950	90	90	90	1	2	3	1	
leave sc	100	644	808	90	90	90	1	2	3	1	
open gripper	100	644	808	90	90	90	1	2	3	0	
raise up 142	100	644	950	90	90	90	1	2	3	0	
move CART 400 Westwise	500	644	950	90	90	90	1	2	3	0	

C1R1T4-gc	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
to be completed if after start the stand by request arrives from R1											
above h950, 400 Westwise oc	500	736	950	90	90	90	1	2	3	0	
move CART 400 Eastwise	100	736	950	90	90	90	1	2	3	0	
at pos gc	100	736	808	90	90	90	1	2	3	0	
pick up gc	100	736	808	90	90	90	1	2	3	1	
raise up 142	100	736	950	90	90	90	1	2	3	1	
move CART 400 Westwise	500	736	950	90	90	90	1	2	3	1	
GP 80W-80N from L1 centre & h100	580	590	880	90	90	90	1	2	3	1	
rotate -135°	580	590	880	90	90	-45	1	2	3	1	
shaking +20 up	580	590	900	90	90	-45	1	2	3	1	
shaking -20 down	580	590	880	90	90	-45	1	2	3	1	
move 160 Eastwise	420	590	880	90	90	-45	1	2	3	1	
shaking +20 up	420	590	900	90	90	-45	1	2	3	1	
shaking -20 down	420	590	880	90	90	-45	1	2	3	1	
move 160 Southwise	420	750	880	90	90	-45	1	2	3	1	
shaking +20 up	420	750	900	90	90	-45	1	2	3	1	
shaking -20 down	420	750	880	90	90	-45	1	2	3	1	
move 160 Westwise	580	750	880	90	90	-45	1	2	3	1	
shaking +20 up	580	750	900	90	90	-45	1	2	3	1	
shaking -20 down	580	750	880	90	90	-45	1	2	3	1	
rotate +135°	580	750	880	90	90	90	1	2	3	1	
raise up 70, 400 Westwise gc	500	736	950	90	90	90	1	2	3	1	
move CART 400 Eastwise	100	736	950	90	90	90	1	2	3	1	
leave gc	100	736	808	90	90	90	1	2	3	1	
open gripper	100	736	808	90	90	90	1	2	3	0	
raise up 142	100	736	950	90	90	90	1	2	3	0	
move CART 400 Westwise	500	736	950	90	90	90	1	2	3	0	

C1R1T5	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
			to be always completed								
h200, 400 Westwise ooc	500	828	950	90	90	90	1	2	3	0	
move CART 400 Eastwise	100	828	950	90	90	90	1	2	3	0	
at pos ooc	100	828	808	90	90	90	1	2	3	0	
pick up ooc	100	828	808	90	90	90	1	2	3	1	
above h200	100	828	950	90	90	90	1	2	3	1	
move CART 400 Westwise	500	828	950	90	90	90	1	2	3	1	
GP over L1 centre & h200	500	670	950	90	90	90	1	2	3	1	
rotate -135°	500	670	950	90	90	-45	1	2	3	1	
olive oil spread	520	705	950	90	90	-45	1	2	3	1	
“	542	712	950	90	90	-45	1	2	3	1	
“	587	720	950	90	90	-45	1	2	3	1	
“	600	670	950	90	90	-45	1	2	3	1	
“	587	620	950	90	90	-45	1	2	3	1	
“	571	599	950	90	90	-45	1	2	3	1	
“	550	583	950	90	90	-45	1	2	3	1	
“	500	570	950	90	90	-45	1	2	3	1	
“	450	583	950	90	90	-45	1	2	3	1	
“	429	599	950	90	90	-45	1	2	3	1	
“	413	620	950	90	90	-45	1	2	3	1	
“	400	670	950	90	90	-45	1	2	3	1	
“	413	720	950	90	90	-45	1	2	3	1	
“	429	741	950	90	90	-45	1	2	3	1	
“	450	757	950	90	90	-45	1	2	3	1	
“	500	770	950	90	90	-45	1	2	3	1	
rotate +135°	500	770	950	90	90	90	1	2	3	1	
above h200, 400 Westwise ooc	500	828	950	90	90	90	1	2	3	1	
move CART 400 Eastwise	100	828	950	90	90	90	1	2	3	1	
leave ooc	100	828	808	90	90	90	1	2	3	1	
open gripper	100	828	808	90	90	90	1	2	3	0	
above h200	100	828	950	90	90	90	1	2	3	0	
move CART 400 Westwise	500	828	950	90	90	90	1	2	3	0	
			continue with next task								

C1R1T6-c1pst1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
			to be always completed after R2 confirmation								
send request to R1											
stand by for R1 confirmation											
70 & -45° Northwise of ps1	747	600	778	180	45	90	1	2	3	0	
at pos ps1	747	670	778	180	45	90	1	2	3	0	
pick up ps1	747	670	778	180	45	90	1	2	3	1	
raise 340	747	670	1118	180	45	90	1	2	3	1	
Rotation -90°	747	670	1118	180	-45	90	1	2	3	1	
GP h28 & 508 Westwise Loc 1	1008	670	778	180	-45	90	1	2	3	1	
pick up pizza CART 320 Eastwise	688	670	778	180	-45	90	1	2	3	1	**CART movement ONLY**
raise up GP h117 + 100	688	670	967	135	0	270	2	3	1	1	
GP at X=80 (R1 pos)	80	670	967	135	0	270	2	3	1	1	
turn around from Eastside	-309	831	967	135	0	225	2	3	1	1	
"	-470	1220	967	135	0	180	2	3	1	1	
"	-309	1609	967	135	0	135	2	3	1	1	
move to 169 Eastwise of c3pst1	331	1920	967	135	0	90	2	3	1	1	
down to h117	331	1920	867	135	0	90	2	3	1	1	
Rotation 15°	331	1920	867	150	0	90	2	3	1	1	
move 20 Eastwise (shake)	311	1920	867	150	0	90	2	3	1	1	
move 20 Westwise (shake)	331	1920	867	150	0	90	2	3	1	1	
Move CART 340 Eastwise more	-9	1920	867	150	0	90	2	3	1	1	**CART movement ONLY**
rotation -15°	-9	1920	867	135	0	90	2	3	1	1	
move up 100	-9	1920	967	135	0	90	2	3	1	1	
rotate back from Eastside	-260	1770	967	135	0	90	2	3	1	1	
"	-649	1609	967	135	0	135	2	3	1	1	
"	-810	1200	967	135	0	180	2	3	1	1	
"	-649	831	967	135	0	225	2	3	1	1	
"	-260	670	967	135	0	270	2	3	1	1	
Move CART 660 Westwise	400	670	967	135	0	270	2	3	1	1	**CART movement ONLY**
move to X747,Y670,Z1118	747	670	1118	180	-45	90	1	2	3	1	
rotation 90°	747	670	1118	180	45	90	1	2	3	1	
down to Loc 2	747	670	778	180	45	90	1	2	3	1	
send finish info to R1	747	670	778	180	45	90	1	2	3	1	
open gripper	747	670	778	180	45	90	1	2	3	0	
disingage ps1	747	600	778	180	45	90	1	2	3	0	
raise 100	747	600	878	180	45	90	1	2	3	0	
send message to kitchen assistant											
go at rest											

Unless dpti = dpt10 remain at rest position till confirmation from R2 of new pizza left at location 1, otherwise stop at rest

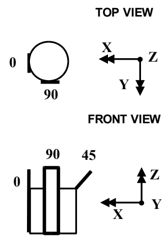
C1R1T6-c1pst2	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
	to be always completed after R2 confirmation										
send request to R1											
stand by for R1 confirmation											
70 & -45° Northwise of ps1	747	600	778	180	45	90	1	2	3	0	
at pos ps1	747	670	778	180	45	90	1	2	3	0	
pick up ps1	747	670	778	180	45	90	1	2	3	1	
raise 340	747	670	1118	180	45	90	1	2	3	1	
Rotation -90°	747	670	1118	180	-45	90	1	2	3	1	
GP h28 & 508 Westwise Loc 1	1008	670	778	180	-45	90	1	2	3	1	
pick up pizza CART 320 Eastwise	688	670	778	180	-45	90	1	2	3	1	**CART movement ONLY**
raise up GP h117 + 100	688	670	967	135	0	270	2	3	1	1	
GP at X=80 (R1 pos)	80	670	967	135	0	270	2	3	1	1	
turn around from Eastside	-309	831	967	135	0	225	2	3	1	1	
"	-470	1220	967	135	0	180	2	3	1	1	
"	-309	1609	967	135	0	135	2	3	1	1	
move to 169 Eastwise of c3pst2	-69	1920	967	135	0	90	2	3	1	1	
down to h117	-69	1920	867	135	0	90	2	3	1	1	
Rotation 15°	-69	1920	867	150	0	90	2	3	1	1	
move 20 Eastwise (shake)	-89	1920	867	150	0	90	2	3	1	1	
move 20 Westwise (shake)	-69	1920	867	150	0	90	2	3	1	1	
Move CART 340 Eastwise more	-409	1920	867	150	0	90	2	3	1	1	**CART movement ONLY**
rotation -15°	-409	1920	867	135	0	90	2	3	1	1	
move up 100	-409	1920	967	135	0	90	2	3	1	1	
rotate back from Eastside	-649	1609	967	135	0	135	2	3	1	1	
"	-810	1200	967	135	0	180	2	3	1	1	
"	-649	831	967	135	0	225	2	3	1	1	
"	-260	670	967	135	0	270	2	3	1	1	
Move CART 660 Westwise	400	670	967	135	0	270	2	3	1	1	**CART movement ONLY**
move to X747,Y670,Z1118	747	670	1118	180	-45	90	1	2	3	1	
rotation 90°	747	670	1118	180	45	90	1	2	3	1	
down to Loc 2	747	670	778	180	45	90	1	2	3	1	
send finish info to R1	747	670	778	180	45	90	1	2	3	1	
open gripper	747	670	778	180	45	90	1	2	3	0	
disingage ps1	747	600	778	180	45	90	1	2	3	0	
raise 100	747	600	878	180	45	90	1	2	3	0	
send message to kitchen assistant											
go at rest											
remain at rest position till confirmation from R2 of new pizza left at location 1											

C1R1T6-c1pst3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
	to be always completed after R2 confirmation										
send request to R1											
stand by for R1 confirmation											
70 & -45° Northwise of ps1	747	600	778	180	45	90	1	2	3	0	
at pos ps1	747	670	778	180	45	90	1	2	3	0	
pick up ps1	747	670	778	180	45	90	1	2	3	1	
raise 340	747	670	1118	180	45	90	1	2	3	1	
Rotation -90°	747	670	1118	180	-45	90	1	2	3	1	
GP h28 & 508 Westwise Loc 1	1008	670	778	180	-45	90	1	2	3	1	
pick up pizza CART 320 Eastwise	688	670	778	180	-45	90	1	2	3	1	**CART movement ONLY**
raise up GP h117 + 100	688	670	967	135	0	270	2	3	1	1	
GP at X=80 (R1 pos)	80	670	967	135	0	270	2	3	1	1	
turn around from Eastside	-309	831	967	135	0	225	2	3	1	1	
move to 169 Northwise of c3pst3	-300	1751	967	135	0	180	2	3	1	1	
down to h117	-300	1751	867	135	0	180	2	3	1	1	
Rotation 15°	-300	1751	867	150	0	180	2	3	1	1	
move 20 Northwise (shake)	-300	1731	867	150	0	180	2	3	1	1	
move 20 Southwise (shake)	-300	1751	867	150	0	180	2	3	1	1	
Move 340 NorthWise	-300	1411	867	150	0	180	2	3	1	1	
rotation -15°	-300	1411	867	135	0	180	2	3	1	1	
move up 100	-300	1411	967	135	0	180	2	3	1	1	
turn around from Eastside	-309	831	967	135	0	225	2	3	1	1	
GP at X=80 (R1 pos)	80	670	967	135	0	270	2	3	1	1	
Move CART 320 Westwise	400	670	967	135	0	270	2	3	1	1	**CART movement ONLY**
move to X747,Y670,Z1118	747	670	1118	180	-45	90	1	2	3	1	
rotation 90°	747	670	1118	180	45	90	1	2	3	1	
down to Loc 2	747	670	778	180	45	90	1	2	3	1	
send finish info to R1	747	670	778	180	45	90	1	2	3	1	
open gripper	747	670	778	180	45	90	1	2	3	0	
disingage ps1	747	600	778	180	45	90	1	2	3	0	
raise 100	747	600	878	180	45	90	1	2	3	0	
send message to kitchen assistant											
go at rest											
remain at rest position till confirmation from R2 of new pizza left at location 1											

GRIPPING POINT TASK PATHS FOR CONFIGURATION NR. 2

TOOLS LOCATION AND PICK UP POINT COORDINATES

Location	X [mm]	Y [mm]	Z [mm]	Pick up point	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [deg]	
Base Robot 1 at rest	400	1220	787								
C1GPR1 at rest	543	1384	958								Gripping point Robot 1
Base Robot 2 at rest	1200	1220	787								
C1GPR2 at rest	1057	1056	958								Gripping point Robot 2
Robot 1 Base change	1200	1380	787								
C1GPR2 at rest with changed Base	1057	1216	958								
C1PST1	500	2020	750								Pizza Storage 1
C1PST2	100	2020	750								Pizza Storage 2
C1PST3	-300	2020	750								Pizza Storage 3
Location 1	500	670	750	pp	500	670	750				Roll out location Module 1
Location 2	775	670	750	**ps1**	747	670	778	0	45	0	Pizza shovel 1
Location 3	683	116	848	**cc1**	602	116	1048	0	0	0	Cond cont 1 Mozzarella
Location 4	494	116	848	**cc2**	413	116	1048	0	0	0	Cond cont 1 Aubergin
Location 5	305	116	848	**cc3**	224	116	1048	0	0	0	Cond cont 1 Zucchini
Location 6	116	116	848	**cc4**	35	116	1048	0	0	0	Cond cont 1 Peppers
Location 7	683	328	748	**cc5**	602	328	948	0	0	0	Cond cont 1 Wurstels
Location 8	494	328	748	**cc6**	413	328	948	0	0	0	Cond cont 1 Sausages
Location 9	305	328	748	**cc7**	224	328	948	0	0	0	Cond cont 1 Mushrooms
Location 10	116	328	748	**cc8**	35	328	948	0	0	0	Cond cont 1 Ham
Location 11	215	790	725	**tsl**	215	861	795	0	0	90	Tomato sauce ladle
Location 12	215	552	725	**cs**	215	593	795	0	0	90	Condiment spreading tool
Location 13	100	552	748	**oc**	100	552	808				Origan container
Location 14	100	644	748	**sc**	100	644	808				Salt container
Location 15	100	736	748	**gc**	100	736	808				Garlic container
Location 16	100	828	748	**ooc**	100	828	808				Olive oil container
Location 17	1200	670	750	**ro**	1200	670	750				Pizza prep loc Module 2
Location 18	1575	670	750	**ps2**	1547	670	778	0	45	0	Pizza shovel 2
Location 19	1278	60	774	**rp**	1282	60	886	0	0	0	Roll pin
Location 20	950	81	748	**fc**	1001	81	928	0	0	0	Flour container
Location 21	1489	217	748	**dpt1**	1550	217	780	0	0	0	Dought partition tray 1
Location 22	1345	217	748	**dpt2**	1406	217	780	0	0	0	Dought partition tray 2
Location 23	1201	217	748	**dpt3**	1262	217	780	0	0	0	Dought partition tray 3
Location 24	1057	217	748	**dpt4**	1118	217	780	0	0	0	Dought partition tray 4
Location 25	913	217	748	**dpt5**	974	217	780	0	0	0	Dought partition tray 5
Location 26	1489	359	748	**dpt6**	1550	359	780	0	0	0	Dought partition tray 6
Location 27	1345	359	748	**dpt7**	1406	359	780	0	0	0	Dought partition tray 7
Location 28	1201	359	748	**dpt8**	1262	359	780	0	0	0	Dought partition tray 8
Location 29	1057	359	748	**dpt9**	1118	359	780	0	0	0	Dought partition tray 9
Location 30	913	359	748	**dpt10**	974	359	780	0	0	0	Dought partition tray 10



ROBOT 2

C2R2T1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											8
	before to start check if a request to go at rest position arrives from R1										
at pos fc	1001	81	928	90	90	180	2	1	3	0	
pick up fc	1001	81	928	90	90	180	2	1	3	1	
raise up 100	1001	81	1028	90	90	180	2	1	3	1	
over Loc 17	1200	670	960	90	90	180	2	1	3	1	
flour spread	1220	705	960	90	90	240	2	1	3	1	
"	1242	712	960	90	90	300	2	1	3	1	
"	1287	720	960	90	90	360	2	1	3	1	
"	1300	670	960	90	90	90	2	1	3	1	
"	1287	620	960	90	90	180	2	1	3	1	
"	1271	599	960	90	90	240	2	1	3	1	
"	1250	583	960	90	90	300	2	1	3	1	
"	1200	570	960	90	90	360	2	1	3	1	
"	1150	583	960	90	90	60	2	1	3	1	
"	1129	599	960	90	90	120	2	1	3	1	
"	1113	620	960	90	90	180	2	1	3	1	
"	1100	670	960	90	90	240	2	1	3	1	
"	1113	720	960	90	90	360	2	1	3	1	
"	1129	741	960	90	90	60	2	1	3	1	
"	1150	757	960	90	90	120	2	1	3	1	
"	1200	770	960	90	90	180	2	1	3	1	
above pos fc	1001	81	1028	90	90	180	2	1	3	1	
leave fc	1001	81	928	90	90	180	2	1	3	1	
open gripper	1001	81	928	90	90	180	2	1	3	0	
raise up 100	1001	81	1028	90	90	180	2	1	3	0	
			continue with next task								

C2R2T2–dpt1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt1	1550	217	780	180	0	90	1	2	3	0	
pick up dpt1	1550	217	780	180	0	90	1	2	3	1	
raise up 100	1550	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt1	1550	217	880	180	0	90	1	2	3	1	
leave dpt1	1550	217	780	180	0	90	1	2	3	1	
open gripper	1550	217	780	180	0	90	1	2	3	0	
raise up 100	1550	217	880	180	0	90	1	2	3	0	
continue with next task											

C2R2T2–dpt2	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt2	1406	217	780	180	0	90	1	2	3	0	
pick up dpt2	1406	217	780	180	0	90	1	2	3	1	
raise up 100	1406	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt2	1406	217	880	180	0	90	1	2	3	1	
leave dpt2	1406	217	780	180	0	90	1	2	3	1	
open gripper	1406	217	780	180	0	90	1	2	3	0	
raise up 100	1406	217	880	180	0	90	1	2	3	0	
continue with next task											

C2R2T2–dpt3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt3	1262	217	780	180	0	90	1	2	3	0	
pick up dpt3	1262	217	780	180	0	90	1	2	3	1	
raise up 100	1262	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt3	1262	217	880	180	0	90	1	2	3	1	
leave dpt3	1262	217	780	180	0	90	1	2	3	1	
open gripper	1262	217	780	180	0	90	1	2	3	0	
raise up 100	1262	217	880	180	0	90	1	2	3	0	
continue with next task											

C2R2T2–dpt4	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt4	1118	217	780	180	0	90	1	2	3	0	
pick up dpt4	1118	217	780	180	0	90	1	2	3	1	
raise up 100	1118	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt4	1118	217	880	180	0	90	1	2	3	1	
leave dpt4	1118	217	780	180	0	90	1	2	3	1	
open gripper	1118	217	780	180	0	90	1	2	3	0	
raise up 100	1118	217	880	180	0	90	1	2	3	0	
continue with next task											

C2R2T2–dpt5	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt5	974	217	780	180	0	90	1	2	3	0	
pick up dpt5	974	217	780	180	0	90	1	2	3	1	
raise up 100	974	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt5	974	217	880	180	0	90	1	2	3	1	
leave dpt5	974	217	780	180	0	90	1	2	3	1	
open gripper	974	217	780	180	0	90	1	2	3	0	
raise up 100	974	217	880	180	0	90	1	2	3	0	
continue with next task											

C2R2T2–dpt6	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt6	1550	359	780	180	0	90	1	2	3	0	
pick up dpt6	1550	359	780	180	0	90	1	2	3	1	
raise up 100	1550	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt6	1550	359	880	180	0	90	1	2	3	1	
leave dpt6	1550	359	780	180	0	90	1	2	3	1	
open gripper	1550	359	780	180	0	90	1	2	3	0	
raise up 100	1550	359	880	180	0	90	1	2	3	0	
continue with next task											

C2R2T2–dpt7	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt7	1406	359	780	180	0	90	1	2	3	0	
pick up dpt7	1406	359	780	180	0	90	1	2	3	1	
raise up 100	1406	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt7	1406	359	880	180	0	90	1	2	3	1	
leave dpt7	1406	359	780	180	0	90	1	2	3	1	
open gripper	1406	359	780	180	0	90	1	2	3	0	
raise up 100	1406	359	880	180	0	90	1	2	3	0	
continue with next task											

C2R2T2–dpt8	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt8	1262	359	780	180	0	90	1	2	3	0	
pick up dpt8	1262	359	780	180	0	90	1	2	3	1	
raise up 100	1262	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt8	1262	359	880	180	0	90	1	2	3	1	
leave dpt8	1262	359	780	180	0	90	1	2	3	1	
open gripper	1262	359	780	180	0	90	1	2	3	0	
raise up 100	1262	359	880	180	0	90	1	2	3	0	
continue with next task											

