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Social Robot as a Support for Sign Language Communication

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Summary

Robots have progressively become more and more pervasive in our everyday lives, for example they help us on some activities like cleaning, working and also entertaining. Furthermore, they can help us to communicate in different languages, by automatic translation, text to speech translation, etc. The focus of this thesis is the study of using a social robot as an interpreter of sign language, specifically the Italian Sign Language (LIS).
The robot considered in this work is Pepper, developed by Aldebaran. Pepper is a social robot, which means that it has sensors that forbid dangerous movements. Also, it is a humanoid robot, so it resembles the human appearance. Pepper is similar to us but has some limitations, for example it cannot control separately its fingers and it has a built-in tablet on the chest that limits the arms movements. Despite these problems, Pepper is ideal for the research since it is a commercial robot and some studies have shown that children love it.
The thesis is divided into 2 main steps: the first step is to implement the signs through the Animation Editor, a tool of the Pepper SDK for Android Studio, fitting the joint values to each movement of each sign; the second step consists in writing a script to automate the creation of the signs. The object is to create a new sign from 3D coordinates without manually changing the joint values. The script is composed of 2 parts: a MATLAB script that computes the joint angles for each movement, from the given coordinates and a Python script that is like a wrapper, it calls the MATLAB script and writes the file containing the details of the sign. The resulting animation file has an XML format that can be opened in the Animation Editor.
The signs to be implemented were chosen by narrowing down the configurations to those physically realizable by the robot. These signs were identified with the help of a human sign interpreter. Some of these signs are linked to the education, the others are verbs and nouns related to different topics.
The total number of implemented signs is up to 52 and, even though this number would surely be higher if a different robot without the limitations mentioned was used, it allowed us to draw some conclusions on the possibility of using such robots to interact with impaired people. A survey, containing a set of signs has been submitted to some deaf people, the results showed that the signs, even if they are not as smooth as human's signs, are understandable and that Pepper can be used to communicate simple concepts in sign language.

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On the other hand, this thesis work is just the end of a long and sometimes difficult study path that got to this point. I have to deeply thank my family, my mother, my father and my sister, for always being by my side, supporting me and for allowing me to take this degree. A special thank to my old friends Yi Ying, Matilde, Serena, Erica and Marco who never lost touch with me despite the different university paths and who always found a way to make life easier. Another big thank to my new friends from Politecnico, in particular Angela, Giulia, Giacomo, Davide, Federico and Aurora, thank you for all the group projects, the crazy moments and the game nights.
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You cannot change what you are,
only what you do
[Philip Pullman, The Golden Compass]

Chapter 1

Introduction

The robotics sector has been growing in the last decades. Robots have been firstly introduced in industries, for example, as robotics arms in the assembly lines or as autonomous vehicles in the warehouses, their job is to help us, making our job less hard. These robots can be considered autonomous or automated machines, they are useful on a practical point of view but they do not interact with us as another being does. The development of artificial intelligence has further increased the focus on robotics, extending their use in the domotic field and the social field. The social sector has become an important field of study: it focuses on the social robots, the robots that interact with us on a social level. Nowadays, it is not unlikely to have a social robot at home or in the workspace. These robots communicate with us talking through speakers or showing images on screens. The spread of social robots and the growing attention on social equality, made us think of inclusion and what we could do to support it.
The research group of Dipartimento di Informatica at University of Turin has been working on natural language, and on social robots such as NAO and Pepper. The idea of implementing sign language on the social robot Pepper came straightforward. Pepper is a social and commercial robot so it can be purchased and used in different contexts, such as welcoming in malls, hospitals, airports or offices. Once implemented sign language on one Pepper, this function can be used on all Peppers making them able to talk in sign language. The deaf community has been left out for a long time and even though nowadays the situation has improved, it is still difficult for them to communicate since very few people know sign language. Having a robot able to interpret for them can make things a lot easier for everyone. Since we are Italian, we decided to work on Italian Sign Language (LIS).

1.1 Thesis work

It is clear that implementing all the existing signs of the Italian Sign Language requires a lot of time and work, for this reason, our goal is to begin implementing a set of signs. Furthermore, the robot Pepper has physical limitations and is not able to perform every sign of the LIS: Pepper is a humanoid robot, has 10 fingers like us but it can only open

and close them all at the same time, while many signs require one or few fingers extended and the other closed.
The first part of the thesis focused on finding a set of signs that could be performed and implementing them on the robot. This work was done along with a human LIS interpreter and a deaf student, they helped with the sign identification and then with the realization. The robot's movements were adapted in real time on the humans' movements. The Animation Editor tool, developed by the robots' creators, was used to implement the signs on the robot. At the end of this phase, Pepper was able to perform a total of 52 signs. The signs are both nouns and verbs and belong to different fields. They are saved as animation files and can be played by the Animation Editor.
The second part of the thesis centered on developing a program to automate the signs creation. The idea underlying the code was to transform 3D space coordinates into joint values. No new signs were implemented, the 52 resulting from the previous phase were recreated, if possible. The program copies the Animation Editor features and was developed to compute the right arm joints, while the left arm mirrors the right one or is left in the standard position. The joint values are computed with the help of a MATLAB numeric solver and are used in a Python script to write the animation file.
The last step dealt with the signs evaluation, by means of a questionnaire containing video of Pepper performing signs. This questionnaire was presented to people who know LIS, most of whom are deaf. They were asked to recognize which sign Pepper was performing and the results were used to support the thesis work.