C2R2T2–dpt9	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											6
before to start check if a request to go at rest position arrives from R1											
at pos dpt9	1118	359	780	180	0	90	1	2	3	0	
pick up dpt9	1118	359	780	180	0	90	1	2	3	1	
raise up 100	1118	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt9	1118	359	880	180	0	90	1	2	3	1	
leave dpt9	1118	359	780	180	0	90	1	2	3	1	
open gripper	1118	359	780	180	0	90	1	2	3	0	
raise up 100	1118	359	880	180	0	90	1	2	3	0	
continue with next task											

C2R2T2–dpt10	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											6
before to start check if a request to go at rest position arrives from R1											
at pos dpt10	974	359	780	180	0	90	1	2	3	0	
pick up dpt10	974	359	780	180	0	90	1	2	3	1	
raise up 100	974	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt10	974	359	880	180	0	90	1	2	3	1	
leave dpt10	974	359	780	180	0	90	1	2	3	1	
open gripper	974	359	780	180	0	90	1	2	3	0	
raise up 100	974	359	880	180	0	90	1	2	3	0	
continue with next task											

C2R2T3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos rp	1282	60	886	180	0	90	1	2	3	0	
pick up rp	1282	60	886	180	0	90	1	2	3	1	
rp release	1267	60	886	180	0	90	1	2	3	1	
raise up	1267	60	986	180	0	90	1	2	3	1	
above Loc 17	1200	670	986	180	0	90	1	2	3	1	
down h40	1200	670	901	180	0	90	1	2	3	1	
move N 80 h36	1200	590	897	180	0	90	1	2	3	1	
move S 160 h36	1200	750	897	180	0	90	1	2	3	1	
move to centre	1200	670	897	180	0	90	1	2	3	1	
turn by 90°	1200	670	897	180	0	180	1	2	3	1	
move E 80 h32	1120	670	893	180	0	180	1	2	3	1	
move W 160 h32	1280	670	893	180	0	180	1	2	3	1	
move to centre	1200	670	893	180	0	180	1	2	3	1	
turn by -45°	1200	670	893	180	0	135	1	2	3	1	
move NE 120 h28	1115	585	889	180	0	135	1	2	3	1	
move SW 240 h28	1285	755	889	180	0	135	1	2	3	1	
move to centre	1200	670	889	180	0	135	1	2	3	1	
turn by -90°	1200	670	889	180	0	45	1	2	3	1	
move NW 120 h24	1285	585	885	180	0	45	1	2	3	1	
move SE 240 h24	1115	755	885	180	0	45	1	2	3	1	
move to centre	1200	670	885	180	0	45	1	2	3	1	
turn by 45°	1200	670	885	180	0	90	1	2	3	1	
move N 160 h20	1200	510	881	180	0	90	1	2	3	1	
move S 320 h20	1200	830	881	180	0	90	1	2	3	1	
move to centre	1200	670	881	180	0	90	1	2	3	1	
turn by 90°	1200	670	881	180	0	180	1	2	3	1	
move E 160 h16	1040	670	877	180	0	180	1	2	3	1	
move W 320 h16	1360	670	877	180	0	180	1	2	3	1	
move to centre	1200	670	877	180	0	180	1	2	3	1	
turn by -45°	1200	670	877	180	0	135	1	2	3	1	
move NE 160 h12	1087	557	873	180	0	135	1	2	3	1	
move SW 320 h12	1313	783	873	180	0	135	1	2	3	1	
move to centre	1200	670	873	180	0	135	1	2	3	1	
turn by -90°	1200	670	873	180	0	45	1	2	3	1	
move NW 160 h8	1313	557	869	180	0	45	1	2	3	1	
move SE 320 h8	1087	783	869	180	0	45	1	2	3	1	
move to centre	1200	670	869	180	0	45	1	2	3	1	
turn by 45°	1200	670	869	180	0	90	1	2	3	1	
move N 160 h7	1200	510	868	180	0	90	1	2	3	1	
move S 320 h7	1200	830	868	180	0	90	1	2	3	1	
move to centre	1200	670	868	180	0	90	1	2	3	1	
turn by 90°	1200	670	868	180	0	180	1	2	3	1	
move E 160 h6	1040	670	867	180	0	180	1	2	3	1	
move W 320 h6	1360	670	867	180	0	180	1	2	3	1	
move to centre	1200	670	867	180	0	180	1	2	3	1	
turn by -45°	1200	670	867	180	0	135	1	2	3	1	
move NE 160 h5	1087	557	866	180	0	135	1	2	3	1	
move SW 320 h5	1313	783	866	180	0	135	1	2	3	1	
move to centre	1200	670	866	180	0	135	1	2	3	1	
turn by -90°	1200	670	866	180	0	45	1	2	3	1	
move NW 160 h4	1313	557	865	180	0	45	1	2	3	1	
move SE 320 h4	1087	783	865	180	0	45	1	2	3	1	
move to centre	1200	670	865	180	0	45	1	2	3	1	
turn by 45°	1200	670	865	180	0	90	1	2	3	1	
raise up	1200	670	986	180	0	90	1	2	3	1	
back to pos rp	1267	60	986	180	0	90	1	2	3	1	
down to Loc 19	1267	60	886	180	0	90	1	2	3	1	
engaging	1282	60	886	180	0	90	1	2	3	1	
open gripper	1282	60	886	180	0	90	1	2	3	0	
raise up 100	1282	60	986	180	0	90	1	2	3	0	
continue with next task											

C2R2T4	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
send request to R1											
70 & -30° Northwise of ps2	1547	600	778	180	45	90	1	2	3	0	
at pos ps2	1547	670	778	180	45	90	1	2	3	0	
pick up ps2	1547	670	778	180	45	90	1	2	3	1	
raise 340	1547	670	1118	180	45	90	1	2	3	1	
rotation 90°	1547	670	1118	180	-45	90	1	2	3	1	
GP h28 & 508 Westwise Loc 17	1708	670	778	180	-45	90	1	2	3	1	
pick up pizza moving CART 320 Eastwise	1388	670	778	180	-45	90	1	2	3	1	CART movement ONLY
stby for R1 conf & R1 800 East	1388	670	778	180	-45	90	1	2	3	1	
raise up h104	1388	670	867	180	-45	90	1	2	3	1	
move to L1 CART 719 Eastwise	669	670	867	180	-45	90	1	2	3	1	CART movement ONLY
rotation -15°	669	670	867	180	-30	90	1	2	3	1	
move 20 Westwise (shake)	689	670	867	180	-30	90	1	2	3	1	
move 20 Eastwise (shake)	669	670	867	180	-30	90	1	2	3	1	
Rotation 15°	669	670	867	180	-45	90	1	2	3	1	
move CART 1039 Westwise	1708	670	867	180	-45	90	1	2	3	1	CART movement ONLY
up to 1116 and right to 1560	1547	670	1118	180	-45	90	1	2	3	1	
Rotation -90°	1547	670	1118	180	45	90	1	2	3	1	
down to Loc 18	1547	670	778	180	45	90	1	2	3	1	
send finish info to R1	1547	670	778	180	45	90	1	2	3	1	
open gripper	1547	670	778	180	45	90	1	2	3	0	
disingage	1547	600	778	180	45	90	1	2	3	0	
raise 100	1547	600	878	180	45	90	1	2	3	0	
continue with next task or stop at rest if dpti = dpt10											

ROBOT 1

C2R1T1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
before to start check if a request to remain at rest position arrives from R2											
after R2 confirmation											
at pos tsl	215	861	795	0	-90	0	2	1	3	0	
pick up tsl	215	861	795	0	-90	0	2	1	3	1	
move forward 60	215	801	795	0	-90	0	2	1	3	1	
wait 3 sec to collect souce	215	801	795	0	-90	0	2	1	3	1	souce from dispenser
move backward 40	215	821	795	0	-90	0	2	1	3	1	
raise by 145	215	821	940	0	-90	0	2	1	3	1	
W2 rotation +90	450	586	940	90	-90	0	2	1	3	1	
over Loc 1 centre	500	670	940	90	-90	0	2	1	3	1	
W3 rotation +90	500	670	940	90	-90	-90	2	1	3	1	
W3 rotation +180	500	670	940	90	-90	-180	2	1	3	1	
W3 rotation +270	500	670	940	90	-90	-270	2	1	3	1	
W3 rotation +360	500	670	940	90	-90	-360	2	1	3	1	
move down by 115	500	670	825	90	-90	0	2	1	3	1	
spread tomato sauce	510	687	825	90	-90	0	2	1	3	1	
“	528	698	825	90	-90	0	2	1	3	1	
“	540	670	825	90	-90	0	2	1	3	1	
“	528	642	825	90	-90	0	2	1	3	1	
“	500	630	825	90	-90	0	2	1	3	1	
“	472	642	825	90	-90	0	2	1	3	1	
“	460	670	825	90	-90	0	2	1	3	1	
“	448	700	825	90	-90	0	2	1	3	1	
“	450	757	825	90	-90	0	2	1	3	1	
“	500	780	825	90	-90	0	2	1	3	1	
“	555	765	825	90	-90	0	2	1	3	1	
“	595	725	825	90	-90	0	2	1	3	1	
“	610	670	825	90	-90	0	2	1	3	1	
“	595	615	825	90	-90	0	2	1	3	1	
“	555	575	825	90	-90	0	2	1	3	1	
“	500	560	825	90	-90	0	2	1	3	1	
“	445	575	825	90	-90	0	2	1	3	1	
“	405	615	825	90	-90	0	2	1	3	1	
“	390	670	825	90	-90	0	2	1	3	1	
“	422	715	825	90	-90	0	2	1	3	1	
“	465	690	825	90	-90	0	2	1	3	1	
“	500	670	825	90	-90	0	2	1	3	1	
raise up by 100	500	670	925	90	-90	0	2	1	3	1	
above pos tsl	215	861	925	0	-90	0	2	1	3	1	
W2 rotation -90	215	861	925	0	-90	0	2	1	3	1	
leave tsl	215	861	795	0	-90	0	2	1	3	1	
open gripper	215	861	795	0	-90	0	2	1	3	0	
raise up 100	215	861	895	0	-90	0	2	1	3	0	
continue with next task											

C2R1T2-cc1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											1
		to be always completed									
at pos cc1	602	116	1048	90	90	180	2	1	3	0	
pick up cc1	602	116	1048	90	90	180	2	1	3	1	
raise up 100	602	116	1148	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc1	602	116	1148	90	90	180	2	1	3	1	
leave cc1	602	116	1048	90	90	180	2	1	3	1	
open gripper	602	116	1048	90	90	180	2	1	3	0	
raise up 100	602	116	1148	90	90	180	2	1	3	0	
		continue with next task									

C2R1T2-cc2	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											1
		to be always completed									
at pos cc2	413	116	1048	90	90	180	2	1	3	0	
pick up cc2	413	116	1048	90	90	180	2	1	3	1	
raise up 100	413	116	1148	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc2	413	116	1148	90	90	180	2	1	3	1	
leave cc2	413	116	1048	90	90	180	2	1	3	1	
open gripper	413	116	1048	90	90	180	2	1	3	0	
raise up 100	413	116	1148	90	90	180	2	1	3	0	
		continue with next task									

C2R1T2-cc3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											1
		to be always completed									
at pos cc3	224	116	1048	90	90	180	2	1	3	0	
pick up cc3	224	116	1048	90	90	180	2	1	3	1	
raise up 100	224	116	1148	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc3	224	116	1148	90	90	180	2	1	3	1	
leave cc3	224	116	1048	90	90	180	2	1	3	1	
open gripper	224	116	1048	90	90	180	2	1	3	0	
raise up 100	224	116	1148	90	90	180	2	1	3	0	
		continue with next task									

C2R1T2-cc4	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
			to be always completed								1
at pos cc4	35	116	1048	90	90	180	2	1	3	0	
pick up cc4	35	116	1048	90	90	180	2	1	3	1	
raise up 100	35	116	1148	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc4	35	116	1148	90	90	180	2	1	3	1	
leave cc4	35	116	1048	90	90	180	2	1	3	1	
open gripper	35	116	1048	90	90	180	2	1	3	0	
raise up 100	35	116	1148	90	90	180	2	1	3	0	
			continue with next task								

C2R1T2-cc5	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
			to be always completed								1
at pos cc5	602	328	948	90	90	180	2	1	3	0	
pick up cc5	602	328	948	90	90	180	2	1	3	1	
raise up 100	602	328	1048	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc5	602	328	1048	90	90	180	2	1	3	1	
leave cc5	602	328	948	90	90	180	2	1	3	1	
open gripper	602	328	948	90	90	180	2	1	3	0	
raise up 100	602	328	1048	90	90	180	2	1	3	0	
			continue with next task								

C2R1T2-cc6	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
			to be always completed								1
at pos cc6	413	328	948	90	90	180	2	1	3	0	
pick up cc6	413	328	948	90	90	180	2	1	3	1	
raise up 100	413	328	1048	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc6	413	328	1048	90	90	180	2	1	3	1	
leave cc6	413	328	948	90	90	180	2	1	3	1	
open gripper	413	328	948	90	90	180	2	1	3	0	
raise up 100	413	328	1048	90	90	180	2	1	3	0	
			continue with next task								

C2R1T2-cc7	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
			to be always completed								
at pos cc7	224	328	948	90	90	180	2	1	3	0	
pick up cc7	224	328	948	90	90	180	2	1	3	1	
raise up 100	224	328	1048	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc7	224	328	1048	90	90	180	2	1	3	1	
leave cc7	224	328	948	90	90	180	2	1	3	1	
open gripper	224	328	948	90	90	180	2	1	3	0	
raise up 100	224	328	1048	90	90	180	2	1	3	0	
			continue with next task								

C2R1T2-cc8	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
			to be always completed								
at pos cc8	35	328	948	90	90	180	2	1	3	0	
pick up cc8	35	328	948	90	90	180	2	1	3	1	
raise up 100	35	328	1048	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc8	35	328	1048	90	90	180	2	1	3	1	
leave cc8	35	328	948	90	90	180	2	1	3	1	
open gripper	35	328	948	90	90	180	2	1	3	0	
raise up 100	35	328	1048	90	90	180	2	1	3	0	
			continue with next task								

C2R1T3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
			to be always completed								
at pos cs	215	593	795	0	-90	0	2	1	3	0	
pick up cs	215	593	795	0	-90	0	2	1	3	1	
raise up 100	215	593	895	0	-90	0	2	1	3	1	
W2 rotation +90	450	358	895	90	-90	0	2	1	3	1	
over Loc 1 centre	500	670	895	90	-90	0	2	1	3	1	
move down by 65	500	670	830	90	-90	0	2	1	3	1	
spread condiments	510	687	830	90	-90	0	2	1	3	1	
“	528	698	830	90	-90	0	2	1	3	1	
“	540	670	830	90	-90	0	2	1	3	1	
“	528	642	830	90	-90	0	2	1	3	1	
“	500	630	830	90	-90	0	2	1	3	1	
“	472	642	830	90	-90	0	2	1	3	1	
“	460	670	830	90	-90	0	2	1	3	1	
“	448	700	830	90	-90	0	2	1	3	1	
“	450	757	830	90	-90	0	2	1	3	1	
“	500	780	830	90	-90	0	2	1	3	1	
“	555	765	830	90	-90	0	2	1	3	1	
“	595	725	830	90	-90	0	2	1	3	1	
“	610	670	830	90	-90	0	2	1	3	1	
“	595	615	830	90	-90	0	2	1	3	1	
“	555	575	830	90	-90	0	2	1	3	1	
“	500	560	830	90	-90	0	2	1	3	1	
“	445	575	830	90	-90	0	2	1	3	1	
“	405	615	830	90	-90	0	2	1	3	1	
“	390	670	830	90	-90	0	2	1	3	1	
“	422	715	830	90	-90	0	2	1	3	1	
“	500	690	830	90	-90	0	2	1	3	1	
“	465	670	830	90	-90	0	2	1	3	1	
raise up by 65	465	670	895	90	-90	0	2	1	3	1	
back to 100 above pos cs	215	593	895	0	-90	0	2	1	3	1	
W2 rotation -90	215	593	895	0	-90	0	2	1	3	1	
leave cs	215	593	795	0	-90	0	2	1	3	1	
open gripper	215	593	795	0	-90	0	2	1	3	0	
raise up 100	215	593	895	0	-90	0	2	1	3	0	
			continue with next task								

C2R1T4-oc	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
			to be always completed								
arrive from the above h950	100	552	950	90	90	90	1	2	3	0	
at pos oc	100	552	808	90	90	90	1	2	3	0	
pick up os	100	552	808	90	90	90	1	2	3	1	
raise up 100	100	552	908	90	90	90	1	2	3	1	
GP 80W-80N from L1 centre & h100	580	590	880	90	90	90	1	2	3	1	
rotate -135°	580	590	880	90	90	-45	1	2	3	1	
shaking +20 up	580	590	900	90	90	-45	1	2	3	1	
shaking -20 down	580	590	880	90	90	-45	1	2	3	1	
move 160 Eastwise	420	590	880	90	90	-45	1	2	3	1	
shaking +20 up	420	590	900	90	90	-45	1	2	3	1	
shaking -20 down	420	590	880	90	90	-45	1	2	3	1	
move 160 Southwise	420	750	880	90	90	-45	1	2	3	1	
shaking +20 up	420	750	900	90	90	-45	1	2	3	1	
shaking -20 down	420	750	880	90	90	-45	1	2	3	1	
move 160 Westwise	580	750	880	90	90	-45	1	2	3	1	
shaking +20 up	580	750	900	90	90	-45	1	2	3	1	
shaking -20 down	580	750	880	90	90	-45	1	2	3	1	
rotate +135°	580	750	880	90	90	90	1	2	3	1	
back to pos oc h950	100	552	950	90	90	90	1	2	3	1	
leave oc	100	552	808	90	90	90	1	2	3	1	
open gripper	100	552	808	90	90	90	1	2	3	0	
raise up 142	100	552	950	90	90	90	1	2	3	0	
			continue with next task								

C2R1T4-sc	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
			to be completed if after start the stand by request arrives from R1								
arrive from the above h950	100	644	950	90	90	90	1	2	3	0	
at pos sc	100	644	808	90	90	90	1	2	3	0	
pick up sc	100	644	808	90	90	90	1	2	3	1	
raise up 100	100	644	908	90	90	90	1	2	3	1	
GP 80W-80N from L1 centre & h100	580	590	880	90	90	90	1	2	3	1	
rotate -135°	580	590	880	90	90	-45	1	2	3	1	
shaking +20 up	580	590	900	90	90	-45	1	2	3	1	
shaking -20 down	580	590	880	90	90	-45	1	2	3	1	
move 160 Eastwise	420	590	880	90	90	-45	1	2	3	1	
shaking +20 up	420	590	900	90	90	-45	1	2	3	1	
shaking -20 down	420	590	880	90	90	-45	1	2	3	1	
move 160 Southwise	420	750	880	90	90	-45	1	2	3	1	
shaking +20 up	420	750	900	90	90	-45	1	2	3	1	
shaking -20 down	420	750	880	90	90	-45	1	2	3	1	
move 160 Westwise	580	750	880	90	90	-45	1	2	3	1	
shaking +20 up	580	750	900	90	90	-45	1	2	3	1	
shaking -20 down	580	750	880	90	90	-45	1	2	3	1	
rotate +135°	580	750	880	90	90	90	1	2	3	1	
back to pos sc h950	100	644	950	90	90	90	1	2	3	1	
leave sc	100	644	808	90	90	90	1	2	3	1	
open gripper	100	644	808	90	90	90	1	2	3	0	
raise up 142	100	644	950	90	90	90	1	2	3	0	
			continue with next task								

C2R1T4-gc	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
			to be completed if after start the stand by request arrives from R1								
arrive from the above h950	100	736	950	90	90	90	1	2	3	0	
at pos gc	100	736	808	90	90	90	1	2	3	0	
pick up gc	100	736	808	90	90	90	1	2	3	1	
raise up 100	100	736	908	90	90	90	1	2	3	1	
GP 80W-80N from L1 centre & h100	580	590	880	90	90	90	1	2	3	1	
rotate -135°	580	590	880	90	90	-45	1	2	3	1	
shaking +20 up	580	590	900	90	90	-45	1	2	3	1	
shaking -20 down	580	590	880	90	90	-45	1	2	3	1	
move 160 Eastwise	420	590	880	90	90	-45	1	2	3	1	
shaking +20 up	420	590	900	90	90	-45	1	2	3	1	
shaking -20 down	420	590	880	90	90	-45	1	2	3	1	
move 160 Southwise	420	750	880	90	90	-45	1	2	3	1	
shaking +20 up	420	750	900	90	90	-45	1	2	3	1	
shaking -20 down	420	750	880	90	90	-45	1	2	3	1	
move 160 Westwise	580	750	880	90	90	-45	1	2	3	1	
shaking +20 up	580	750	900	90	90	-45	1	2	3	1	
shaking -20 down	580	750	880	90	90	-45	1	2	3	1	
rotate +135°	580	750	880	90	90	90	1	2	3	1	
back to pos gc h950	100	736	950	90	90	90	1	2	3	1	
leave gc	100	736	808	90	90	90	1	2	3	1	
open gripper	100	736	808	90	90	90	1	2	3	0	
raise up 142	100	736	950	90	90	90	1	2	3	0	
			continue with next task								

C2R1T5	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
			to be always completed								
arrive from the above h200	100	828	950	90	90	90	1	2	3	0	
at pos ooc	100	828	808	90	90	90	1	2	3	0	
pick up ooc	100	828	808	90	90	90	1	2	3	1	
raise up 142	100	828	950	90	90	90	1	2	3	1	
GP over L1 centre & h200	500	670	950	90	90	90	1	2	3	1	
rotate -135°	500	670	950	90	90	-45	1	2	3	1	
olive oil spread	520	705	950	90	90	-45	1	2	3	1	
"	542	712	950	90	90	-45	1	2	3	1	
"	587	720	950	90	90	-45	1	2	3	1	
"	600	670	950	90	90	-45	1	2	3	1	
"	587	620	950	90	90	-45	1	2	3	1	
"	571	599	950	90	90	-45	1	2	3	1	
"	550	583	950	90	90	-45	1	2	3	1	
"	500	570	950	90	90	-45	1	2	3	1	
"	450	583	950	90	90	-45	1	2	3	1	
"	429	599	950	90	90	-45	1	2	3	1	
"	413	620	950	90	90	-45	1	2	3	1	
"	400	670	950	90	90	-45	1	2	3	1	
"	413	720	950	90	90	-45	1	2	3	1	
"	429	741	950	90	90	-45	1	2	3	1	
"	450	757	950	90	90	-45	1	2	3	1	
"	500	770	950	90	90	-45	1	2	3	1	
rotate +135°	500	770	950	90	90	90	1	2	3	1	
back to pos oc h200	100	828	950	90	90	90	1	2	3	1	
leave oc	100	828	808	90	90	90	1	2	3	1	
open gripper	100	828	808	90	90	90	1	2	3	0	
raise up 142	100	828	950	90	90	90	1	2	3	0	
			continue with next task								

C2R1T6-c1pst1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
			to be always completed after R2 confirmation								
send request to R2											
stand by for R2 confirmation											
70 & -45° Northwise of ps1	747	600	778	180	45	90	1	2	3	0	
at pos ps1	747	670	778	180	45	90	1	2	3	0	
pick up ps1	747	670	778	180	45	90	1	2	3	1	
raise 340	747	670	1118	180	45	90	1	2	3	1	
Rotation -90°	747	670	1118	180	-45	90	1	2	3	1	
GP h28 & 508 Westwise Loc 1	1008	670	778	180	-45	90	1	2	3	1	
pick up pizza CART 320 Eastwise	688	670	778	180	-45	90	1	2	3	1	CART movement ONLY
raise up GP h117 + 100	688	670	967	135	0	270	2	3	1	1	
GP at X=80 (R1 pos)	80	670	967	135	0	270	2	3	1	1	
turn around from Eastside	-309	831	967	135	0	225	2	3	1	1	
"	-470	1220	967	135	0	180	2	3	1	1	
"	-309	1609	967	135	0	135	2	3	1	1	
move to 169 Eastwise of c3pst1	331	2020	967	135	0	90	2	3	1	1	
down to h117	331	2020	867	135	0	90	2	3	1	1	
Rotation 15°	331	2020	867	150	0	90	2	3	1	1	
move 20 Eastwise (shake)	311	2020	867	150	0	90	2	3	1	1	
move 20 Westwise (shake)	331	2020	867	150	0	90	2	3	1	1	
Move CART 340 Eastwise more	-9	2020	867	150	0	90	2	3	1	1	CART movement ONLY
rotation -15°	-9	2020	867	135	0	90	2	3	1	1	
move up 100	-9	2020	967	135	0	90	2	3	1	1	
rotate back from Eastside	-260	1770	967	135	0	90	2	3	1	1	
"	-649	1609	967	135	0	135	2	3	1	1	
"	-810	1200	967	135	0	180	2	3	1	1	
"	-649	831	967	135	0	225	2	3	1	1	
"	-260	670	967	135	0	270	2	3	1	1	
Move CART 660 Westwise	400	670	967	135	0	270	2	3	1	1	CART movement ONLY
move to X747,Y670,Z1118	747	670	1118	180	-45	90	1	2	3	1	
rotation 90°	747	670	1118	180	45	90	1	2	3	1	
down to Loc 2	747	670	778	180	45	90	1	2	3	1	
send finish info to R1	747	670	778	180	45	90	1	2	3	1	
open gripper	747	670	778	180	45	90	1	2	3	0	
disingage ps1	747	600	778	180	45	90	1	2	3	0	
raise 100	747	600	878	180	45	90	1	2	3	0	
send message to kitchen assistant											
go at rest											
Unless dpti = dpt10 remain at rest position till confirmation from R2 of new pizza left at location 1, otherwise stop at rest											

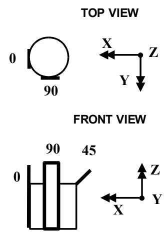
C2R1T6-c1pst2	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
	to be always completed after R2 confirmation										
send request to R2											
stand by for R2 confirmation											
70 & -45° Northwise of ps1	747	600	778	180	45	90	1	2	3	0	
at pos ps1	747	670	778	180	45	90	1	2	3	0	
pick up ps1	747	670	778	180	45	90	1	2	3	1	
raise 340	747	670	1118	180	45	90	1	2	3	1	
Rotation -90°	747	670	1118	180	-45	90	1	2	3	1	
GP h28 & 508 Westwise Loc 1	1008	670	778	180	-45	90	1	2	3	1	
pick up pizza CART 320 Eastwise	688	670	778	180	-45	90	1	2	3	1	CART movement ONLY
raise up GP h117 + 100	688	670	967	135	0	270	2	3	1	1	
GP at X=80 (R1 pos)	80	670	967	135	0	270	2	3	1	1	
turn around from Eastside	-309	831	967	135	0	225	2	3	1	1	
"	-470	1220	967	135	0	180	2	3	1	1	
"	-309	1609	967	135	0	135	2	3	1	1	
move to 169 Eastwise of c3pst2	-69	2020	967	135	0	90	2	3	1	1	
down to h117	-69	2020	867	135	0	90	2	3	1	1	
Rotation 15°	-69	2020	867	150	0	90	2	3	1	1	
move 20 Eastwise (shake)	-89	2020	867	150	0	90	2	3	1	1	
move 20 Westwise (shake)	-69	2020	867	150	0	90	2	3	1	1	
Move CART 340 Eastwise more	-409	2020	867	150	0	90	2	3	1	1	CART movement ONLY
rotation -15°	-409	2020	867	135	0	90	2	3	1	1	
move up 100	-409	2020	967	135	0	90	2	3	1	1	
rotate back from Eastside	-649	1609	967	135	0	135	2	3	1	1	
"	-810	1200	967	135	0	180	2	3	1	1	
"	-649	831	967	135	0	225	2	3	1	1	
"	-260	670	967	135	0	270	2	3	1	1	
Move CART 660 Westwise	400	670	967	135	0	270	2	3	1	1	CART movement ONLY
move to X747,Y670,Z1118	747	670	1118	180	-45	90	1	2	3	1	
rotation 90°	747	670	1118	180	45	90	1	2	3	1	
down to Loc 2	747	670	778	180	45	90	1	2	3	1	
send finish info to R1	747	670	778	180	45	90	1	2	3	1	
open gripper	747	670	778	180	45	90	1	2	3	0	
disingage ps1	747	600	778	180	45	90	1	2	3	0	
raise 100	747	600	878	180	45	90	1	2	3	0	
send message to kitchen assistant											
go at rest											
	remain at rest position till confirmation from R2 of new pizza left at location 1										

C2R1T6-c1pst3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
	to be always completed after R2 confirmation										
send request to R2											
stand by for R2 confirmation											
70 & -45° Northwise of ps1	747	600	778	180	45	90	1	2	3	0	
at pos ps1	747	670	778	180	45	90	1	2	3	0	
pick up ps1	747	670	778	180	45	90	1	2	3	1	
raise 340	747	670	1118	180	45	90	1	2	3	1	
Rotation -90°	747	670	1118	180	-45	90	1	2	3	1	
GP h28 & 508 Westwise Loc 1	1008	670	778	180	-45	90	1	2	3	1	
pick up pizza CART 320 Eastwise	688	670	778	180	-45	90	1	2	3	1	
raise up GP h117 + 100	688	670	967	135	0	270	2	3	1	1	
GP at X=80 (R1 pos)	80	670	967	135	0	270	2	3	1	1	
turn around from Eastside	-309	831	967	135	0	225	2	3	1	1	
move to 169 Northwise of c3pst3	-300	1851	967	135	0	180	2	3	1	1	
down to h117	-300	1851	867	135	0	180	2	3	1	1	
Rotation 15°	-300	1851	867	150	0	180	2	3	1	1	
move 20 Northwise (shake)	-300	1851	867	150	0	180	2	3	1	1	
move 20 Southwise (shake)	-300	1851	867	150	0	180	2	3	1	1	
Move 340 NorthWise	-300	1511	867	150	0	180	2	3	1	1	
rotation -15°	-300	1511	867	135	0	180	2	3	1	1	
move up 100	-300	1511	967	135	0	180	2	3	1	1	
turn around from Eastside	-309	831	967	135	0	225	2	3	1	1	
GP at X=80 (R1 pos)	80	670	967	135	0	270	2	3	1	1	
Move CART 320 Westwise	400	670	967	135	0	270	2	3	1	1	
move to X747,Y670,Z1118	747	670	1118	180	-45	90	1	2	3	1	
rotation 90°	747	670	1118	180	45	90	1	2	3	1	
down to Loc 2	747	670	778	180	45	90	1	2	3	1	
send finish info to R1	747	670	778	180	45	90	1	2	3	1	
open gripper	747	670	778	180	45	90	1	2	3	0	
disingage ps1	747	600	778	180	45	90	1	2	3	0	
raise 100	747	600	878	180	45	90	1	2	3	0	
send message to kitchen assistant											
go at rest											
	remain at rest position till confirmation from R2 of new pizza left at location 1										

GRIPPING POINT TASK PATHS FOR CONFIGURATION NR. 3

TOOLS LOCATION AND PICK UP POINT COORDINATES

Location	X [mm]	Y [mm]	Z [mm]	Pick up point	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [deg]	
Base Robot 1	400	1220	767								
C3GPR1	543	1384	938								Gripping point Robot 1
Base Robot 2	1200	1220	767								
C3GPR2	1057	1056	938								Gripping point Robot 2
Base Robot 3	400	2570	767								
C3GPR3	257	2406	938								Gripping point Robot 3
C3PST1	800	1920	750								Pizza Storage 1
C3PST2	400	1920	750								Pizza Storage 2
C3PST3	0	1920	750								Pizza Storage 3
C3CP1	0	3220	770								Cooked pizza 1 on dish
C3CP2	400	3220	770								Cooked pizza 2 on dish
C3CP3	800	3220	770								Cooked pizza 3 on dish
Oven	-700	2570	1000								Pizza in the oven
Location 1	500	670	750	pp	500	670	750				Pizza prep location Module 1
Location 2	775	670	750	**ps1**	747	670	778	0	45	0	Pizza shovel 1
Location 3	683	116	848	**cc1**	602	116	1048	0	0	0	Cond cont 1 Mozzarella
Location 4	494	116	848	**cc2**	413	116	1048	0	0	0	Cond cont 1 Aubergin
Location 5	305	116	848	**cc3**	224	116	1048	0	0	0	Cond cont 1 Zucchini
Location 6	116	116	848	**cc4**	35	116	1048	0	0	0	Cond cont 1 Peppers
Location 7	683	328	748	**cc5**	602	328	948	0	0	0	Cond cont 1 Wurstels
Location 8	494	328	748	**cc6**	413	328	948	0	0	0	Cond cont 1 Sausages
Location 9	305	328	748	**cc7**	224	328	948	0	0	0	Cond cont 1 Mushrooms
Location 10	116	328	748	**cc8**	35	328	948	0	0	0	Cond cont 1 Ham
Location 11	215	790	725	**tsl**	215	861	795	0	0	90	Tomato sauce ladle
Location 12	215	552	725	**cs**	215	593	795	0	0	90	Condiment spreading tool
Location 13	100	552	748	**oc**	100	552	808				Origan container
Location 14	100	644	748	**sc**	100	644	808				Salt container
Location 15	100	736	748	**gc**	100	736	808				Garlic container
Location 16	100	828	748	**ooc**	100	828	808				Olive oil container
Location 17	1200	670	750	**ro**	1200	670	750				Pizza roll out loc Module 2
Location 18	1575	670	750	**ps2**	1547	670	778	0	45	0	Pizza shovel 2
Location 19	1278	60	774	**rp**	1282	60	886	0	0	0	Roll pin
Location 20	950	81	748	**fc**	1001	81	928	0	0	0	Flour container
Location 21	1489	217	748	**dpt1**	1550	217	780	0	0	0	Dought partition tray 1
Location 22	1345	217	748	**dpt2**	1406	217	780	0	0	0	Dought partition tray 2
Location 23	1201	217	748	**dpt3**	1262	217	780	0	0	0	Dought partition tray 3
Location 24	1057	217	748	**dpt4**	1118	217	780	0	0	0	Dought partition tray 4
Location 25	913	217	748	**dpt5**	974	217	780	0	0	0	Dought partition tray 5
Location 26	1489	359	748	**dpt6**	1550	359	780	0	0	0	Dought partition tray 6
Location 27	1345	359	748	**dpt7**	1406	359	780	0	0	0	Dought partition tray 7
Location 28	1201	359	748	**dpt8**	1262	359	780	0	0	0	Dought partition tray 8
Location 29	1057	359	748	**dpt9**	1118	359	780	0	0	0	Dought partition tray 9
Location 30	913	359	748	**dpt10**	974	359	780	0	0	0	Dought partition tray 10



ROBOT 2

C3R2T1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											8
before to start check if a request to go at rest position arrives from R1											
at pos fc	1001	81	928	90	90	180	2	1	3	0	
pick up fc	1001	81	928	90	90	180	2	1	3	1	
raise up 100	1001	81	1028	90	90	180	2	1	3	1	
over Loc 17	1200	670	960	90	90	180	2	1	3	1	
flour spread	1220	705	960	90	90	240	2	1	3	1	
"	1242	712	960	90	90	300	2	1	3	1	
"	1287	720	960	90	90	360	2	1	3	1	
"	1300	670	960	90	90	90	2	1	3	1	
"	1287	620	960	90	90	180	2	1	3	1	
"	1271	599	960	90	90	240	2	1	3	1	
"	1250	583	960	90	90	300	2	1	3	1	
"	1200	570	960	90	90	360	2	1	3	1	
"	1150	583	960	90	90	60	2	1	3	1	
"	1129	599	960	90	90	120	2	1	3	1	
"	1113	620	960	90	90	180	2	1	3	1	
"	1100	670	960	90	90	240	2	1	3	1	
"	1113	720	960	90	90	360	2	1	3	1	
"	1129	741	960	90	90	60	2	1	3	1	
"	1150	757	960	90	90	120	2	1	3	1	
"	1200	770	960	90	90	180	2	1	3	1	
above pos fc	1001	81	1028	90	90	180	2	1	3	1	
leave fc	1001	81	928	90	90	180	2	1	3	1	
open gripper	1001	81	928	90	90	180	2	1	3	0	
raise up 100	1001	81	1028	90	90	180	2	1	3	0	
continue with next task											

C3R2T2–dpt1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt1	1550	217	780	180	0	90	1	2	3	0	
pick up dpt1	1550	217	780	180	0	90	1	2	3	1	
raise up 100	1550	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt1	1550	217	880	180	0	90	1	2	3	1	
leave dpt1	1550	217	780	180	0	90	1	2	3	1	
open gripper	1550	217	780	180	0	90	1	2	3	0	
raise up 100	1550	217	880	180	0	90	1	2	3	0	
continue with next task											

C3R2T2–dpt2	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt2	1406	217	780	180	0	90	1	2	3	0	
pick up dpt2	1406	217	780	180	0	90	1	2	3	1	
raise up 100	1406	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt2	1406	217	880	180	0	90	1	2	3	1	
leave dpt2	1406	217	780	180	0	90	1	2	3	1	
open gripper	1406	217	780	180	0	90	1	2	3	0	
raise up 100	1406	217	880	180	0	90	1	2	3	0	
continue with next task											

C3R2T2–dpt3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt3	1262	217	780	180	0	90	1	2	3	0	
pick up dpt3	1262	217	780	180	0	90	1	2	3	1	
raise up 100	1262	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt3	1262	217	880	180	0	90	1	2	3	1	
leave dpt3	1262	217	780	180	0	90	1	2	3	1	
open gripper	1262	217	780	180	0	90	1	2	3	0	
raise up 100	1262	217	880	180	0	90	1	2	3	0	
continue with next task											

C3R2T2–dpt4	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt4	1118	217	780	180	0	90	1	2	3	0	
pick up dpt4	1118	217	780	180	0	90	1	2	3	1	
raise up 100	1118	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt4	1118	217	880	180	0	90	1	2	3	1	
leave dpt4	1118	217	780	180	0	90	1	2	3	1	
open gripper	1118	217	780	180	0	90	1	2	3	0	
raise up 100	1118	217	880	180	0	90	1	2	3	0	
continue with next task											

C3R2T2–dpt5	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt5	974	217	780	180	0	90	1	2	3	0	
pick up dpt5	974	217	780	180	0	90	1	2	3	1	
raise up 100	974	217	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt5	974	217	880	180	0	90	1	2	3	1	
leave dpt5	974	217	780	180	0	90	1	2	3	1	
open gripper	974	217	780	180	0	90	1	2	3	0	
raise up 100	974	217	880	180	0	90	1	2	3	0	
continue with next task											

C3R2T2–dpt6	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt6	1550	359	780	180	0	90	1	2	3	0	
pick up dpt6	1550	359	780	180	0	90	1	2	3	1	
raise up 100	1550	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt6	1550	359	880	180	0	90	1	2	3	1	
leave dpt6	1550	359	780	180	0	90	1	2	3	1	
open gripper	1550	359	780	180	0	90	1	2	3	0	
raise up 100	1550	359	880	180	0	90	1	2	3	0	
continue with next task											

C3R2T2–dpt7	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt7	1406	359	780	180	0	90	1	2	3	0	
pick up dpt7	1406	359	780	180	0	90	1	2	3	1	
raise up 100	1406	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt7	1406	359	880	180	0	90	1	2	3	1	
leave dpt7	1406	359	780	180	0	90	1	2	3	1	
open gripper	1406	359	780	180	0	90	1	2	3	0	
raise up 100	1406	359	880	180	0	90	1	2	3	0	
continue with next task											

C3R2T2–dpt8	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
at pos dpt8	1262	359	780	180	0	90	1	2	3	0	
pick up dpt8	1262	359	780	180	0	90	1	2	3	1	
raise up 100	1262	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt8	1262	359	880	180	0	90	1	2	3	1	
leave dpt8	1262	359	780	180	0	90	1	2	3	1	
open gripper	1262	359	780	180	0	90	1	2	3	0	
raise up 100	1262	359	880	180	0	90	1	2	3	0	
continue with next task											

C3R2T2–dpt9	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											6
before to start check if a request to go at rest position arrives from R1											
at pos dpt9	1118	359	780	180	0	90	1	2	3	0	
pick up dpt9	1118	359	780	180	0	90	1	2	3	1	
raise up 100	1118	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt9	1118	359	880	180	0	90	1	2	3	1	
leave dpt9	1118	359	780	180	0	90	1	2	3	1	
open gripper	1118	359	780	180	0	90	1	2	3	0	
raise up 100	1118	359	880	180	0	90	1	2	3	0	
continue with next task											

C3R2T2–dpt10	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											6
before to start check if a request to go at rest position arrives from R1											
at pos dpt10	974	359	780	180	0	90	1	2	3	0	
pick up dpt10	974	359	780	180	0	90	1	2	3	1	
raise up 100	974	359	880	180	0	90	1	2	3	1	
GP h70 over L17, shift 40 S, 60 W	1260	710	820	180	0	90	1	2	3	1	
turn 45°	1260	710	820	135	0	90	1	2	3	1	
Shaking -20 Northwise	1260	690	820	135	0	90	1	2	3	1	
Shaking +20 Southwise	1260	710	820	135	0	90	1	2	3	1	
move 100 Northwise	1260	610	820	135	0	90	1	2	3	1	
raise up 60	1260	630	880	135	0	90	1	2	3	1	
Turn -45	1260	630	880	180	0	90	1	2	3	1	
100 above pos dpt10	974	359	880	180	0	90	1	2	3	1	
leave dpt10	974	359	780	180	0	90	1	2	3	1	
open gripper	974	359	780	180	0	90	1	2	3	0	
raise up 100	974	359	880	180	0	90	1	2	3	0	
continue with next task											