1.2 Thesis structure

The thesis is developed as follows:

- Chapter 2 : An introduction on sign language is presented, describing the treatment of deaf community in the past till nowadays. Then a description of Italian Sign Language (LIS) is given.
- Chapter 3 : This chapter describes humanoid, social and assistive robots. In the last section, a description of the robot Pepper is depicted.
- Chapter 4 : An analysis of past works related to social robots and sign language is conducted. Then a comparison with the work done in this thesis is made, supporting the implementation choices.
- Chapter 5 : This chapter focuses on the first part of the thesis work: implementing signs on Pepper by hand.
- Chapter 6 : This chapter focuses on the second part of the thesis work: replicating the signs already implemented in an automated way.
- Chapter 7 : In this chapter, the implemented signs are evaluated and discussed. A questionnaire was proposed to LIS-knowing people, mostly deaf people.

- Chapter 8 : Some conclusions on the thesis work are drawn and some future works are suggested.

Chapter 2

Sign Language

All the information related to the sign language are gathered from the lessons by Professor Virginia Volterra [1], [2], suggested by the ENS association [3].

2.1 What is a sign language?

The sign languages are, as said, languages. These languages do not try to mimic the oral languages, to translate the words in movements; they are ruled by grammar conventions as all the other known oral languages, they are all on the same level, the only difference is that they do not make use of the sounds produced by the voice. The sign languages express themselves by means of hands, facial expressions, body movements; the perception sense is the sight, not the hearing. The signs are different from the gestures that some people make when talking, they have a specific meaning and purpose.
These languages continuously evolve, even faster than the oral languages since there is not a relative written language that slows the changing. Furthermore, there is not a geographic correlation, the language is related to the community that uses it and when this community vanishes, the language follows the same path. Since the languages are created independently by each community, the same concept can be expressed with different signs in different languages and the same sign can represent different concepts in different languages. There are in fact some characteristics to look upon:

- **systematicity and iconicity**: studies showed that signs representing a certain concept can be different among sign languages but they all recall a particular of the concept they are expressing. Moreover, there are different hand configurations that slightly differ but are different in what their shape recalls. This recalling can vary from language to language and can happen that a particular shape in one culture recalls negative feelings while in another the same shape is considered with a positive meaning.

- **variability**: the languages evolve with the community and keep on with the time, for example, following the changes in technologies. They are also different between regions and community, even when considering a single language.

2.2 The sign languages in the past

There is no a specific date saying when these languages were born but we have many documents from the past referring to people talking with hands and gestures in different parts of the world. One of the most important evidences is found in *Cratilo* by Platone: he writes about mute people speaking with hands. Platone acknowledges these gestures as a form of communication based on imitation. Another important character of the past is Aristotele, he was the first one to understand that deaf people are also mute because they are not able to listen to the words and so mimic the sounds. In fact, they do not have any issue with their vocal organs and they can produce sounds even if they are not able to put them together into words. Unfortunately, this valuable piece of information is lost through the years and deaf people are ostracized by society and law that does not allow them to testimony or make will. Despite this, we know that deaf people were acknowledged for their excellent visual skills and they were usually introduced to the painting activity; many writings on deaf painters of the past tell us about their skills and also about their form of communication. Leonardo Da Vinci affirmed that *"one can learn a lot from a deaf person"*, history shows that he came in contact with the deaf painter Cristoforo De Predis when he was guest of the De Predis family. From his testimony we know that deaf people were still cut out of the legal actions and also that Cristoforo could talk to his family making use of gestures.

2.3 Teaching to deaf people

Deaf people were considered not able to understand and they were not given any kind of education. Nevertheless there were some people that stood up against this idea. A first important figure was Agricola, a doctor who showed that deaf people do not have any problems in understanding matters even if they cannot talk. He showed that a deaf person can express himself through the writing process as a hearing person can, they are able to understand a text and to write like any other person. From this moment on, teaching deaf people how to understand written sentences and how to write them becomes more popular.

A part from writing and reading, in the XVI century, the monk Ponce De Leon started teaching deaf people through the dactylology, or fingerspelling, he used different configurations of the hands to represent the alphabet letters. Then in the XVII century, Johann Conrad Amman tried to make use of the hearing residual in deaf people and taught them how to pronounce phonemes and put them together to articulate words. This oral pattern was followed by Jacob Rodrigue Pereire who became very famous across Europe, he taught deaf people to read aloud and write; these skills were mandatory for deaf people belonging to the important families, they had to know how to read and write in order to take part to public functions. In Germany, Heinicke was a follower of Amman's method, he is considered the father of the pure oralism (deaf people have to talk and cannot use the sign language).