C3R2T3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
			before to start check if a request to go at rest position arrives from R1								
at pos rp	1282	60	886	180	0	90	1	2	3	0	
pick up rp	1282	60	886	180	0	90	1	2	3	1	
rp release	1267	60	886	180	0	90	1	2	3	1	
raise up	1267	60	986	180	0	90	1	2	3	1	
above Loc 17	1200	670	986	180	0	90	1	2	3	1	
down h40	1200	670	901	180	0	90	1	2	3	1	
move N 80 h36	1200	590	897	180	0	90	1	2	3	1	
move S 160 h36	1200	750	897	180	0	90	1	2	3	1	
move to centre	1200	670	897	180	0	90	1	2	3	1	
turn by 90°	1200	670	897	180	0	180	1	2	3	1	
move E 80 h32	1120	670	893	180	0	180	1	2	3	1	
move W 160 h32	1280	670	893	180	0	180	1	2	3	1	
move to centre	1200	670	893	180	0	180	1	2	3	1	
turn by -45°	1200	670	893	180	0	135	1	2	3	1	
move NE 120 h28	1115	585	889	180	0	135	1	2	3	1	
move SW 240 h28	1285	755	889	180	0	135	1	2	3	1	
move to centre	1200	670	889	180	0	135	1	2	3	1	
turn by -90°	1200	670	889	180	0	45	1	2	3	1	
move NW 120 h24	1285	585	885	180	0	45	1	2	3	1	
move SE 240 h24	1115	755	885	180	0	45	1	2	3	1	
move to centre	1200	670	885	180	0	45	1	2	3	1	
turn by 45°	1200	670	885	180	0	90	1	2	3	1	
move N 160 h20	1200	510	881	180	0	90	1	2	3	1	
move S 320 h20	1200	830	881	180	0	90	1	2	3	1	
move to centre	1200	670	881	180	0	90	1	2	3	1	
turn by 90°	1200	670	881	180	0	180	1	2	3	1	
move E 160 h16	1040	670	877	180	0	180	1	2	3	1	
move W 320 h16	1360	670	877	180	0	180	1	2	3	1	
move to centre	1200	670	877	180	0	180	1	2	3	1	
turn by -45°	1200	670	877	180	0	135	1	2	3	1	
move NE 160 h12	1087	557	873	180	0	135	1	2	3	1	
move SW 320 h12	1313	783	873	180	0	135	1	2	3	1	
move to centre	1200	670	873	180	0	135	1	2	3	1	
turn by -90°	1200	670	873	180	0	45	1	2	3	1	
move NW 160 h8	1313	557	869	180	0	45	1	2	3	1	
move SE 320 h8	1087	783	869	180	0	45	1	2	3	1	
move to centre	1200	670	869	180	0	45	1	2	3	1	
turn by 45°	1200	670	869	180	0	90	1	2	3	1	
move N 160 h7	1200	510	868	180	0	90	1	2	3	1	
move S 320 h7	1200	830	868	180	0	90	1	2	3	1	
move to centre	1200	670	868	180	0	90	1	2	3	1	
turn by 90°	1200	670	868	180	0	180	1	2	3	1	
move E 160 h6	1040	670	867	180	0	180	1	2	3	1	
move W 320 h6	1360	670	867	180	0	180	1	2	3	1	
move to centre	1200	670	867	180	0	180	1	2	3	1	
turn by -45°	1200	670	867	180	0	135	1	2	3	1	
move NE 160 h5	1087	557	866	180	0	135	1	2	3	1	
move SW 320 h5	1313	783	866	180	0	135	1	2	3	1	
move to centre	1200	670	866	180	0	135	1	2	3	1	
turn by -90°	1200	670	866	180	0	45	1	2	3	1	
move NW 160 h4	1313	557	865	180	0	45	1	2	3	1	
move SE 320 h4	1087	783	865	180	0	45	1	2	3	1	
move to centre	1200	670	865	180	0	45	1	2	3	1	
turn by 45°	1200	670	865	180	0	90	1	2	3	1	
raise up	1200	670	986	180	0	90	1	2	3	1	
back to pos rp	1267	60	986	180	0	90	1	2	3	1	
down to Loc 19	1267	60	886	180	0	90	1	2	3	1	
engaging	1282	60	886	180	0	90	1	2	3	1	
open gripper	1282	60	886	180	0	90	1	2	3	0	
raise up 100	1282	60	986	180	0	90	1	2	3	0	
			continue with next task								

C3R2T4	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 6
before to start check if a request to go at rest position arrives from R1											
send request to R1											
70 & -45° Northwise of ps2	1547	600	778	180	45	90	1	2	3	0	
at pos ps2	1547	670	778	180	45	90	1	2	3	0	
pick up ps2	1547	670	778	180	45	90	1	2	3	1	
raise 340	1547	670	1118	180	45	90	1	2	3	1	
rotation 90°	1547	670	1118	180	-45	90	1	2	3	1	
GP 28 & 508 Westwise Loc 17	1708	670	778	180	-45	90	1	2	3	1	
pick up pizza 320 Eastwise	1388	670	778	180	-45	90	1	2	3	1	
stand by for R1 confirmation	1388	670	778	180	-45	90	1	2	3	1	
move to h117	1388	670	867	180	-45	90	1	2	3	1	
move to 169 before L1	669	670	867	180	-45	90	1	2	3	1	
rotation -15°	669	670	867	180	-30	90	1	2	3	1	
move 20 Westwise (shake)	689	670	867	180	-30	90	1	2	3	1	
move 20 Eastwise (shake)	669	670	867	180	-30	90	1	2	3	1	
Rotation 15°	669	670	867	180	-45	90	1	2	3	1	
move to X 1708	1708	670	867	180	-45	90	1	2	3	1	
up to 1118 and right to 1547	1547	670	1118	180	-45	90	1	2	3	1	
Rotation -90°	1547	670	1118	180	45	90	1	2	3	1	
down to Loc 18	1547	670	778	180	45	90	1	2	3	1	
send finish info to R1	1547	670	778	180	45	90	1	2	3	1	
open gripper	1547	670	778	180	45	90	1	2	3	0	
disingage	1547	600	778	180	45	90	1	2	3	0	
raise 100	1547	600	878	180	45	90	1	2	3	0	
continue with next task or stop at rest if dpti = dpt10											

Robot 1

C3R1T1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
before to start check if a request to remain at rest position arrives from R2											
after R2 confirmation											
at pos tsl	215	861	795	0	-90	0	2	1	3	0	
pick up tsl	215	861	795	0	-90	0	2	1	3	1	
move forward 60	215	801	795	0	-90	0	2	1	3	1	
wait 3 sec to collect souce	215	801	795	0	-90	0	2	1	3	1	souce from dispenser
move backward 40	215	821	795	0	-90	0	2	1	3	1	
raise by 145	215	821	940	0	-90	0	2	1	3	1	
W2 rotation +90	450	586	940	90	-90	0	2	1	3	1	
over Loc 1 centre	500	670	940	90	-90	0	2	1	3	1	
W3 rotation +90	500	670	940	90	-90	-90	2	1	3	1	
W3 rotation +180	500	670	940	90	-90	-180	2	1	3	1	
W3 rotation +270	500	670	940	90	-90	-270	2	1	3	1	
W3 rotation +360	500	670	940	90	-90	-360	2	1	3	1	
move down by 115	500	670	825	90	-90	0	2	1	3	1	
spread tomato sauce	510	687	825	90	-90	0	2	1	3	1	
"	528	698	825	90	-90	0	2	1	3	1	
"	540	670	825	90	-90	0	2	1	3	1	
"	528	642	825	90	-90	0	2	1	3	1	
"	500	630	825	90	-90	0	2	1	3	1	
"	472	642	825	90	-90	0	2	1	3	1	
"	460	670	825	90	-90	0	2	1	3	1	
"	448	700	825	90	-90	0	2	1	3	1	
"	450	757	825	90	-90	0	2	1	3	1	
"	500	780	825	90	-90	0	2	1	3	1	
"	555	765	825	90	-90	0	2	1	3	1	
"	595	725	825	90	-90	0	2	1	3	1	
"	610	670	825	90	-90	0	2	1	3	1	
"	595	615	825	90	-90	0	2	1	3	1	
"	555	575	825	90	-90	0	2	1	3	1	
"	500	560	825	90	-90	0	2	1	3	1	
"	445	575	825	90	-90	0	2	1	3	1	
"	405	615	825	90	-90	0	2	1	3	1	
"	390	670	825	90	-90	0	2	1	3	1	
"	422	715	825	90	-90	0	2	1	3	1	
"	465	690	825	90	-90	0	2	1	3	1	
"	500	670	825	90	-90	0	2	1	3	1	
raise up by 100	500	670	925	90	-90	0	2	1	3	1	
above pos tsl	215	861	925	0	-90	0	2	1	3	1	
W2 rotation -90	215	861	925	0	-90	0	2	1	3	1	
leave tsl	215	861	795	0	-90	0	2	1	3	1	
open gripper	215	861	795	0	-90	0	2	1	3	0	
raise up 100	215	861	895	0	-90	0	2	1	3	0	
continue with next task											

C3R1T2-cc1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											1
		to be always completed									
at pos cc1	602	116	1048	90	90	180	2	1	3	0	
pick up cc1	602	116	1048	90	90	180	2	1	3	1	
raise up 100	602	116	1148	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc1	602	116	1148	90	90	180	2	1	3	1	
leave cc1	602	116	1048	90	90	180	2	1	3	1	
open gripper	602	116	1048	90	90	180	2	1	3	0	
raise up 100	602	116	1148	90	90	180	2	1	3	0	
		continue with next task									

C3R1T2-cc2	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											1
		to be always completed									
at pos cc2	413	116	1048	90	90	180	2	1	3	0	
pick up cc2	413	116	1048	90	90	180	2	1	3	1	
raise up 100	413	116	1148	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc2	413	116	1148	90	90	180	2	1	3	1	
leave cc2	413	116	1048	90	90	180	2	1	3	1	
open gripper	413	116	1048	90	90	180	2	1	3	0	
raise up 100	413	116	1148	90	90	180	2	1	3	0	
		continue with next task									

C3R1T2-cc3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											1
		to be always completed									
at pos cc3	224	116	1048	90	90	180	2	1	3	0	
pick up cc3	224	116	1048	90	90	180	2	1	3	1	
raise up 100	224	116	1148	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc3	224	116	1148	90	90	180	2	1	3	1	
leave cc3	224	116	1048	90	90	180	2	1	3	1	
open gripper	224	116	1048	90	90	180	2	1	3	0	
raise up 100	224	116	1148	90	90	180	2	1	3	0	
		continue with next task									

C3R1T2-cc4	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
			to be always completed								
at pos cc4	35	116	1048	90	90	180	2	1	3	0	
pick up cc4	35	116	1048	90	90	180	2	1	3	1	
raise up 100	35	116	1148	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc4	35	116	1148	90	90	180	2	1	3	1	
leave cc4	35	116	1048	90	90	180	2	1	3	1	
open gripper	35	116	1048	90	90	180	2	1	3	0	
raise up 100	35	116	1148	90	90	180	2	1	3	0	
			continue with next task								

C3R1T2-cc5	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
			to be always completed								
at pos cc5	602	328	948	90	90	180	2	1	3	0	
pick up cc5	602	328	948	90	90	180	2	1	3	1	
raise up 100	602	328	1048	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc5	602	328	1048	90	90	180	2	1	3	1	
leave cc5	602	328	948	90	90	180	2	1	3	1	
open gripper	602	328	948	90	90	180	2	1	3	0	
raise up 100	602	328	1048	90	90	180	2	1	3	0	
			continue with next task								

C3R1T2-cc6	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1
			to be always completed								
at pos cc6	413	328	948	90	90	180	2	1	3	0	
pick up cc6	413	328	948	90	90	180	2	1	3	1	
raise up 100	413	328	1048	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc6	413	328	1048	90	90	180	2	1	3	1	
leave cc6	413	328	948	90	90	180	2	1	3	1	
open gripper	413	328	948	90	90	180	2	1	3	0	
raise up 100	413	328	1048	90	90	180	2	1	3	0	
			continue with next task								

C3R1T2-cc7	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											1
			to be always completed								
at pos cc7	224	328	948	90	90	180	2	1	3	0	
pick up cc7	224	328	948	90	90	180	2	1	3	1	
raise up 100	224	328	1048	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc7	224	328	1048	90	90	180	2	1	3	1	
leave cc7	224	328	948	90	90	180	2	1	3	1	
open gripper	224	328	948	90	90	180	2	1	3	0	
raise up 100	224	328	1048	90	90	180	2	1	3	0	
			continue with next task								

C3R1T2-cc8	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											1
			to be always completed								
at pos cc8	35	328	948	90	90	180	2	1	3	0	
pick up cc8	35	328	948	90	90	180	2	1	3	1	
raise up 100	35	328	1048	90	90	180	2	1	3	1	
GP h270 over L1, shift 80 left (West)	580	670	1020	90	90	180	2	1	3	1	
Rotate 90°	580	670	1020	90	90	90	2	1	3	1	
Rotate 90° more	580	670	1020	90	90	0	2	1	3	1	
down 150	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Shaking +20 Upward	580	670	890	90	90	0	2	1	3	1	
Shaking -20 Downward	580	670	870	90	90	0	2	1	3	1	
Up 150	580	670	1020	90	90	0	2	1	3	1	
back rotation 90°	580	670	1020	90	90	90	2	1	3	1	
back rotation 90° more	580	670	1020	90	90	180	2	1	3	1	
raise up	580	670	1148	90	90	180	2	1	3	1	
100 above pos cc8	35	328	1048	90	90	180	2	1	3	1	
leave cc8	35	328	948	90	90	180	2	1	3	1	
open gripper	35	328	948	90	90	180	2	1	3	0	
raise up 100	35	328	1048	90	90	180	2	1	3	0	
			continue with next task								

C3R1T3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											1
		to be always completed									
at pos cs	215	593	795	0	-90	0	2	1	3	0	
pick up cs	215	593	795	0	-90	0	2	1	3	1	
raise up 100	215	593	895	0	-90	0	2	1	3	1	
W2 rotation +90	450	358	895	90	-90	0	2	1	3	1	
over Loc 1 centre	500	670	895	90	-90	0	2	1	3	1	
move down by 65	500	670	830	90	-90	0	2	1	3	1	
spread condiments	510	687	830	90	-90	0	2	1	3	1	
“	528	698	830	90	-90	0	2	1	3	1	
“	540	670	830	90	-90	0	2	1	3	1	
“	528	642	830	90	-90	0	2	1	3	1	
“	500	630	830	90	-90	0	2	1	3	1	
“	472	642	830	90	-90	0	2	1	3	1	
“	460	670	830	90	-90	0	2	1	3	1	
“	448	700	830	90	-90	0	2	1	3	1	
“	450	757	830	90	-90	0	2	1	3	1	
“	500	780	830	90	-90	0	2	1	3	1	
“	555	765	830	90	-90	0	2	1	3	1	
“	595	725	830	90	-90	0	2	1	3	1	
“	610	670	830	90	-90	0	2	1	3	1	
“	595	615	830	90	-90	0	2	1	3	1	
“	555	575	830	90	-90	0	2	1	3	1	
“	500	560	830	90	-90	0	2	1	3	1	
“	445	575	830	90	-90	0	2	1	3	1	
“	405	615	830	90	-90	0	2	1	3	1	
“	390	670	830	90	-90	0	2	1	3	1	
“	422	715	830	90	-90	0	2	1	3	1	
“	500	690	830	90	-90	0	2	1	3	1	
“	465	670	830	90	-90	0	2	1	3	1	
raise up by 65	465	670	895	90	-90	0	2	1	3	1	
back to 100 above pos cs	215	593	895	0	-90	0	2	1	3	1	
W2 rotation -90	215	593	895	0	-90	0	2	1	3	1	
leave cs	215	593	795	0	-90	0	2	1	3	1	
open gripper	215	593	795	0	-90	0	2	1	3	0	
raise up 100	215	593	895	0	-90	0	2	1	3	0	
		continue with next task									

C3R1T4-oc	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set
											3
		to be always completed									
arrive from the above h950	100	552	950	90	90	90	1	2	3	0	
at pos oc	100	552	808	90	90	90	1	2	3	0	
pick up os	100	552	808	90	90	90	1	2	3	1	
raise up 100	100	552	908	90	90	90	1	2	3	1	
GP 80W-80N from L1 centre & h100	580	590	880	90	90	90	1	2	3	1	
rotate -135°	580	590	880	90	90	-45	1	2	3	1	
shaking +20 up	580	590	900	90	90	-45	1	2	3	1	
shaking -20 down	580	590	880	90	90	-45	1	2	3	1	
move 160 Eastwise	420	590	880	90	90	-45	1	2	3	1	
shaking +20 up	420	590	900	90	90	-45	1	2	3	1	
shaking -20 down	420	590	880	90	90	-45	1	2	3	1	
move 160 Southwise	420	750	880	90	90	-45	1	2	3	1	
shaking +20 up	420	750	900	90	90	-45	1	2	3	1	
shaking -20 down	420	750	880	90	90	-45	1	2	3	1	
move 160 Westwise	580	750	880	90	90	-45	1	2	3	1	
shaking +20 up	580	750	900	90	90	-45	1	2	3	1	
shaking -20 down	580	750	880	90	90	-45	1	2	3	1	
rotate +135°	580	750	880	90	90	90	1	2	3	1	
back to pos oc h950	100	552	950	90	90	90	1	2	3	1	
leave oc	100	552	808	90	90	90	1	2	3	1	
open gripper	100	552	808	90	90	90	1	2	3	0	
raise up 142	100	552	950	90	90	90	1	2	3	0	
		continue with next task									

C3R1T4-sc	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
			to be always completed								
arrive from the above h950	100	644	950	90	90	90	1	2	3	0	
at pos sc	100	644	808	90	90	90	1	2	3	0	
pick up sc	100	644	808	90	90	90	1	2	3	1	
raise up 100	100	644	908	90	90	90	1	2	3	1	
GP 80W-80N from L1 centre & h100	580	590	880	90	90	90	1	2	3	1	
rotate -135°	580	590	880	90	90	-45	1	2	3	1	
shaking +20 up	580	590	900	90	90	-45	1	2	3	1	
shaking -20 down	580	590	880	90	90	-45	1	2	3	1	
move 160 Eastwise	420	590	880	90	90	-45	1	2	3	1	
shaking +20 up	420	590	900	90	90	-45	1	2	3	1	
shaking -20 down	420	590	880	90	90	-45	1	2	3	1	
move 160 Southwise	420	750	880	90	90	-45	1	2	3	1	
shaking +20 up	420	750	900	90	90	-45	1	2	3	1	
shaking -20 down	420	750	880	90	90	-45	1	2	3	1	
move 160 Westwise	580	750	880	90	90	-45	1	2	3	1	
shaking +20 up	580	750	900	90	90	-45	1	2	3	1	
shaking -20 down	580	750	880	90	90	-45	1	2	3	1	
rotate +135°	580	750	880	90	90	90	1	2	3	1	
back to pos sc h950	100	644	950	90	90	90	1	2	3	1	
leave sc	100	644	808	90	90	90	1	2	3	1	
open gripper	100	644	808	90	90	90	1	2	3	0	
raise up 142	100	644	950	90	90	90	1	2	3	0	
			continue with next task								

C3R1T4-gc	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
			to be always completed								
arrive from the above h950	100	736	950	90	90	90	1	2	3	0	
at pos gc	100	736	808	90	90	90	1	2	3	0	
pick up gc	100	736	808	90	90	90	1	2	3	1	
raise up 100	100	736	908	90	90	90	1	2	3	1	
GP 80W-80N from L1 centre & h100	580	590	880	90	90	90	1	2	3	1	
rotate -135°	580	590	880	90	90	-45	1	2	3	1	
shaking +20 up	580	590	900	90	90	-45	1	2	3	1	
shaking -20 down	580	590	880	90	90	-45	1	2	3	1	
move 160 Eastwise	420	590	880	90	90	-45	1	2	3	1	
shaking +20 up	420	590	900	90	90	-45	1	2	3	1	
shaking -20 down	420	590	880	90	90	-45	1	2	3	1	
move 160 Southwise	420	750	880	90	90	-45	1	2	3	1	
shaking +20 up	420	750	900	90	90	-45	1	2	3	1	
shaking -20 down	420	750	880	90	90	-45	1	2	3	1	
move 160 Westwise	580	750	880	90	90	-45	1	2	3	1	
shaking +20 up	580	750	900	90	90	-45	1	2	3	1	
shaking -20 down	580	750	880	90	90	-45	1	2	3	1	
rotate +135°	580	750	880	90	90	90	1	2	3	1	
back to pos gc h950	100	736	950	90	90	90	1	2	3	1	
leave gc	100	736	808	90	90	90	1	2	3	1	
open gripper	100	736	808	90	90	90	1	2	3	0	
raise up 142	100	736	950	90	90	90	1	2	3	0	
			continue with next task								

C3R1T5	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
			to be always completed								
arrive from the above h200	100	828	950	90	90	90	1	2	3	0	
at pos ooc	100	828	808	90	90	90	1	2	3	0	
pick up ooc	100	828	808	90	90	90	1	2	3	1	
raise up 142	100	828	950	90	90	90	1	2	3	1	
GP over L1 centre & h200	500	670	950	90	90	90	1	2	3	1	
rotate -135°	500	670	950	90	90	-45	1	2	3	1	
olive oil spread	520	705	950	90	90	-45	1	2	3	1	
"	542	712	950	90	90	-45	1	2	3	1	
"	587	720	950	90	90	-45	1	2	3	1	
"	600	670	950	90	90	-45	1	2	3	1	
"	587	620	950	90	90	-45	1	2	3	1	
"	571	599	950	90	90	-45	1	2	3	1	
"	550	583	950	90	90	-45	1	2	3	1	
"	500	570	950	90	90	-45	1	2	3	1	
"	450	583	950	90	90	-45	1	2	3	1	
"	429	599	950	90	90	-45	1	2	3	1	
"	413	620	950	90	90	-45	1	2	3	1	
"	400	670	950	90	90	-45	1	2	3	1	
"	413	720	950	90	90	-45	1	2	3	1	
"	429	741	950	90	90	-45	1	2	3	1	
"	450	757	950	90	90	-45	1	2	3	1	
"	500	770	950	90	90	-45	1	2	3	1	
rotate +135°	500	770	950	90	90	90	1	2	3	1	
back to pos oc h200	100	828	950	90	90	90	1	2	3	1	
leave oc	100	828	808	90	90	90	1	2	3	1	
open gripper	100	828	808	90	90	90	1	2	3	0	
raise up 142	100	828	950	90	90	90	1	2	3	0	
			continue with next task								

C3R1T6-c3pst1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
			to be always completed after R2 confirmation								
send request to R2											
stand by for R2 confirmation											
70 & -45° Northwise of ps1	747	600	778	180	45	90	1	2	3	0	
at pos ps1	747	670	778	180	45	90	1	2	3	0	
pick up ps1	747	670	778	180	45	90	1	2	3	1	
raise 340	747	670	1118	180	45	90	1	2	3	1	
Rotation -90°	747	670	1118	180	-45	90	1	2	3	1	
GP h28 & 508 Westwise Loc 1	1008	670	778	180	-45	90	1	2	3	1	
pick up pizza move 320 Eastwise	688	670	778	180	-45	90	1	2	3	1	
raise up GP h117 + 100	688	670	967	135	0	270	2	3	1	1	
GP at X=400 (R1 pos)	400	670	967	180	-45	90	1	2	3	1	
turn around from Eastside	11	831	967	135	0	225	2	3	1	1	
"	-150	1220	967	135	0	180	2	3	1	1	
"	11	1609	967	135	0	135	2	3	1	1	
Compl base rot & 169 E c3pst1	631	1920	967	135	0	90	2	3	1	1	
down to h117	631	1920	867	135	0	90	2	3	1	1	
Rotation 15°	631	1920	867	150	0	90	2	3	1	1	
move 20 Eastwise (shake)	611	1920	867	150	0	90	2	3	1	1	
move 20 Westwise (shake)	631	1920	867	150	0	90	2	3	1	1	
Move 340 Eastwise	291	1920	867	150	0	90	2	3	1	1	
rotation -15°	291	1920	867	135	0	90	2	3	1	1	
move up 100	291	1920	967	135	0	90	2	3	1	1	
rotate back from Eastside	11	1609	967	135	0	135	2	3	1	1	
"	-150	1220	967	135	0	180	2	3	1	1	
"	11	831	967	135	0	225	2	3	1	1	
GP at X=400 (R1 pos)	400	670	967	180	-45	90	1	2	3	1	
move to X747,Y670,Z1118	747	670	1118	180	-45	90	1	2	3	1	
rotation 90°	747	670	1118	180	45	90	1	2	3	1	
down to Loc 2	747	670	778	180	45	90	1	2	3	1	
send finish info to R2	747	670	778	180	45	90	1	2	3	1	
open gripper	747	670	778	180	45	90	1	2	3	0	
disingage ps1	747	600	778	180	45	90	1	2	3	0	
raise 100	747	600	878	180	45	90	1	2	3	0	
send message to R3											
go at rest											
			Unless dpti = dpt10 remain at rest position till confirmation from R2 of new pizza left at location 1, otherwise stop at rest								

C3R1T6-c3pst2	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
	to be always completed after R2 confirmation										
send request to R2											
stand by for R2 confirmation											
70 & -45° Northwise of ps1	747	600	778	180	45	90	1	2	3	0	
at pos ps1	747	670	778	180	45	90	1	2	3	0	
pick up ps1	747	670	778	180	45	90	1	2	3	1	
raise 340	747	670	1118	180	45	90	1	2	3	1	
Rotation -90°	747	670	1118	180	-45	90	1	2	3	1	
GP H28 & 508 Westwise Loc 1	1008	670	778	180	-45	90	1	2	3	1	
pick up pizza move 320 Eastwise	688	670	778	180	-45	90	1	2	3	1	
raise up h117 + 100	688	670	967	180	-45	90	1	2	3	1	
GP at X=400 (R1 pos)	400	670	967	180	-45	90	1	2	3	1	
turn around from Eastside	11	831	967	135	0	225	2	3	1	1	
"	-150	1220	967	135	0	180	2	3	1	1	
"	11	1609	967	135	0	135	2	3	1	1	
Compl base rot & 169 E c3pst2	231	1920	967	135	0	90	2	3	1	1	
down to h117	231	1920	867	135	0	90	2	3	1	1	
Rotation 15°	231	1920	867	150	0	90	2	3	1	1	
move 20 Eastwise (shake)	211	1920	867	150	0	90	2	3	1	1	
move 20 Westwise (shake)	231	1920	867	150	0	90	2	3	1	1	
Move 340 Eastwise	-109	1920	867	150	0	90	2	3	1	1	
rotation -15°	-109	1920	867	135	0	90	2	3	1	1	
move up 100	-109	1920	967	135	0	90	2	3	1	1	
rotate back from Eastside	-150	1220	967	135	0	180	2	3	1	1	
"	11	831	967	135	0	225	2	3	1	1	
GP at X=400 (R1 pos)	400	670	967	180	-45	90	1	2	3	1	
move to X747,Y670,Z1118	747	670	1118	180	-45	90	1	2	3	1	
rotation 90°	747	670	1118	180	45	90	1	2	3	1	
down to Loc 2	747	670	778	180	45	90	1	2	3	1	
send finish info to R2	747	670	778	180	45	90	1	2	3	1	
open gripper	747	670	778	180	45	90	1	2	3	0	
disingage ps1	747	600	778	180	45	90	1	2	3	0	
raise 100	747	600	878	180	45	90	1	2	3	0	
send message to R3											
go at rest											
	remain at rest position till confirmation from R2 of new pizza left at location 1										

C3R1T6-c3pst3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 3
	to be always completed after R2 confirmation										
send request to R2											
stand by for R2 confirmation											
70 & -45° Northwise of ps1	747	600	778	180	45	90	1	2	3	0	
at pos ps1	747	670	778	180	45	90	1	2	3	0	
pick up ps1	747	670	778	180	45	90	1	2	3	1	
raise 340	747	670	1118	180	45	90	1	2	3	1	
Rotation -90°	747	670	1118	180	-45	90	1	2	3	1	
GP H28 & 508 Westwise Loc 1	1008	670	778	180	-45	90	1	2	3	1	
pick up pizza move 320 Eastwise	688	670	778	180	-45	90	1	2	3	1	
raise up GP h117 + 100	688	670	967	135	0	270	2	3	1	1	
GP at X=400 (R1 pos)	400	670	967	180	-45	90	1	2	3	1	
turn around from Eastside	11	831	967	135	0	225	2	3	1	1	
"	-150	1220	967	135	0	180	2	3	1	1	
move to 169 Northwise of c3pst3	0	1751	967	135	0	180	2	3	1	1	
down to h117	0	1751	867	135	0	180	2	3	1	1	
Rotation 15°	0	1751	867	150	0	180	2	3	1	1	
move 20 Northwise (shake)	0	1731	867	150	0	180	2	3	1	1	
move 20 Southwise (shake)	0	1751	867	150	0	180	2	3	1	1	
Move 340 Northtwise	0	1411	867	150	0	180	2	3	1	1	
rotation -15°	0	1411	867	135	0	180	2	3	1	1	
move up 100	0	1411	967	135	0	180	2	3	1	1	
rotate back from Eastside	-150	1220	967	135	0	180	2	3	1	1	
"	11	831	967	135	0	225	2	3	1	1	
GP at X=400 (R1 pos)	400	670	967	180	-45	90	1	2	3	1	
move to X747,Y670,Z1118	747	670	1118	180	-45	90	1	2	3	1	
rotation 90°	747	670	1118	180	45	90	1	2	3	1	
down to Loc 2	747	670	778	180	45	90	1	2	3	1	
send finish info to R2	747	670	778	180	45	90	1	2	3	1	
open gripper	747	670	778	180	45	90	1	2	3	0	
disingage ps1	747	600	778	180	45	90	1	2	3	0	
raise 100	747	600	878	180	45	90	1	2	3	0	
send message to R3											
go at rest											
	remain at rest position till confirmation from R2 of new pizza left at location 1										

ROBOT 3

C3R3T1-c3pst1ov	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set manually except
before to start check if there is confirmation of pizza presence from R1											
upon request from R1											
from rest	1157	2406	938	180	0	-90	1	2	3	1	
W2 rotation 90	1157	2171	1173	90	0	-90	1	2	3	1	
W1 rotation 90	1273	2171	1057	90	0	0	1	2	3	1	
408 + 160 Southwise c3pst1 & h100	800	2488	850	90	0	0	1	2	3	1	**3**
move 320 Northwise to pick up pizza	800	2168	850	90	0	0	1	2	3	1	**1**
raise at 1202	800	2168	1202	90	0	0	1	2	3	1	**1**
orient towards oven (W2 rotation 90)	408	2570	1202	90	-90	0	1	2	3	1	**1**
move CART 900 EastSide	-492	2570	1202	90	-90	0	1	2	3	1	**1**
inside the oven (X=-492)	-492	2570	1202	90	-90	0	1	2	3	1	**1**
rotation -15°	-492	2570	1202	105	0	-90	2	3	1	1	**1**
move 20 Eastwise (shake)	-502	2570	1202	105	0	-90	2	3	1	1	**1**
move 20 Westwise (shake)	-492	2570	1202	105	0	-90	2	3	1	1	**1**
move CART 900 WestSide	408	2570	1202	105	0	-90	2	3	1	1	**1**
Rotation 15°	408	2570	1202	90	-90	0	1	2	3	1	**1**
rise up to Z=1400	429	2406	1400	-90	-90	180	1	2	3	1	
W2 rotation -90	664	2171	1400	90	0	0	1	2	3	1	
W1 rotation -90	548	2171	1516	90	0	-90	1	2	3	1	
W2 rotation -90	548	2406	1281	180	0	-90	1	2	3	1	
at rest	1157	2406	938	180	0	-90	1	2	3	1	
send message to R1											
remain at rest during the cooking time											

C3R3T1-c3pst2ov	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set manually except
before to start check if there is confirmation of pizza presence from R1											
upon request from R1											
from rest	1157	2406	938	180	0	-90	1	2	3	1	
W2 rotation 90	1157	2171	1173	90	0	-90	1	2	3	1	
W1 rotation 90	1273	2171	1057	90	0	0	1	2	3	1	
408 + 160 Southwise c3pst2 & h100	400	2488	850	90	0	0	1	2	3	1	**3**
move 320 Northwise to pick up pizza	400	2168	850	90	0	0	1	2	3	1	**1**
raise at 1202	400	2168	1202	90	0	0	1	2	3	1	**1**
orient towards oven (W2 rotation 90)	408	2570	1202	90	-90	0	1	2	3	1	**1**
move CART 900 EastSide	-492	2570	1202	90	-90	0	1	2	3	1	**1**
inside the oven (X=-492)	-492	2570	1202	90	-90	0	1	2	3	1	**1**
rotation -15°	-492	2570	1202	105	0	-90	2	3	1	1	**1**
move 20 Eastwise (shake)	-502	2570	1202	105	0	-90	2	3	1	1	**1**
move 20 Westwise (shake)	-492	2570	1202	105	0	-90	2	3	1	1	**1**
move CART 900 WestSide	408	2570	1202	105	0	-90	2	3	1	1	**1**
Rotation 15°	408	2570	1202	90	-90	0	1	2	3	1	**1**
rise up to Z=1400	429	2406	1400	-90	-90	180	1	2	3	1	
W2 rotation -90	664	2171	1400	90	0	0	1	2	3	1	
W1 rotation -90	548	2171	1516	90	0	-90	1	2	3	1	
W2 rotation -90	548	2406	1281	180	0	-90	1	2	3	1	
at rest	1157	2406	938	180	0	-90	1	2	3	1	
send message to R1											
remain at rest during the cooking time											

C3R3T1-c3pst3ov	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set manually except
before to start check if there is confirmation of pizza presence from R1											
upon request from R1											
from rest	1157	2406	938	180	0	-90	1	2	3	1	
W2 rotation 90	1157	2171	1173	90	0	-90	1	2	3	1	
W1 rotation 90	1273	2171	1057	90	0	0	1	2	3	1	
move CART 400 EastSide	873	2171	1057	90	0	0	1	2	3	1	
408 + 160 Southwise c3pst2 & h100	0	2488	850	90	0	0	1	2	3	1	3
move 320 Northwise to pick up pizza	0	2168	850	90	0	0	1	2	3	1	1
raise at 1202	0	2168	1202	90	0	0	1	2	3	1	1
move CART 400 WestSide	400	2168	1202	90	0	0	1	2	3	1	1
orient towards oven (W2 rotation 90)	408	2570	1202	90	-90	0	1	2	3	1	1
move CART 900 EastSide	-492	2570	1202	90	-90	0	1	2	3	1	1
inside the oven (X=-492)	-492	2570	1202	90	-90	0	1	2	3	1	1
rotation -15°	-492	2570	1202	105	0	-90	2	3	1	1	1
move 20 Eastwise (shake)	-502	2570	1202	105	0	-90	2	3	1	1	1
move 20 Westwise (shake)	-492	2570	1202	105	0	-90	2	3	1	1	1
move CART 900 WestSide	408	2570	1202	105	0	-90	2	3	1	1	1
Rotation 15°	408	2570	1202	90	-90	0	1	2	3	1	1
rise up to Z=1400	429	2406	1400	-90	-90	180	1	2	3	1	
W2 rotation -90	664	2171	1400	90	0	0	1	2	3	1	
W1 rotation -90	548	2171	1516	90	0	-90	1	2	3	1	
W2 rotation -90	548	2406	1281	180	0	-90	1	2	3	1	
at rest	1157	2406	938	180	0	-90	1	2	3	1	
send message to R1											
remain at rest during the cooking time											

C3R3T2-ovcp1	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1 and manually
	to be performed at the end of the cooking time										
from rest	1157	2406	938	180	0	-90	1	2	3	1	
W2 rotation 90	1157	2171	1173	90	0	-90	1	2	3	1	
W1 rotation 90	1273	2171	1057	90	0	0	1	2	3	1	
orient towards oven (W2 rotation 90)	768	2570	1100	90	-90	0	1	2	3	1	
move CART 900 EastSide	-132	2570	1100	90	-90	0	1	2	3	1	
320 inside the oven	-452	2570	1100	90	-90	0	1	2	3	1	
rise up 100	-452	2570	1200	90	-90	0	1	2	3	1	
move CART 400 WestSide	-52	2570	1200	90	-90	0	1	2	3	1	
W2 rotation 90	183	2805	1200	-90	0	-180	1	2	3	1	
align with cp1	0	3012	972	-90	0	-180	1	2	3	1	
Rotation 15°	0	3012	972	-105	0	-180	1	2	3	1	
move 20 Northwise (shake)	0	2992	972	-105	0	-180	1	2	3	1	
move 20 Soutwise (shake)	0	3012	972	-105	0	-180	1	2	3	1	
move Northwise 340	0	2672	972	-105	0	-180	1	2	3	1	
rotation -15°	0	2672	972	-90	0	-180	1	2	3	1	
orient towards oven (W2 rotation -90)	-71	2406	1400	90	-90	0	1	2	3	1	
move CART 500 WestSide	429	2406	1400	90	-90	0	1	2	3	1	
rise up to Z=1400	429	2406	1400	-90	-90	180	1	2	3	1	
W2 rotation -90	664	2171	1400	90	0	0	1	2	3	1	
W1 rotation -90	548	2171	1516	90	0	-90	1	2	3	1	
W2 rotation -90	548	2406	1281	180	0	-90	1	2	3	1	
at rest	1157	2406	938	180	0	-90	1	2	3	1	

send info to kitchen assistant

stay at rest till new request arrives from R1

C3R3T2-ovcp2	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1 and manually
	to be performed at the end of the cooking time										
from rest	1157	2406	938	180	0	-90	1	2	3	1	
W2 rotation 90	1157	2171	1173	90	0	-90	1	2	3	1	
W1 rotation 90	1273	2171	1057	90	0	0	1	2	3	1	
orient towards oven (W2 rotation 90)	768	2570	1100	90	-90	0	1	2	3	1	
move CART 900 EastSide	-132	2570	1100	90	-90	0	1	2	3	1	
320 inside the oven	-452	2570	1100	90	-90	0	1	2	3	1	
rise up 100	-452	2570	1200	90	-90	0	1	2	3	1	
move CART 600 WestSide	148	2570	1200	90	-90	0	1	2	3	1	
W2 rotation 90	383	2805	1200	-90	0	-180	1	2	3	1	
align with cp1	400	3012	972	-90	0	-180	1	2	3	1	
Rotation 15°	400	3012	972	-105	0	-180	1	2	3	1	
move 20 Northwise (shake)	400	2992	972	-105	0	-180	1	2	3	1	
move 20 Soutwise (shake)	400	3012	972	-105	0	-180	1	2	3	1	
move Northwise 340	400	2672	972	-105	0	-180	1	2	3	1	
rotation -15°	400	2672	972	-90	0	-180	1	2	3	1	
orient towards oven (W2 rotation -90)	129	2406	1400	90	-90	0	1	2	3	1	
move CART 300 WestSide	429	2406	1400	90	-90	0	1	2	3	1	
rise up to Z=1400	429	2406	1400	-90	-90	180	1	2	3	1	
W2 rotation -90	664	2171	1400	90	0	0	1	2	3	1	
W1 rotation -90	548	2171	1516	90	0	-90	1	2	3	1	
W2 rotation -90	548	2406	1281	180	0	-90	1	2	3	1	
at rest	1157	2406	938	180	0	-90	1	2	3	1	

send info to kitchen assistant

stay at rest till new request arrives from R1

C3R3T2-ovcp3	X [mm]	Y [mm]	Z [mm]	RX [deg]	RY [deg]	RZ [de]	Priority of rotation			Gripper [mm]	Best joint manipulator set 1 and manually
	to be performed at the end of the cooking time										
from rest	1157	2406	938	180	0	-90	1	2	3	1	
W2 rotation 90	1157	2171	1173	90	0	-90	1	2	3	1	
W1 rotation 90	1273	2171	1057	90	0	0	1	2	3	1	
orient towards oven (W2 rotation 90)	768	2570	1100	90	-90	0	1	2	3	1	
move CART 900 EastSide	-132	2570	1100	90	-90	0	1	2	3	1	
320 inside the oven	-452	2570	1100	90	-90	0	1	2	3	1	
rise up 100	-452	2570	1200	90	-90	0	1	2	3	1	
move CART 900 WestSide	448	2570	1200	90	-90	0	1	2	3	1	
W2 rotation 90	683	2805	1200	-90	0	-180	1	2	3	1	
align with cp1	800	3012	972	-90	0	-180	1	2	3	1	
Rotation 15°	800	3012	972	-105	0	-180	1	2	3	1	
move 20 Northwise (shake)	800	2992	972	-105	0	-180	1	2	3	1	
move 20 Soutwise (shake)	800	3012	972	-105	0	-180	1	2	3	1	
move Northwise 340	800	2672	972	-105	0	-180	1	2	3	1	
rotation -15°	800	2672	972	-90	0	-180	1	2	3	1	
orient twrds oven at Z = 1400 (W2 -90)	429	2406	1400	90	-90	0	1	2	3	1	
W2 rotation -90	664	2171	1400	90	0	0	1	2	3	1	
W1 rotation -90	548	2171	1516	90	0	-90	1	2	3	1	
W2 rotation -90	548	2406	1281	180	0	-90	1	2	3	1	
at rest	1157	2406	938	180	0	-90	1	2	3	1	