In the meantime, a different approach was developed in Great Britain where a school was founded that used a mixed method considering both voice and signs. Another important

character that followed this mixed approach was the abbot de l'Épée, he opened an institute for deaf people belonging to any social class, he taught how to read and write but used also the signs, both learned from his students and created by scratch. He developed his own particular method called the "Methodical Signs": he invented signs to explain the french grammar. Since his school was opened to everyone, many educators from all around the world went there to learn how to teach to deaf people. Among these educators we find Tommaso Silvestri, the first italian to learn the method and found a school in Rome, Ottavio Assarotti who does the same thing in Genoa, and Thomas Gallaudet from America, he founds a school there and follows the methodical signs' method.
During the XIX century, many institutes are found in each country, in Italy there were around 50 schools organized similar to colleges: the children started when they were 6 years old and ended at 16 years old, they slept there together and learned to write, read and also to do a practical job. In these colleges the mixed method of methodical signs together with dactylology were used. In the meantime, an opposite movement, that criticized the use of the signs, arose and at the end of the century, in 1880, lead to the Milan Congress which declared the oralism superior to the sign language and put an end to the mixed teaching. From this moment on the sign languages are no more used in public context, deaf people talk in sign language only in private occasions and among other deaf people. There were many reasons behind this decision: firstly politics, Italy needed a unified language following the unification of the country; secondly the italian pedagogy was strictly related to the german one that supported the oralism and thirdly a religious cause which believed that deaf people would sin again if they confessed using the sign language. History showed that this congress was composed mostly by oralism supporters and that deaf people were not considered in taking this decision. The congress lead to a significant break between deaf and hearing people and lead to the birth of deaf associations, unified in 1932 in Italy under the name of ENS.
In 1923, a new law established the foundation of public schools for deaf people and the compulsory schooling till 14 years old. When finishing school they had the elementary degree, in 1962 the compulsory schooling was extended till middle school. It was not until 1977 that deaf people were finally admitted into public schools with hearing children.
In 2006 the UN organization wrote the Convention on the Rights of Persons with Disabilities in which the legal recognition of sign languages was promoted, this was the first legal action supporting these languages. Finally in 2021 a new law was declared in Italy which stated that the country legally acknowledges, promotes and protects the LIS (Italian Sign Language). Nowadays, deaf children go to public school with hearing children and they are assigned a LIS educator or a communication assistant together with a special needs teacher.

2.4 LIS (Italian Sign Language)

During the XX century, researches and studies on the sign languages began. Many of these studies where conducted in the United States, then researches from Italy who had taken part of these analysis started to do the same studies here in Italy. In 1981 a first book was published, as a result of the studies of three different groups, and it talked about the sign

language used in Italy but not yet about the italian sign language. In 1983 took place the third Simposio on the research on sign languages and on this occasion a first description of the italian sign language was developed; it was then made official in 1987 under the name of "Lingua Italiana dei Segni" then changed in "Lingua dei Segni Italiana" in order to highlight that this was a specific language, used in Italy, but not strictly related to the italian oral language.
The LIS is a proper language and so it has rules. Firstly there are conventions regarding the signs themselves, there are different *cheremes* (parallel of phonemes):

- **location**: in the space in front of the speaker or on specific parts of the speaker's body.
- **handshape**: the hand configuration differ in number of fingers used and position of fingers.
- **movement**: the direction, velocity and contact of the hands.
- **orientation**: the orientation assumed by the hand throughout the movement.

These *cheremes* are considered simultaneously and they define the sign. There are also rules on names and verbs. The names are divided in two classes

- **1° class**: they are executed on the body and the plural is made adding "many".
- **2° class**: they are executed in the neutral space (space in front of the speaker) and the plural is made by repeating the sign in different positions in the space.

The verbs are divided in three classes

- **1° class**: verbs performed on the body, the subject doing the action is added as a pronoun.
- **2° class**: these verbs can change direction accordingly to the subject.
- **3° class**: they are executed in the neutral space and they are linked to the subject or the object, they are performed in the same place in the space where the subject/object is placed.

Other important characteristics of the language do not involve the hands, they are called the non-manual components and are:

- **facial expression**: it changes accordingly to the tone of the phrase.
- **gaze point**: pointing towards the interlocutor or a subject/object in the space.
- **mouth movements**: either making part of the worlds in the oral language, or making peculiar gestures that change the sign's meaning.
- **body posture**: orientation left-right or up-down.

Chapter 3

Social Robot

3.1 What is a humanoid robot?

Humanoids are robots built to resemble the human body: they have head, arms, hands, torso, legs or wheeled base that recall our legs closely [4], [5]. They have microphones and cameras to mimic our perception system. Researchers have been trying to make them intelligent so that they can learn and act like a human being would do. Thanks to these characteristics they are usually employed for social or assistive robots.