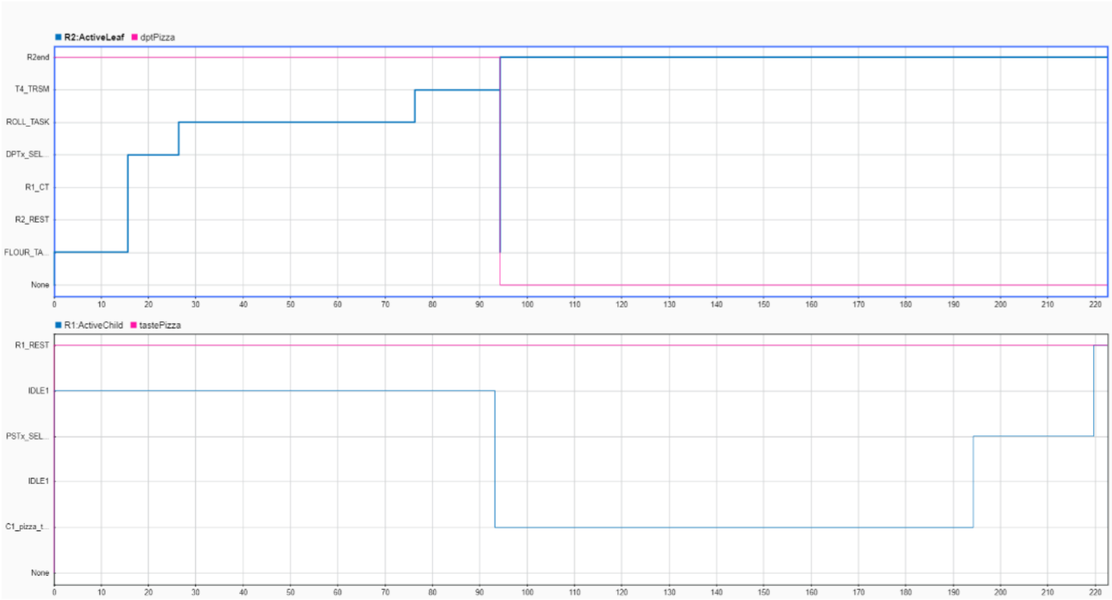
send info to kitchen assistant

stay at rest till new request arrives from R1

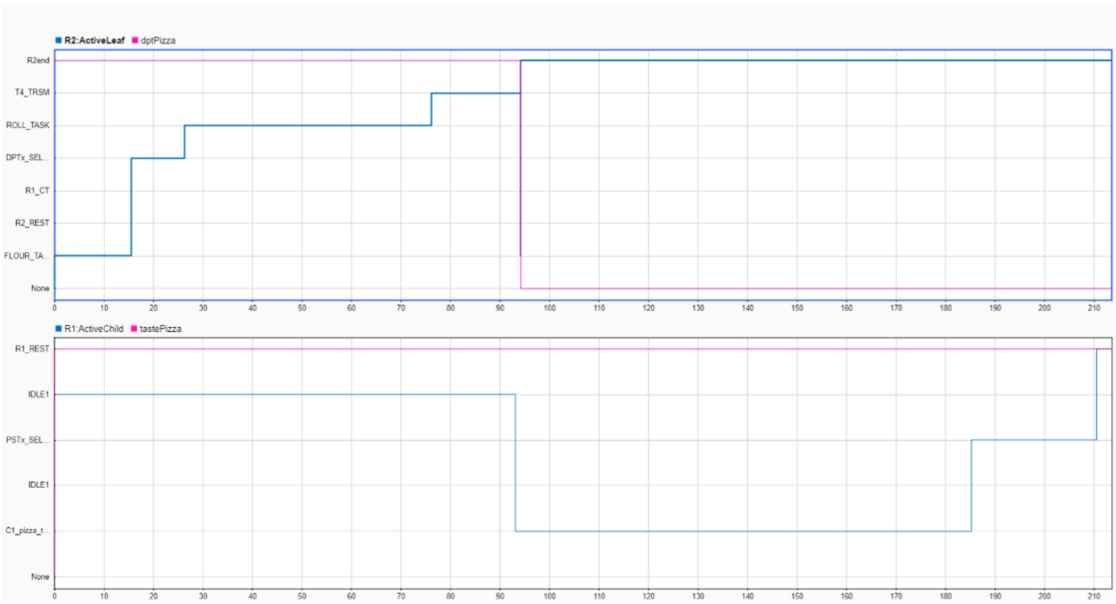
APPENDIX D

SIMULINK OUTPUTS SCENARIO 1 (SINGLE PIZZA PREPARATION)

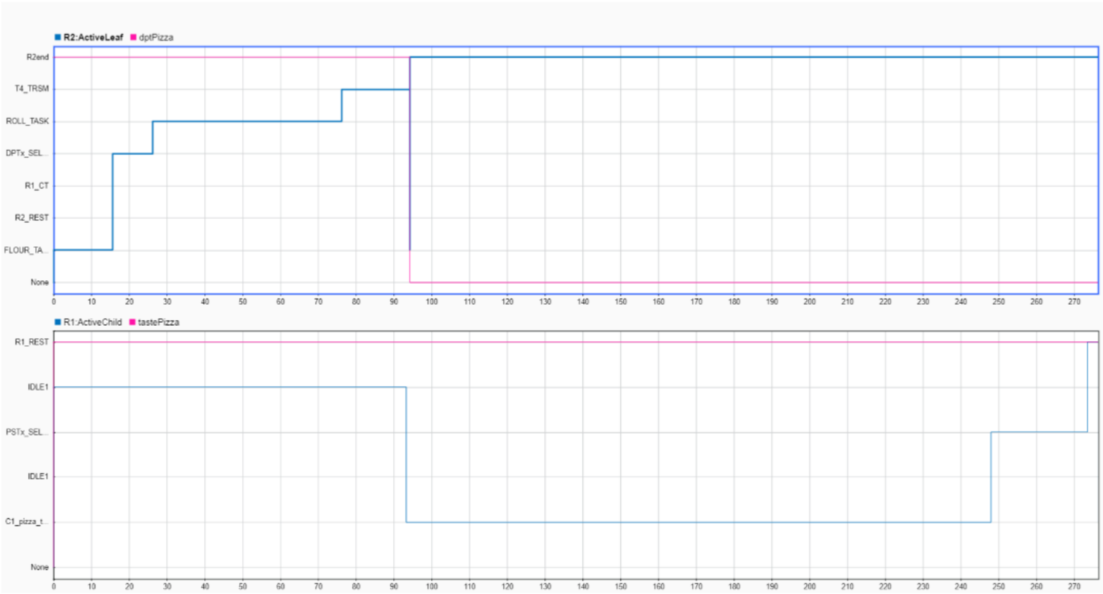
CONFIGURATION NR. 1 - MARINARA PIZZA



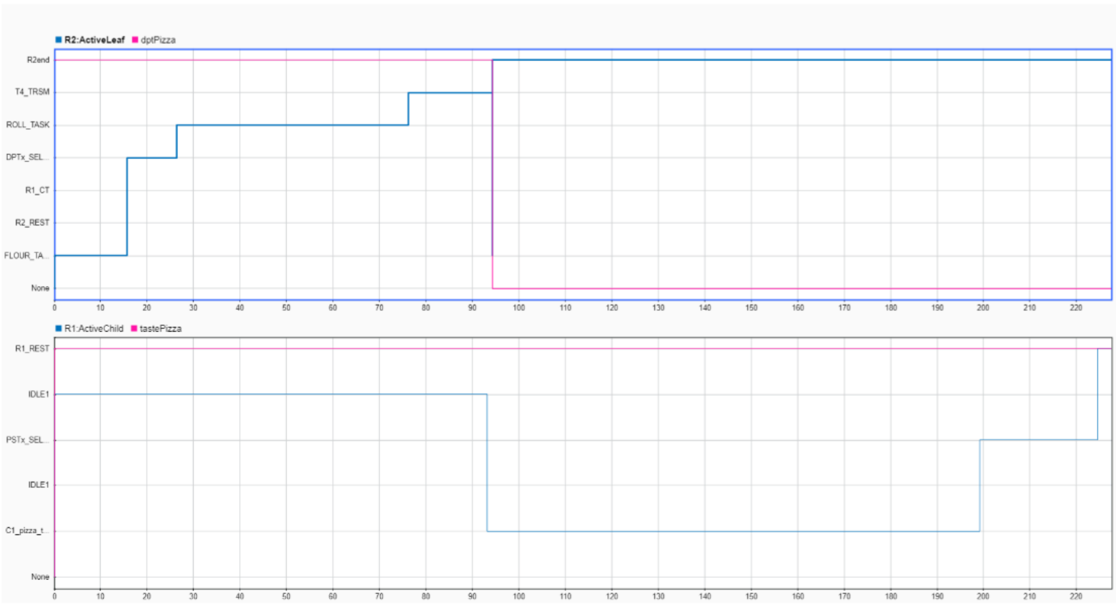
CONFIGURATION NR. 1 - MARGHERITA PIZZA



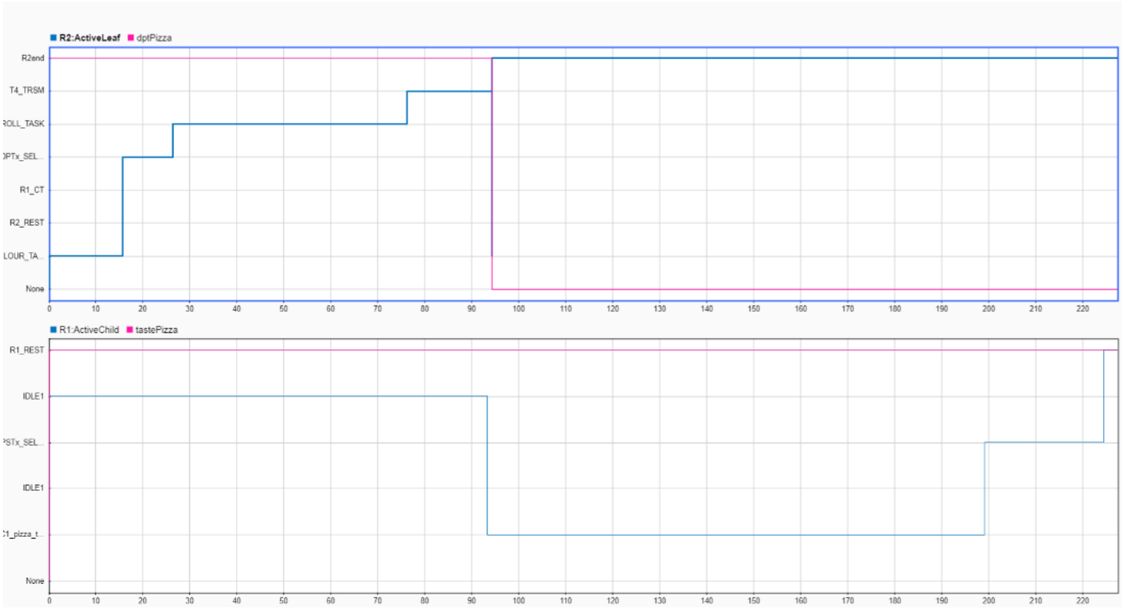
CONFIGURATION NR. 1 - ORTOLANA PIZZA



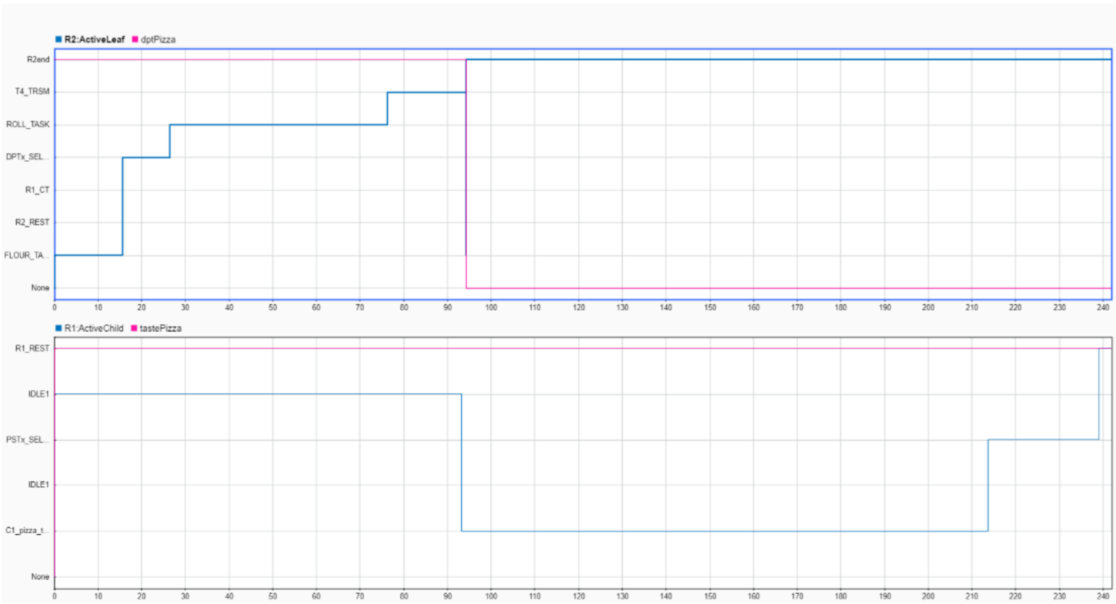
CONFIGURATION NR. 1 - WURSTEL PIZZA



CONFIGURATION NR. 1 - SALSICCIA PIZZA

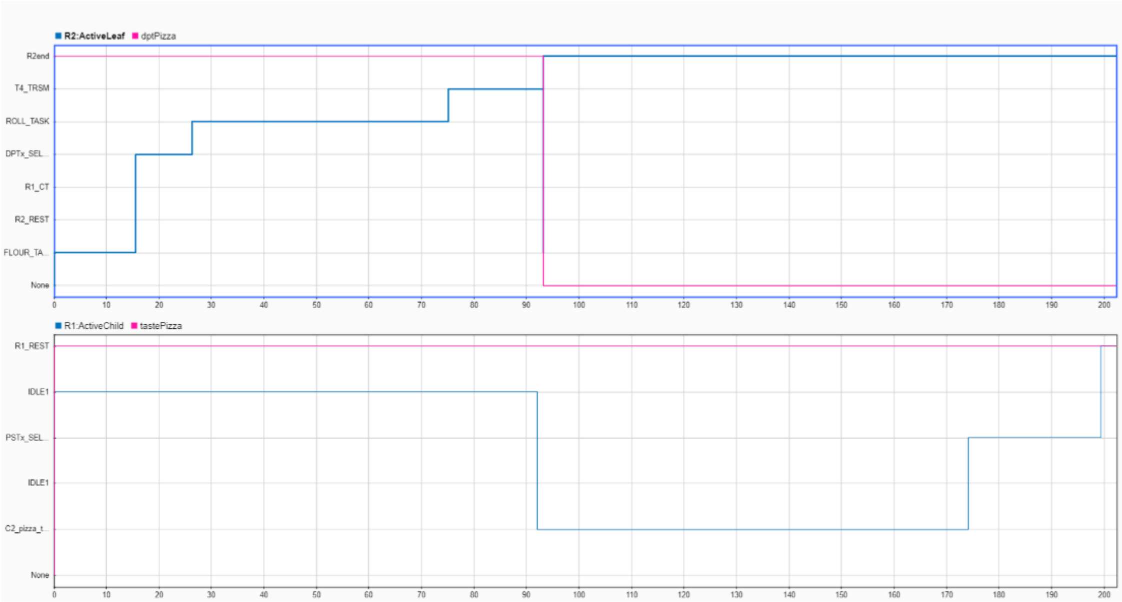


CONFIGURATION NR. 1 - PROSCIUTTO & FUNGHI PIZZA

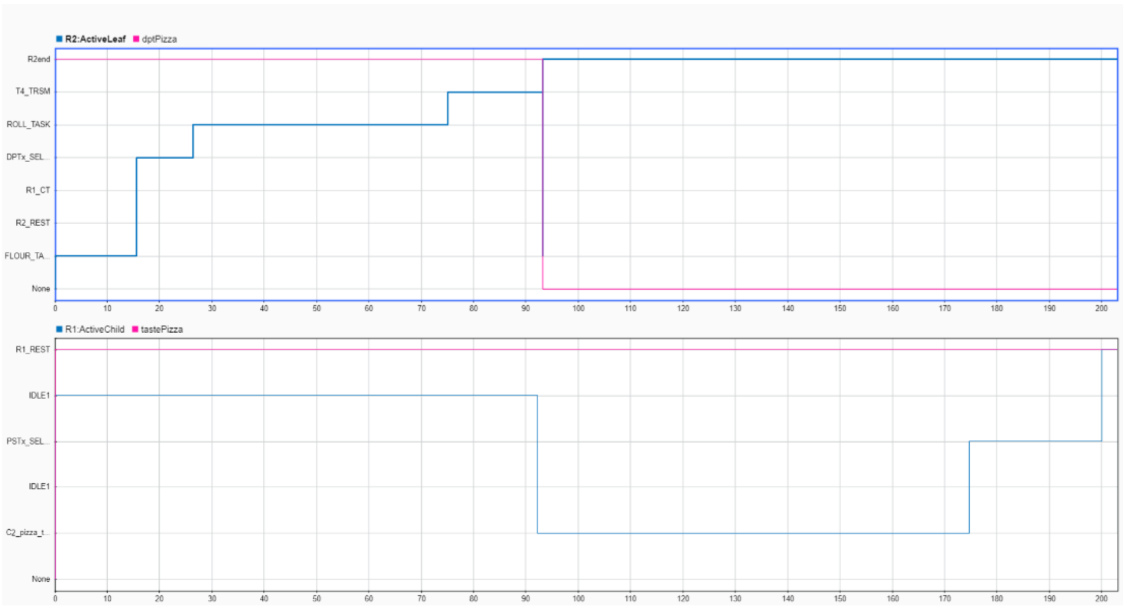


SIMULINK OUTPUTS SCENARIO 1 (SINGLE PIZZA PREPARATION)

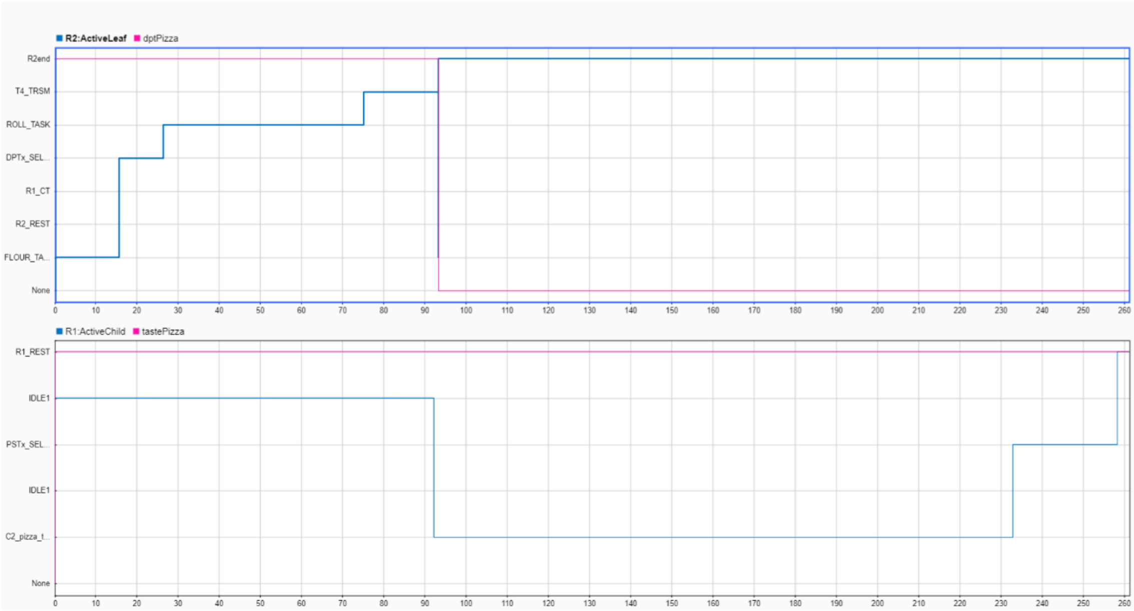
CONFIGURATION NR. 2 - MARINARA PIZZA



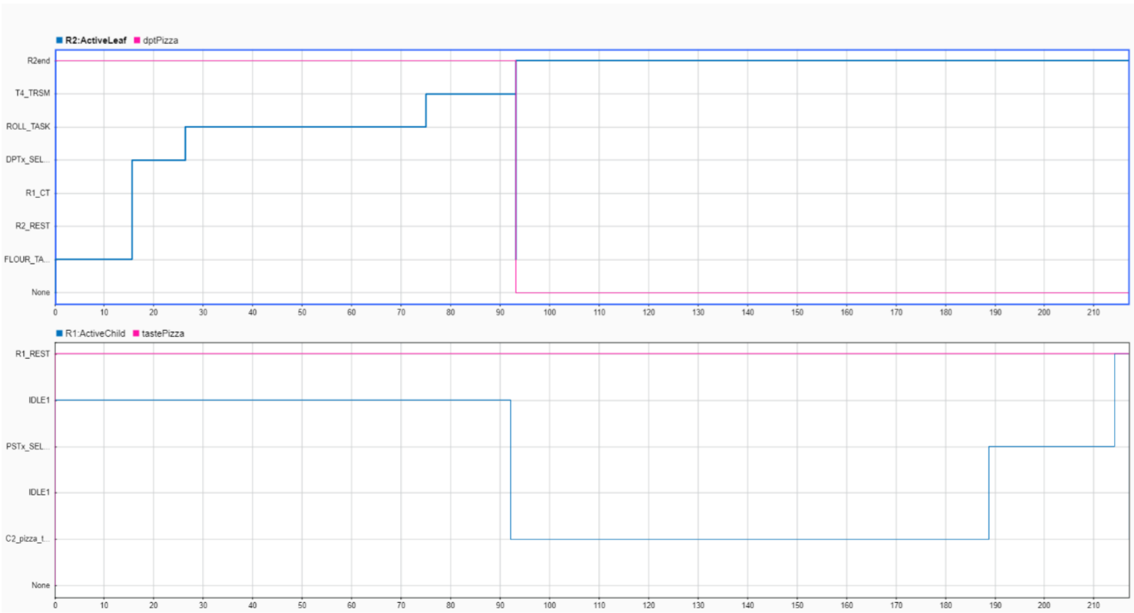
CONFIGURATION NR. 2 - MARGHERITA PIZZA



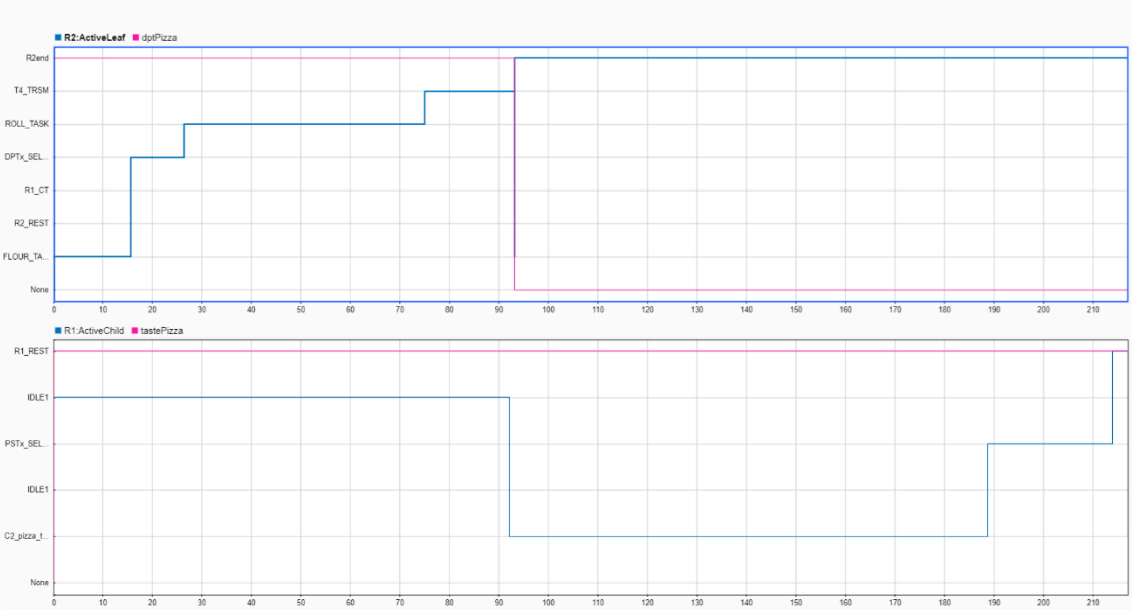
CONFIGURATION NR. 2 - ORTOLANA PIZZA



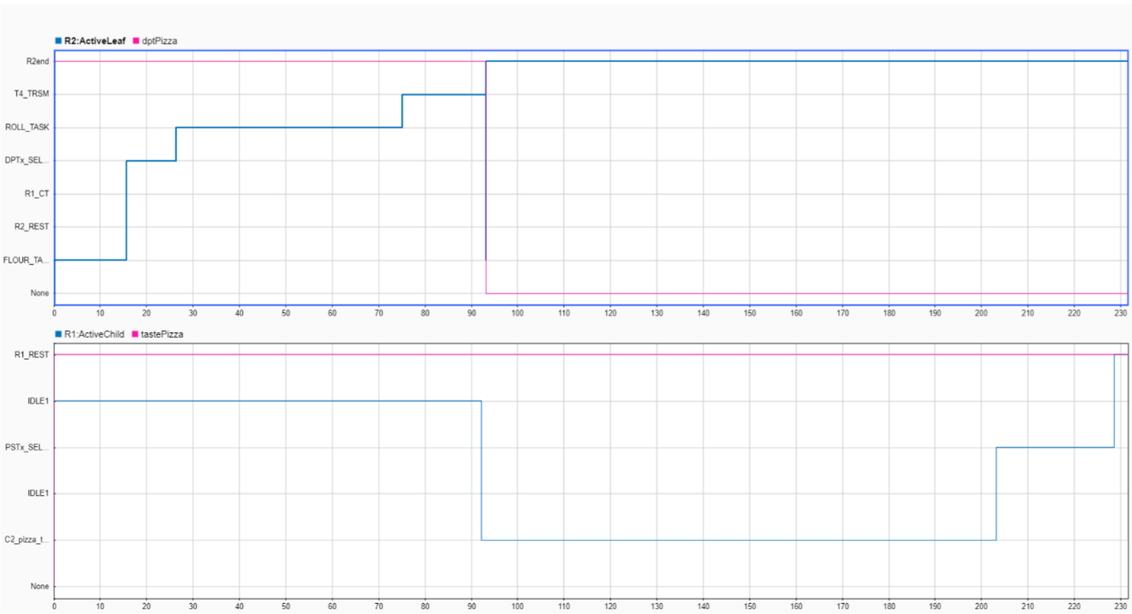
CONFIGURATION NR. 2 - WURSTEL PIZZA



CONFIGURATION NR. 2 - SALSICCIA PIZZA

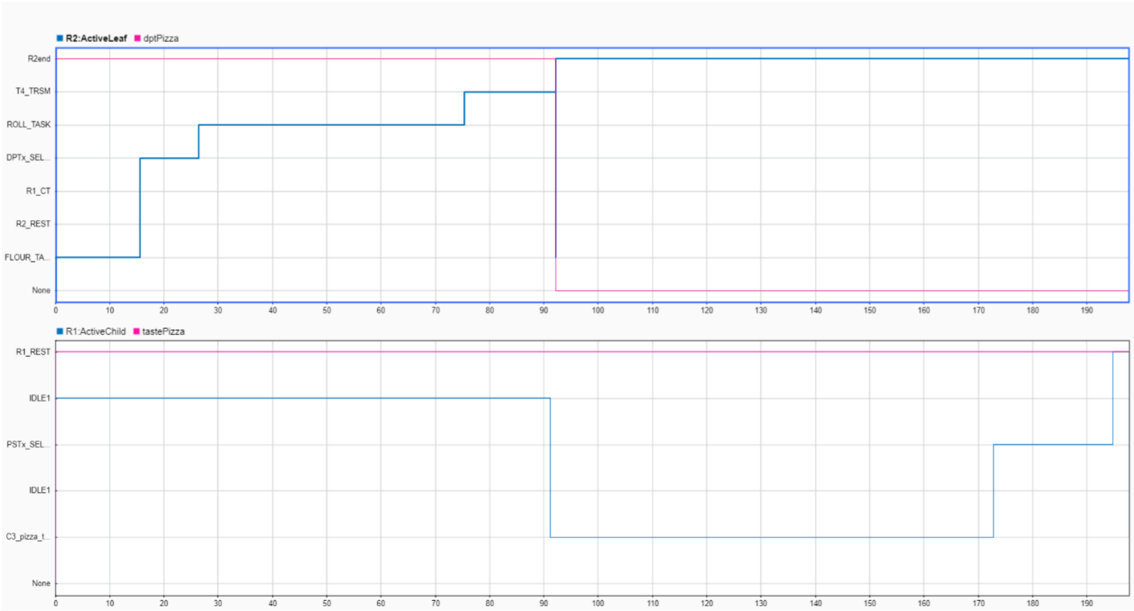


CONFIGURATION NR. 2 - PROSCIUTTO & FUNGHI PIZZA

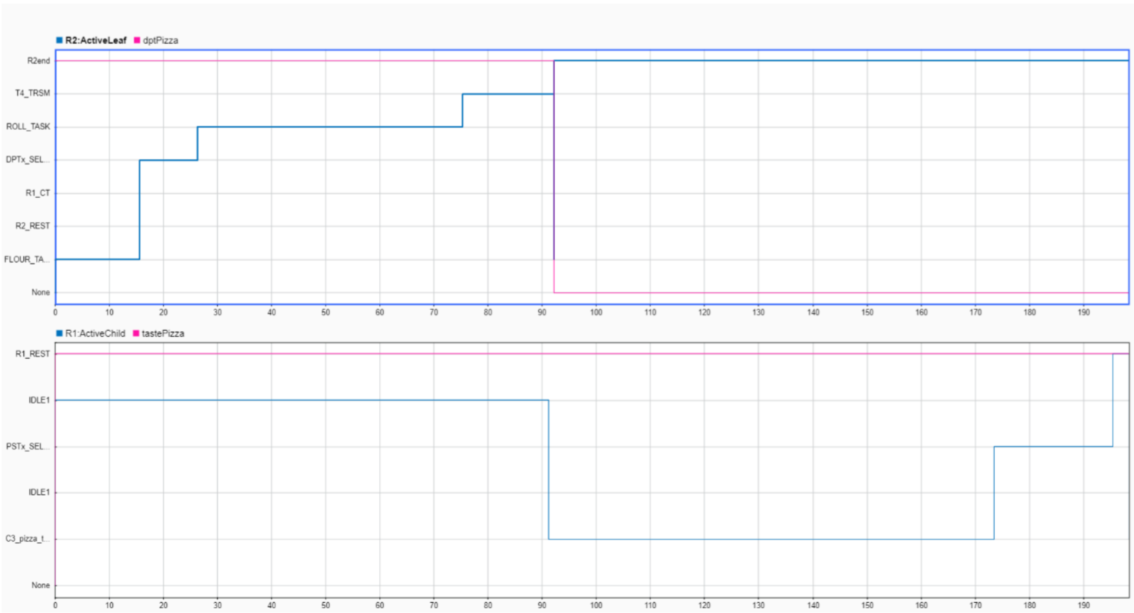


SIMULINK OUTPUTS SCENARIO 1 (SINGLE PIZZA PREPARATION)

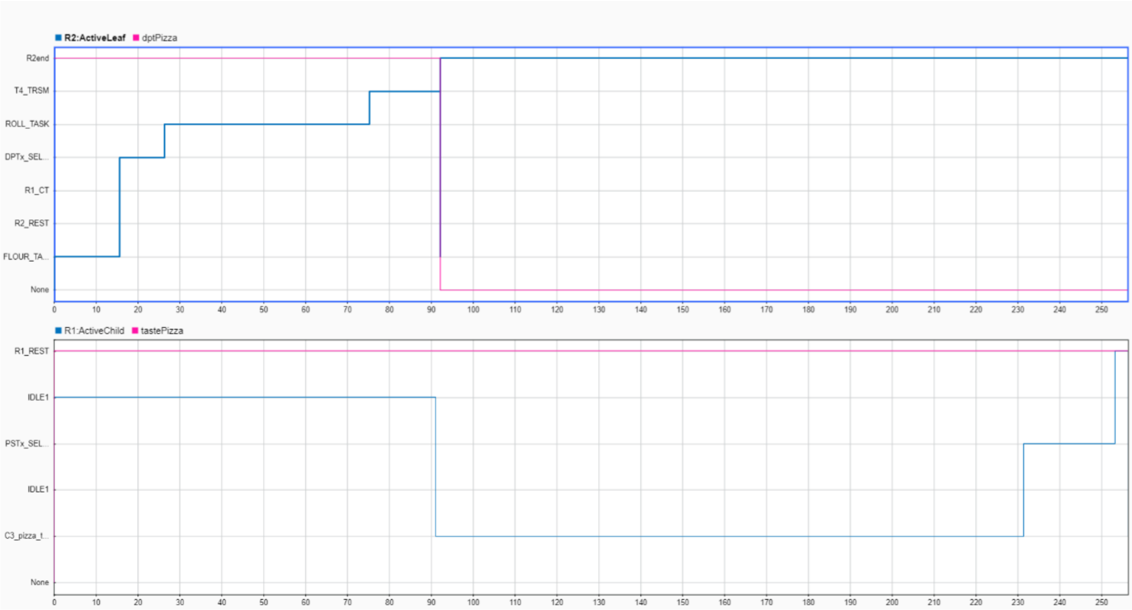
CONFIGURATION NR. 3 - MARINARA PIZZA



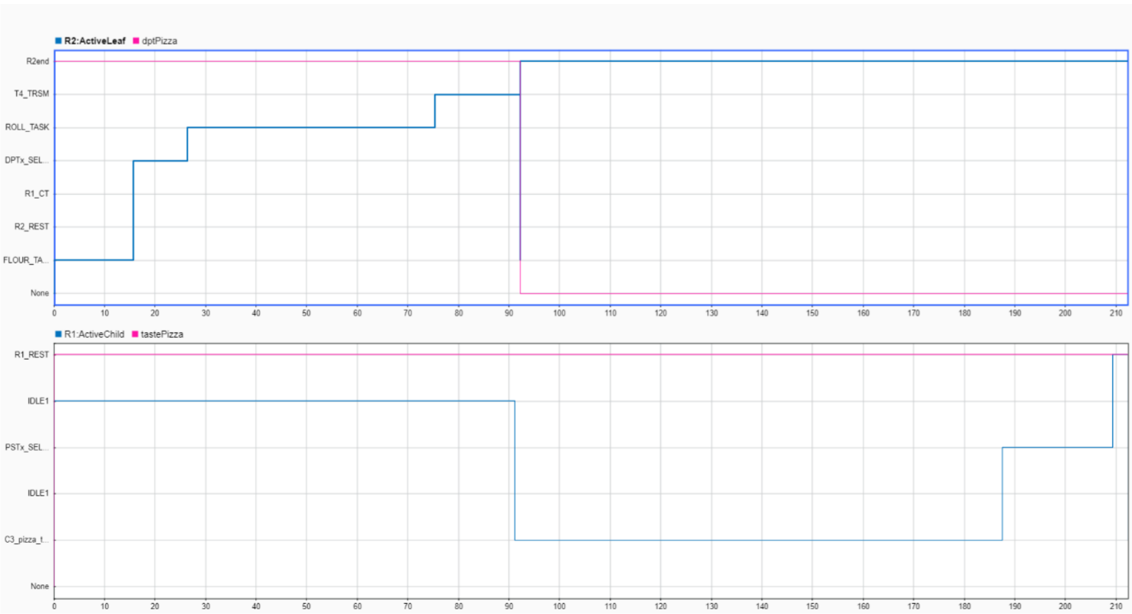
CONFIGURATION NR. 3 - MARGHERITA PIZZA



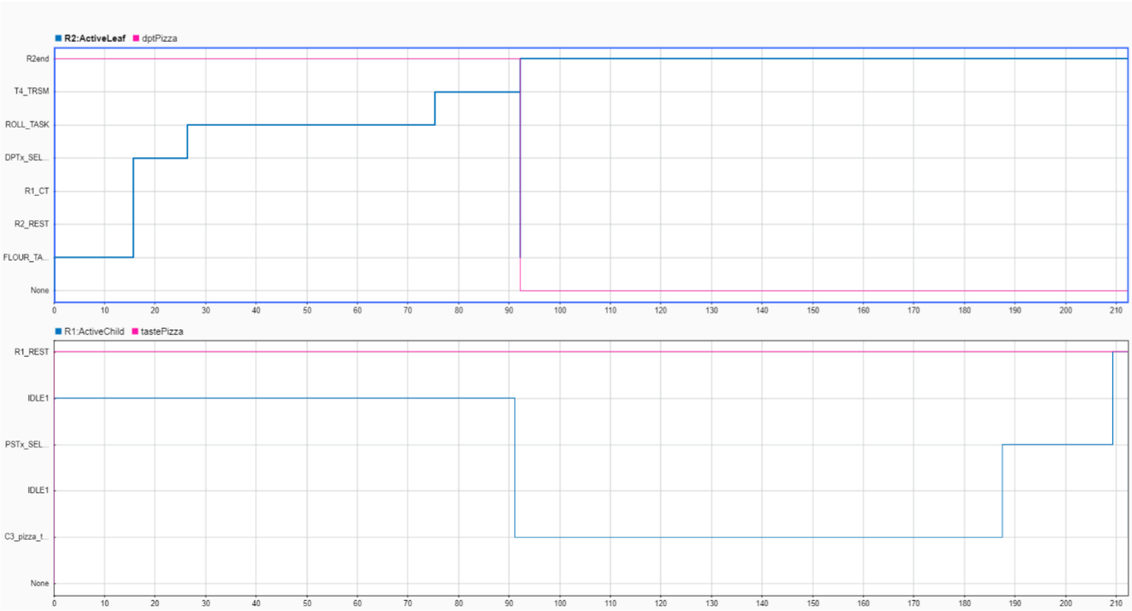
CONFIGURATION NR. 3 - ORTOLANA PIZZA



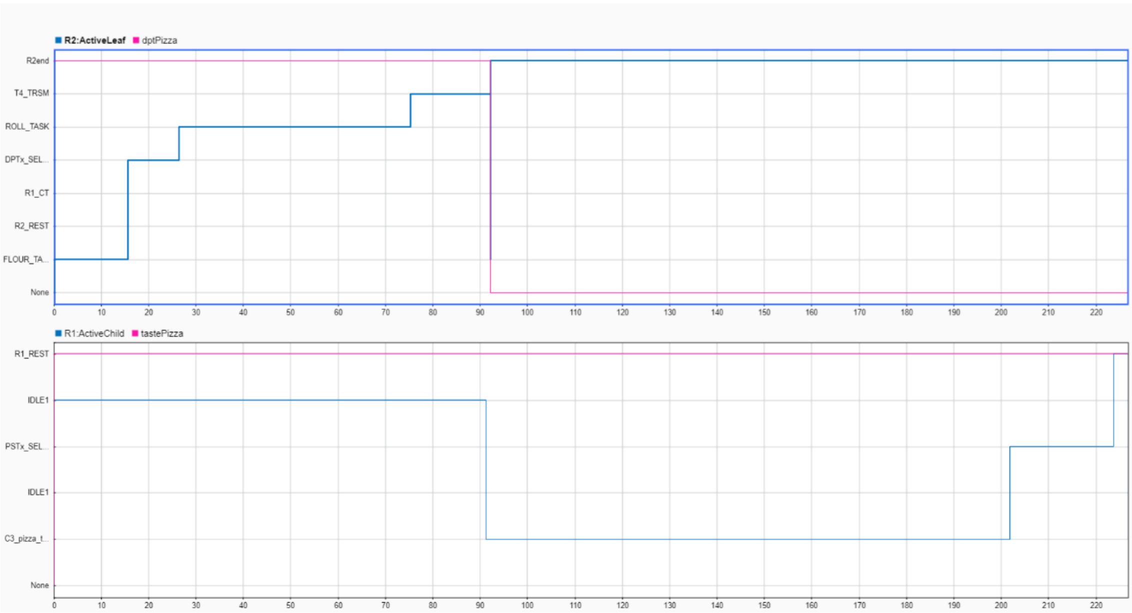
CONFIGURATION NR. 3 - WURSTEL PIZZA



CONFIGURATION NR. 3 - SALSICCIA PIZZA

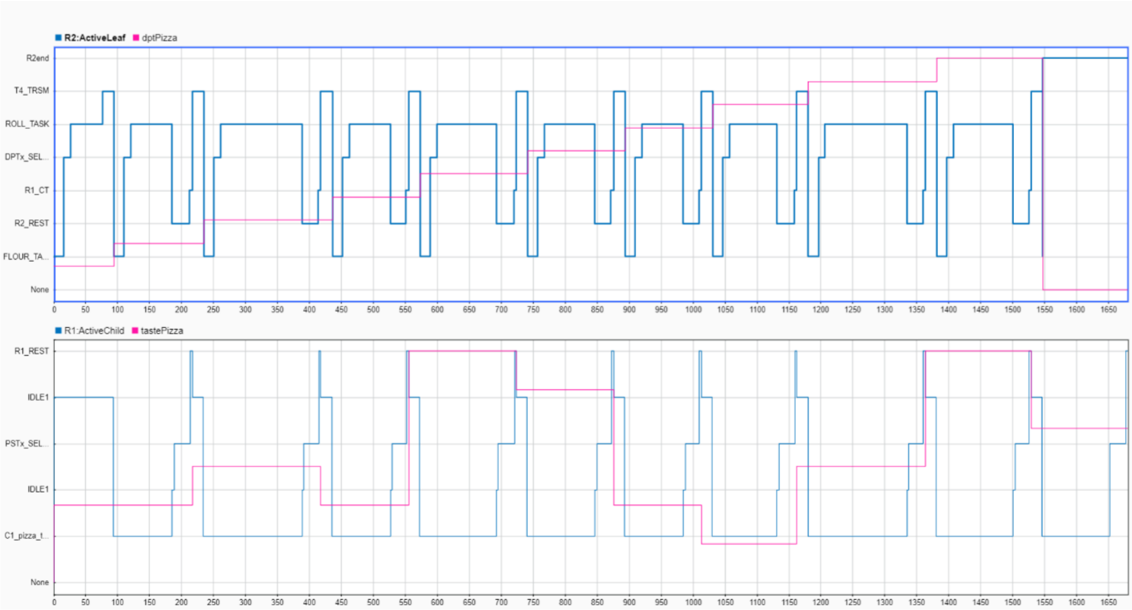


CONFIGURATION NR. 3 - PROSCIUTTO & FUNGHI PIZZA

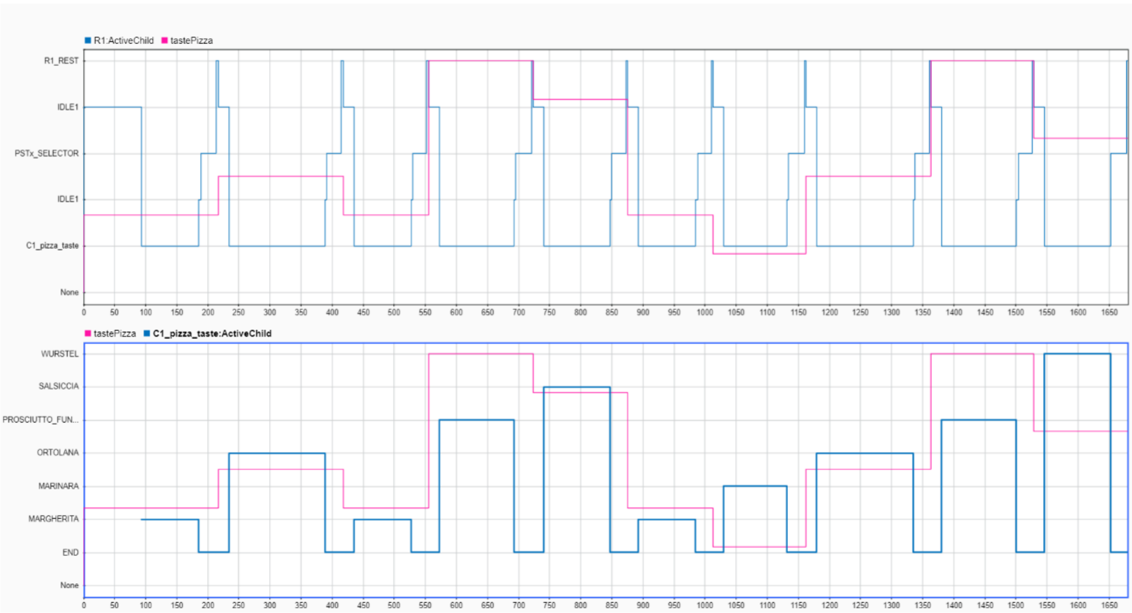


SIMULINK OUTPUTS SCENARIO 2 (MISSION PREPARATION)