3.2 What is a social robot?

A social robot is an autonomous robot designed to interact and communicate with humans or other robots, on a social and emotional level, behaving according to the social rules attached to its role [6], [7], [8], [9]. It is equipped with sensors, cameras and microphones and is supported by a local (sometimes) artificial intelligence that allows the machine to be "social". These robots are usually trained to recognize emotions and faces so that they can engage conversations with people and are equipped with sensors that block their movements if they could be dangerous for the surrounding people. They are able to communicate in verbal or non-verbal modes and maintain social relationships.
By this term we identify specific types of robots, not every robot able to work around people is a social robot: for example, the vacuum robot is not a social robot since it cannot entertain people (it does not talk nor dance or cuddle, it just does a specific task), on the other hand nor Alexa or Google or Siri are social robots, they are considered chatbots, they can talk with us and help us with the grocery list but they do not have a physical body that is a crucial characteristic for social robots. The social robots are those robots built and programmed to stay in a community and help it, whether by engaging conversations to entertain or by giving information. Their goal is to help us on a social level, not on a practical level making our job easier.

3.3 What is an assistive robot?

An assistive robot is a robot whose role is to assist, help people physically or psychologically [10]. Assistive robots can be non-social robots like the ones used to physically help people, such as the exoskeletons. But they can also be social robots that help with basic living actions or that act as companions. The latter one is primarily developed to help on a psychological level.

3.4 Pepper the robot

Pepper (Fig. 3.1) is a nice humanoid social robot, its height is 1.20 meters and weights 28 kilos [12], [11], [13], [14]. It was developed in 2014 by Aldebaran (which became SoftBank Robotics in 2015 and reverted back to Aldebaran in 2022) and it was the first robot able to recognize faces and human emotions and the first full-scale humanoid to be offered to consumers. Pepper was firstly designed as a house companion so we can say that is also an assistive robot.

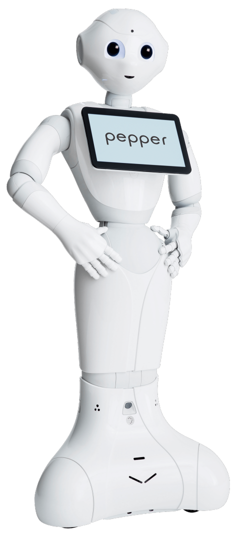


Figure 3.1: The robot Pepper [11]

Unfortunately, probably due to early timing, Pepper did not gain a lot of success and was not adopted in many families. Over the years, it was mostly used as a research tool in robotics labs and as a greeter in shopping malls and airports. It has also been used in some projects researching the possibility to use a social-assistive robot in health clinics, rest homes and as a help for autistic children.

As stated in the previous sections of this chapter, a humanoid social and assistive robot is equipped with sensors used to prevent dangerous movements, to collect data from the surroundings and to perceive physical interactions. The sensors are different based on their scope, it is the overall set that makes Pepper able to interact. In Figure 3.2, a specification of the sensors and their position is reported. It is also equipped with a tablet that is an important tool for interaction.

A humanoid robot requires a certain number of degree of freedom that allow it to move like a human. Pepper is composed by 17 joints (Fig. 3.3): 2 joints connect the upper body to the head, 3 joints are placed in the lower body and 12 joints compose the arms (6 joints for each arm). The thesis focused mainly on the arms so they are described afterwards in details: the two arms are equal but opposite and they are composed by 2 joints for the Shoulder, 2 joints for the Elbow, 1 joint for the Wrist and 1 joint for the Hand. Tab. 3.1

reports the limits of each arm joint.
Details regarding all the joints and other technical information can be found at the following page [15].

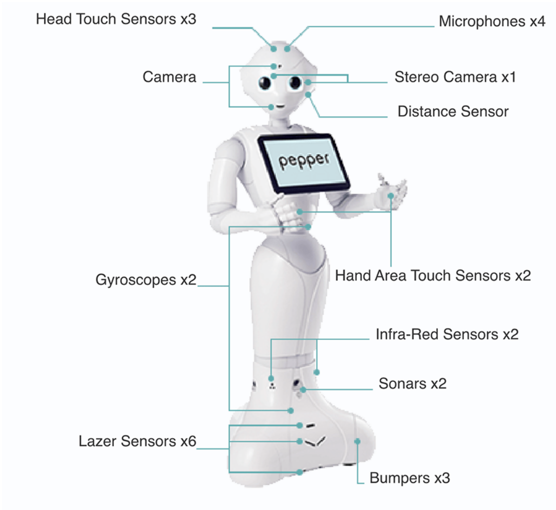


Figure 3.2: Sensors installed on Pepper [14]

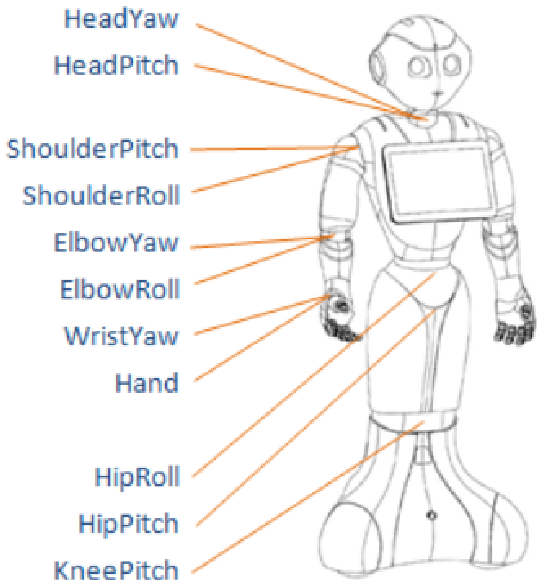


Figure 3.3: Joint names of Pepper [15]

Due to mechanical limitations, the ElbowRoll joints are limited as reported in Tab. 3.2 and Tab. 3.3.

Joint name	Motion (rotation axis)	Range (degrees)	Range (radians)
LShoulderPitch	Left shoulder joint front and back (Y)	-119.5 to 119.5	-2.0857 to 2.0857
RShoulderPitch	Right shoulder joint front and back (Y)	-119.5 to 119.5	-2.0857 to 2.0857
LShoulderRoll	Left shoulder joint right and left (Z)	0.5 to 89.5	0.0087 to 1.5620
RShoulderRoll	Right shoulder joint right and left (Z)	-89.5 to -0.5	-1.5620 to -0.0087
LElbowYaw	Left shoulder joint twist (X')	-119.5 to 119.5	-2.0857 to 2.0857
RElbowYaw	Right shoulder joint twist (X')	-119.5 to 119.5	-2.0857 to 2.0857
LElbowRoll	Left elbow joint (Z')	-89.5 to -0.5	-1.5620 to -0.0087
RElbowRoll	Right elbow joint (Z')	0.5 to 89.5	0.0087 to 1.5620
LWristYaw	Left wrist joint (X')	-104.5 to 104.5	-1.8239 to 1.8239
RWristYaw	Right wrist joint (X')	-104.5 to 104.5	-1.8239 to 1.8239
LHand	Left hand	Open and Close	Open and Close
RHand	Right hand	Open and Close	Open and Close

Table 3.1: Left and Right Arms Joint Limits

LElbowYaw (°)	LElbowRoll Min (°)	LElbowRoll Max (°)
-119.5	-78.0	-0.5
-60.0	-78.0	-0.5
0.0	-89.5	-0.5
99.5	-89.5	-0.5
119.5	-83.0	-0.5

Table 3.2: LElbowRoll limitations

RElbowYaw (°)	RElbowRoll Min (°)	RElbowRoll Max (°)
-119.5	0.5	83.0
-99.5	0.5	89.5
0.0	0.5	89.5
60.0	0.5	78.0
119.5	0.5	78.0

Table 3.3: RElbowRoll limitations

Chapter 4

Related works

In this chapter, a brief overview of previous works is presented, works specifically related to the use of social robots for sign language. First of all, there are not many studies that use the robot to perform signs, as they are mainly used to interpret the signs. Secondly, there are very few studies on the Italian Sign Language.

4.1 What has been done

In 2012, a research group made the first step towards using humanoid robots to help in teaching sign language to deaf children: NAO H25 was filmed while performing a set of chosen signs of the Turkish Sign Language (TSL) and compared to the teacher [16]. NAO was used both physically and virtually through a simulator. This first experiment focused on 5 words and aimed at testing the intelligibility of NAO's movements. Different groups of people evaluated NAO's performance and as a result, they understood that some words were difficult to understand because of NAO's structure: it has only three fingers. Another problem in this research was the robot mobility, it cannot reach certain positions or orientations.
This research group together with other researches continued this work and made different experiments through the years: in 2015, NAO H25 and a modified version of Robovie R3, able to move each finger independently, were used in some games to test the recognition of the signs performed by the robots [17]. The signs were chosen among the most frequently daily used ones, accordingly to the limitations of the robots. The study was conducted again on the Turkish Sign Language. The games with the physical robots involved the use of some cards representing the signs, the robots either reacted to the cards or were evaluated with them. The results showed that R3 obtained higher rates of successful recognition than NAO in most cases, since it can move more similarly to a human thanks to its five independent fingers. Their work went on analyzing the possibility and the benefits of using physically present humanoids to teach sign language rather than videos or avatars.
In 2019, a custom robot called RASA (Robot Assistant for Social Aims) was developed, it was meant to help in teaching Persian Sign Language (PSL) to children [18]. They