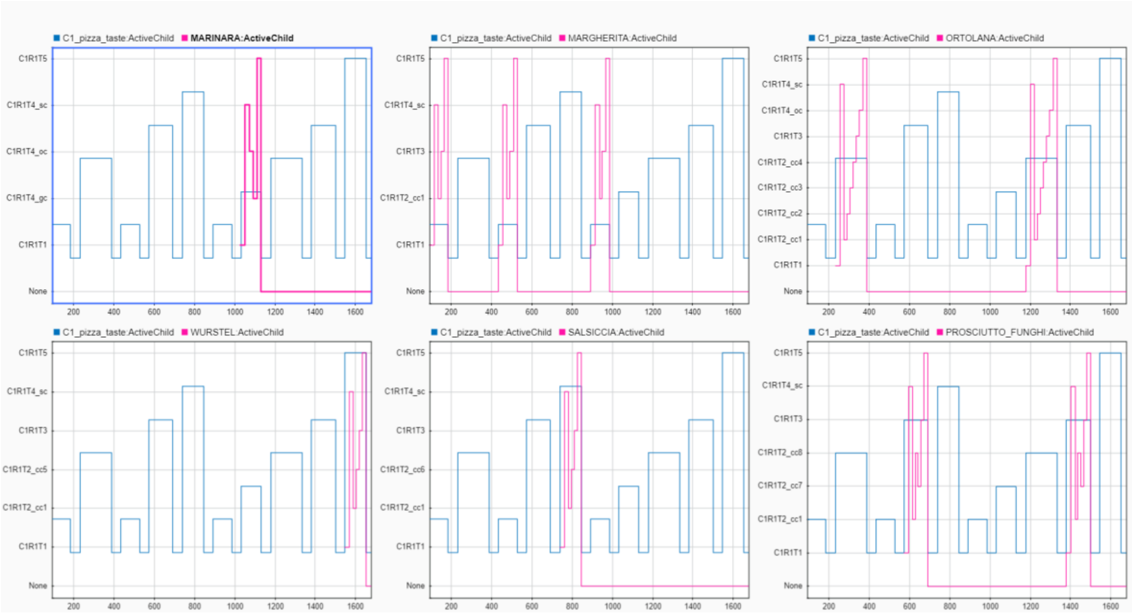
CONFIGURATION NR. 1 – BATCH (or MISSION) PROGRESSION



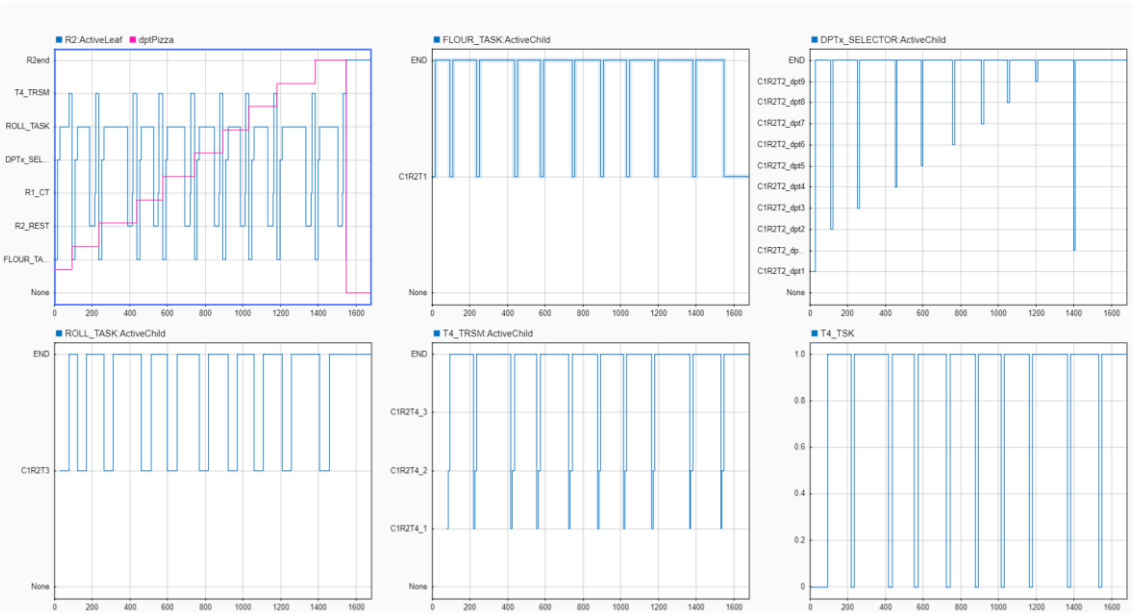
CONFIGURATION NR. 1 – PIZZA TASTE PROGRESSION



CONFIGURATION NR. 1 – TASK DETAILS PER PIZZA TASTE

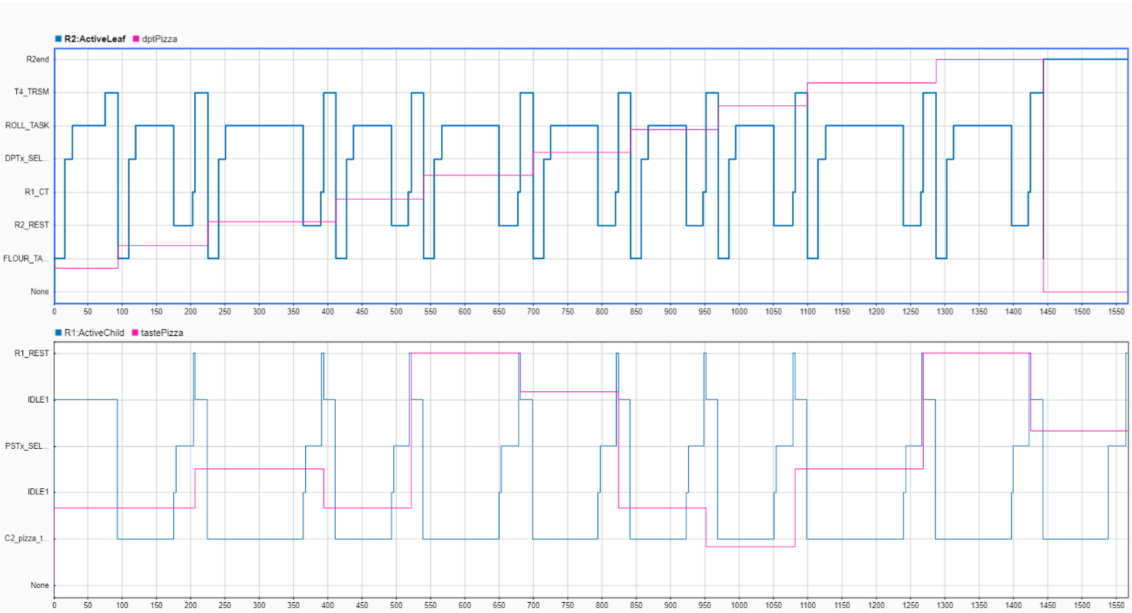


CONFIGURATION NR. 2 – TASKS EXPLOSION

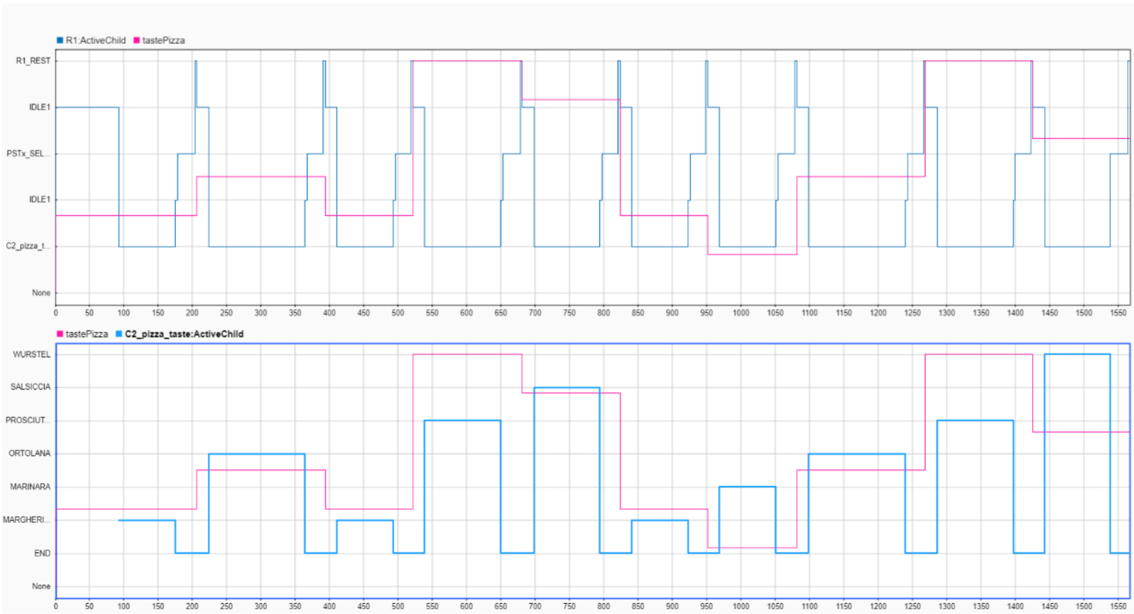


SIMULINK OUTPUTS SCENARIO 2 (MISSION PREPARATION)

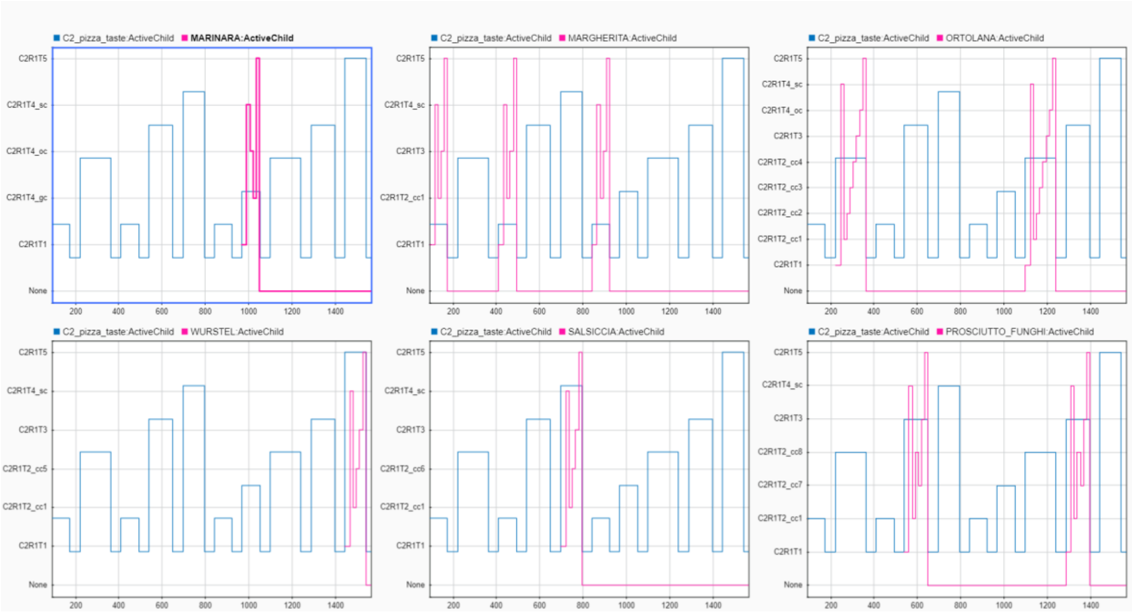
CONFIGURATION NR. 2 – BATCH (or MISSION) PROGRESSION



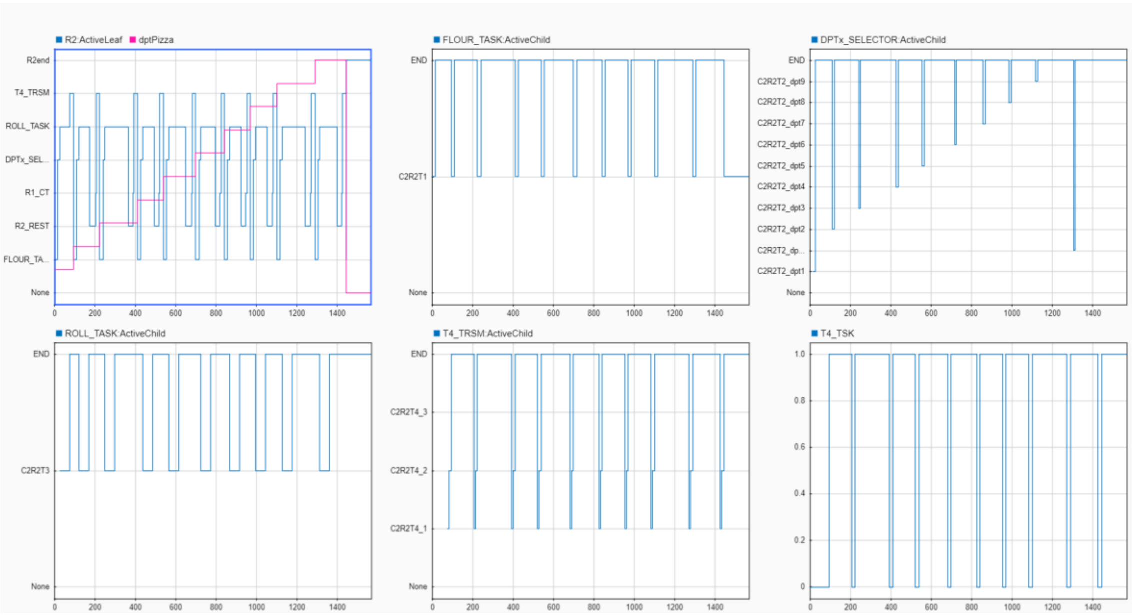
CONFIGURATION NR. 2 – PIZZA TASTE PROGRESSION



CONFIGURATION NR. 2 – TASK DETAILS PER PIZZA TASTE

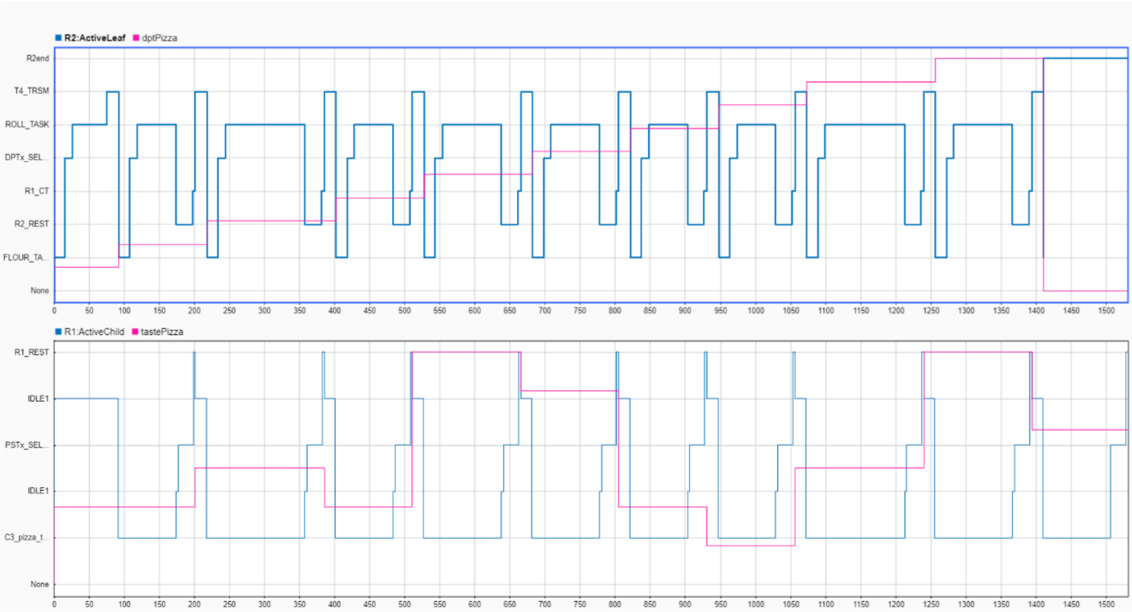


CONFIGURATION NR. 2 – TASKS EXPLOSION

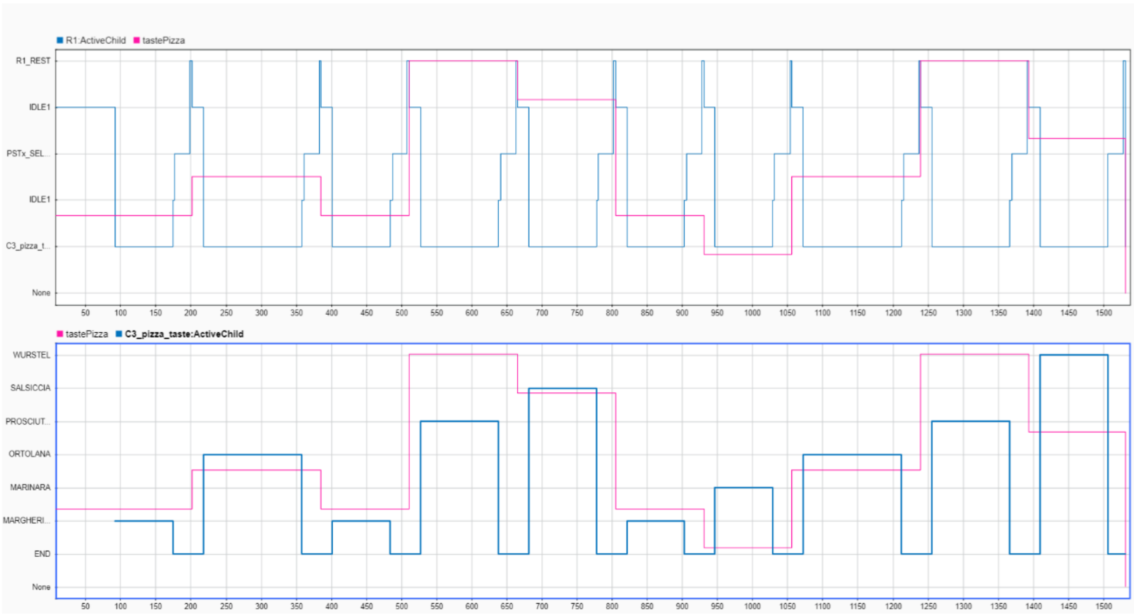


SIMULINK OUTPUTS SCENARIO 2 (MISSION PREPARATION)

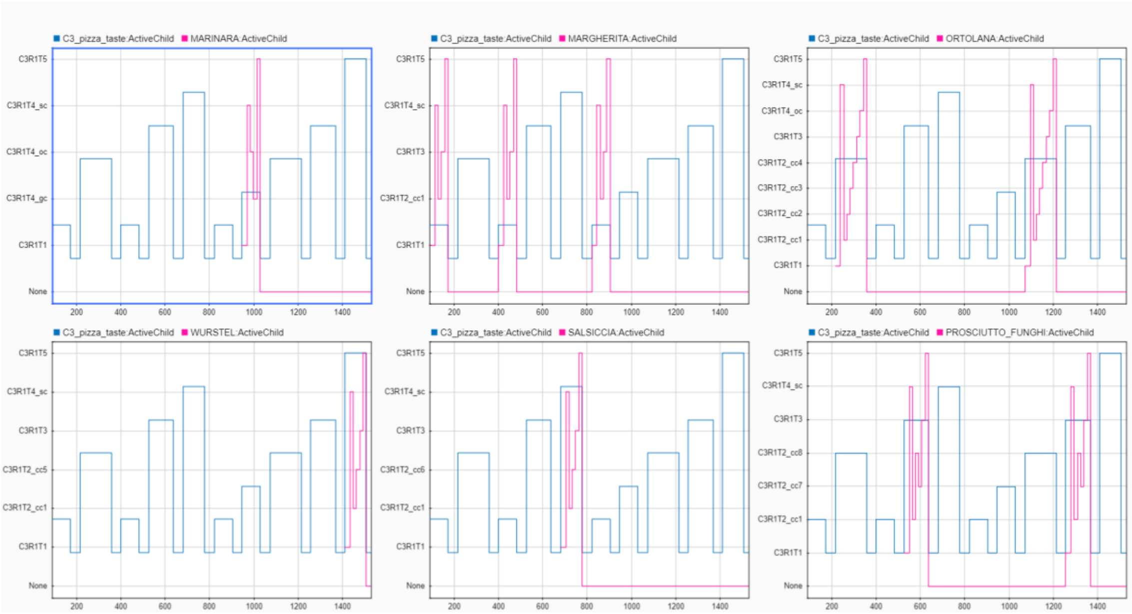
CONFIGURATION NR. 3 – BATCH (or MISSION) PROGRESSION



CONFIGURATION NR. 3 – PIZZA TASTE PROGRESSION



CONFIGURATION NR. 3 – TASK DETAILS PER PIZZA TASTE



CONFIGURATION NR. 3 – TASKS EXPLOSION