analyzed the studies conducted on TSL and understood that a key for success would be a robot constructed specifically for this task. This robot was developed with a social face and two hands that could control independently each finger. Such characteristics eliminated the constraints on the signs due to robot's limitations. They worked on 70 signs, chosen to summarize all the possible configurations in PSL. The custom robot achieved high recognition performances but the testers pointed out that the facial expression, together with the lips movements, are essential parts of sign language and some signs were not recognizable due to this lack.
In the same year, a study focusing on autistic children was conducted. The team wanted to design a suitable robot for teaching sign language [19]. They found a good starting point in the InMoov robot and modified it in order to obtain a more suitable signer robot. They worked on nine words and considered the experiment successful if the children copied the robot's movements. This study showed that autistic children are interested in the robots and are likely to imitate them and learn sign language.
In 2019, another research group worked on a project aiming to convert natural language into Spanish Sign Language (LSE), performed by the robot TEO [20]. TEO is an assistive robot, it is able to do many tasks around the house and can also sign LSE. In order to talk in sign language, the joint values for each sign were detected by means of skeleton analysis of a human signer and then saved into a table. The system transforms the natural language input into LSE and tells the robot which sign to perform, picking the joint values from the saved ones.
In 2021, a work similar to the RASA project developed a low-cost robot to be used as aid for hearing and speaking impaired people in medical situations [21]. It was the first work on Bangla Sign Language (BdSL). The robot is able to recognize some medical signs and alphabets and can sign a set of alphabets. They used neural networks to recognize the signs, the signs performed are stored in memory as joint values manually programmed.
In 2022, a study supported the importance of cooperating with deaf people when designing a robot for sign language communication [22]. The robot used for the experiment was Tiago, a humanoid robot with one arm that has limited fingers motion. The experiment was conducted on LIS and the proposed challenge wanted the robot to understand a signer person and answer her in the same language. The signs generation was done by extracting key points from videos of human signers and interpolating them in order to compute the trajectory to follow for executing the sign. The sign recognition worked on the same key points extraction and used also a neural network. Some experts evaluated the performance of sign execution and the results showed that inserting a social robot as interpreter is a welcomed possibility. The deaf people taking part in the analysis had never seen a signer robot and were happy to see it, they thought that such a development would have been possible only in the future. Nevertheless they highlighted the robot's movement limitation and the lack of expression as a problem. In conclusion, this research showed that using a social robot for sign language communication is a real possibility but it is important to use a robot with certain characteristics and it should be designed accordingly to the deaf community needs.

4.2 Thesis contribution

The past works can be divided into 2 categories: the studies using already existing robots and the ones building a specific robot. There are advantages and disadvantages for both groups: up to this moment, a humanoid robot that meets all the requirements for sign language interpretation (two arms, five independent moving fingers for each arm, a human face able to express emotions and move lips) is not available on the market. For this reason building a specific robot that meets all or most of the requirements is, without a doubt, a good move. RASA, the robot built for BdSL and the modified version of InMoov are all able to move independently their fingers, and so have less limitations with respect to NAO for example, but they are not commercial robots that can be bought on large scale and so cannot be used freely by the public.
On the other hand, NAO, Teo and Tiago are commercial robots so they can be independently bought but they have physical limitations: NAO has only three non-independent fingers, Teo does not have the structure of a common social or assistive robot at all and Tiago has only one hand and is not very human-like.
I think that using a social or assistive robot is a key point in this work. Allowing people to buy a robot that is able to communicate in sign language is far more useful than just testing a custom robot in lab. Being an assistive robot and a commercial robot, Pepper is ideal for the research under this point of view. It has a human-like design and has been shown to be welcomed by people, it has two arms with five fingers each, even if they are not independent. Pepper has some drawbacks and does not meet all the requirements for being a perfect interpreter, but I still think that it was the best available option to work with.
This thesis work focuses on sign generation rather than recognition or natural language translation. It is more similar to the work done in NAO, RASA, InMoove and Tiago researches rather than Teo and the robot developed for BdSL. In fact, some signs have been implemented on Pepper and then tested by deaf people to evaluate their intelligibility. The purpose of this research is to develop a type of communication that can assist people on a daily basis, we would like to actually do something beside only understanding.

Chapter 5

Implementing LIS on Pepper

5.1 Pepper limitations

Pepper can let out its voice through some speakers, in practice Pepper can speak. But, as stated before, the voice is not the only possible means of communication: the sign languages make use of the arms, the hands and the (upper) body. Pepper has arms and hands as well as speakers and so can talk to other people in sign language.
Unfortunately things are not as smooth as they seem to be: Pepper has 5 fingers as a standard human being but it cannot control separately each of them. There is only one joint that controls the fingers and it moves them together; this means that Pepper can open and close its hands but cannot point or make particular configurations with its fingers. This was the first big limitation to deal with, the natural solution was to implement only those signs that used a configuration of the hand as "opened" or "closed" or a combination of them but not other configurations involving only a few fingers.
The second problem that showed up while studying LIS structure was about the head, it is similar to the human one but there is no proper mouth and so Pepper is not able to move the lips when performing signs or to change expression like a human being can do. This actions are very important in sign language and are the key to distinguish some signs. Talking to the human LIS interpreter and the deaf student, we agreed that there was no easy solution apart from picking a robot with a human face. So we decided to *allow Pepper to be a robot*, in other words, the robot is humanoid not human and so can imitate the human behaviour but not behave exactly like one.
The last problem that came up regarded the tablet: the screen is big and limits the arms' movements. The answer to this issue was a mix of the two previous solutions: do not implement signs whose movements are changed by the tablet presence and let the robot be a robot, which means to allow Pepper to make some movements less smoother than a human could do.

5.2 Animation editor

Pepper movements can be defined using the Animation Editor offered by the Android Studio plug-in *Pepper SDK* [23]. The Animation Editor allows the creation of an Animation Timeline in which robot's joint values can be assigned along a timeline. This is the tool used to implement the signs, Fig. 5.1 shows the timeline of the sign "Abbassare" (To lower). The left panels show the timeline, that is editable, while the right panel shows the robot, that can be animated. When clicking on the joints a menu appears in which it is possible to change the joint values respecting the limits. The joints are divided into 3 groups: the head group containing the 2 head joints, the arms group containing the 12 arms joints and the legs group containing the last 3 joints of the lower body. The timeline window is split into 2 windows, the upper one showing the keys of the groups used and the lower one showing the bezier curves of each joint. It is also possible to show more windows with different features. The animation timeline is saved as a file *.qianim* that is an xml file containing the joint values at each timestep and the related tangents of the bezier curves, only the joints belonging to the group/s used are reported.
It is possible to work in simulation watching the image of the robot on the right moving or it is possible to connect the robot and watch it move (the model on the right is still present but in this case it is a copy of the real robot and moves accordingly to it). The big difference between these options is that the simulation robot does not have any limitations on the movements, for example, it is possible to turn the arm and make it go through the robot's body. Working on the real robot the movements are limited so every key in the animation timeline developed in this way is physically valid. It happened to me sometimes that a joint configuration developed in simulation was not physically feasible when tried on the robot: it tried to reach the configuration but stopped in another position or made a strange movement due for example to the tablet.

5.3 Choosing signs

5.3.1 First approach

The research activities on the implementable signs started on the Radutzky dictionary "Dizionario bilingue elementare della lingua dei segni italiana". This dictionary is perfect for research purposes since it is organized in configurations, it does not follow the alphabetical order but divides the signs based on their configuration. Knowing that Pepper can only open and close all its fingers together, the research focused on the configurations based on these characteristics, for example the configurations 5, $\check{5}$, $\overset{>}{\mathrm{A}}$s (Fig. 5.2). The movements are shown on a drawing of the first position and are explained with arrows to show the direction of movement and sometimes also the last position is drawn.
A total of 65 signs was realized, firstly on the animation editor only and then fitting them on the robot. In order to evaluate the signs, they were shown to a LIS interpreter working at the University and to one of the deaf students she is supporting; unfortunately the evaluation had a negative result: they said that many signs were an old version of the signs used nowadays and some were completely wrong and incomprehensible. Only

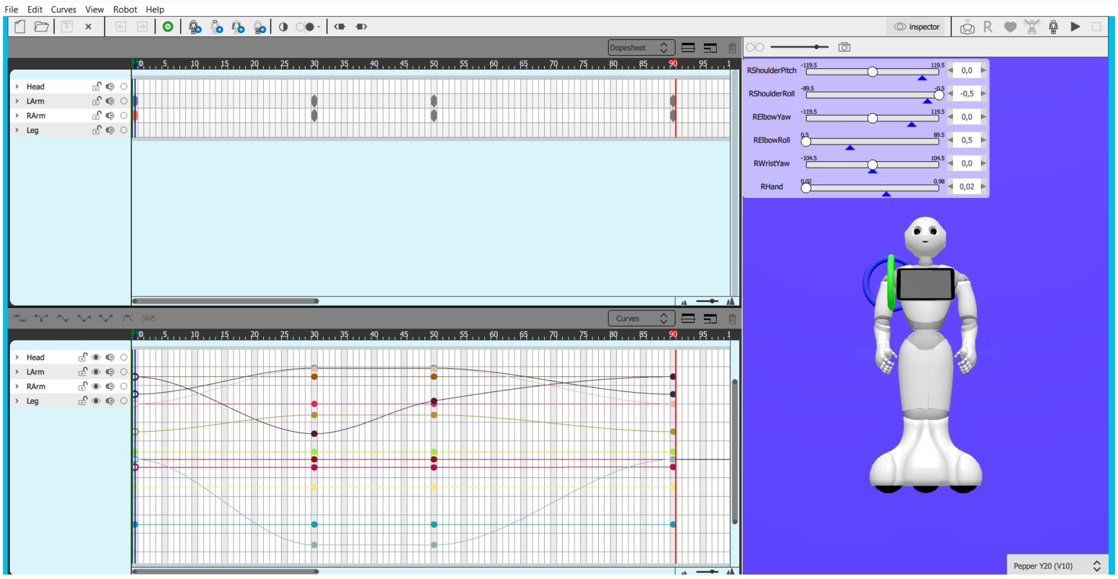
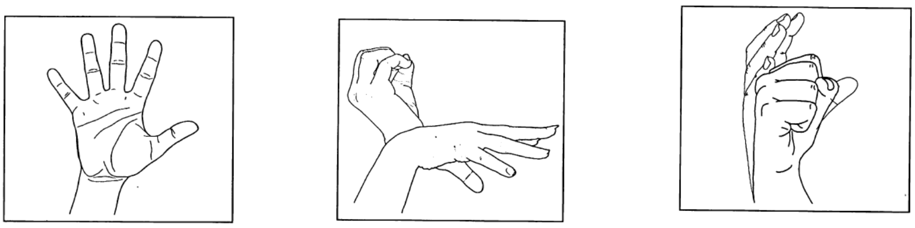


Figure 5.1: Animation editor example



(a) 5 (b) $\check{5}$ (c) $\overset{>}{A}$s

Figure 5.2: Configurations

a little part was considered good and was approved without any changes, some others were modified a little in the movements or the positions (meaning that the sign was not outdated but was not performed correctly), the remainder was discarded.

5.3.2 Second set

After processing the feedback from LIS-knowing people, the second sign set was chosen by the interpreter and was then realized directly on the robot, after watching each sign performed in person. These signs and the ones approved from the first set are the LIS signs that Pepper knows. The signs are the following 52: *abbassare, acqua, alzare, amare, andare, aria, avere, bambino, bilancia, buongiorno, calmo, casa, che/come, chiaro/capito, chiedere, chiudere, chiudere serranda, ciao, cinema, cominciare, comunicare, corpo, dimenticare, dimettere, diminuire, dirigente, diventare, doccia, dormire, dubitare, finire/fatto, grazie, insegnare, libro, mangiare, mela, Monaco, montagna, non*

piacere, pazzo, piacere, picchiare, raccontare, respirare, rimanere, sbagliare, shampoo, studiare, terremoto, tremare, università, variabile.
Some signs are slightly different from the same signs performed by a human, they are adapted to the robot: for example acqua, casa, corpo, libro and others. In this cases the movements recall the human's movements but are more "geometrical" or the hands' positions are approximated, not as close to the body or to each other as they should be.
Each sign was developed starting from the standing position (robot in upright position with the arms at its sides) and ending in the same position, the sign is performed in between.

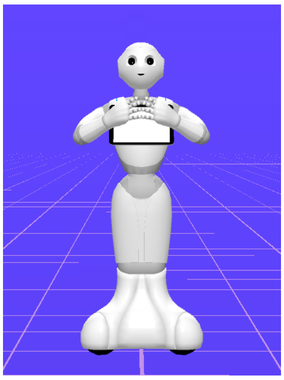
5.3.3 Further step

With the help of this interpreter, some simple sentences have been developed: *ho mangiato una mela, ho studiato, sono andato a Monaco, vado a casa a studiare.* The sentences start from the standing position and end into the same position, the signs are performed in sequence in the middle without coming back to the standing position after each sign. The LIS grammar is different from the Italian grammar so the words are put in a different order and the verbs tenses are formed differently. Let's analyze a sentence in detail for example the first one, *ho mangiato una mela* that is I ate an apple: the related LIS sentence is *mela - mangiare - fatto* (apple - to eat - done). The other sentences are constructed in the same way: *studiare - fatto, Monaco - fatto, casa - studiare - andare.*

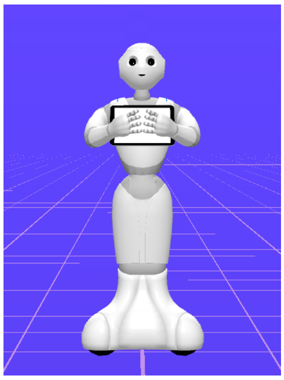
5.4 Signs overview

In this section, some signs will be described in detail, video and animation files of all the realized signs can be found at the following link [24].
The displayed 5 signs were accurately chosen: they belong to different groups, all different for a certain characteristic.

- "Amare" (To Love), this sign is performed with two arms, they both do the same movements and the sign is executed as a repetition of a single movement twice. The movement starts as shown in Fig. 5.3a and ends as shown in Fig. 5.3b, it is repeated twice. In Tab. 5.1 the joint values for each position are reported.



(a) Starting position



(b) Ending position

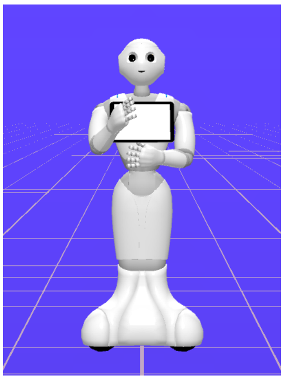
Figure 5.3: Amare starting and ending position

	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	25.6°	-21.5°	36.0°	89.5°	58.9°	0.98*
Left	25.6°	21.5°	-36.0°	-89.5°	-58.9°	0.98*
Ending position						
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	25.6°	-7.5°	36.0°	56.1°	58.9°	0.98*
Left	25.6°	7.5°	-36.0°	-56.1°	-58.9°	0.98*

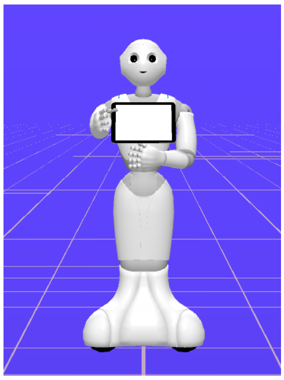
*0.98 = opened, 0.59 = normal, 0.02 = closed

Table 5.1: Amare starting and ending position joints

- "Andare" (To Go), this sign is performed with two arms, they do different movements, the left one stays in a fixed position and the right one executes a movement, there are no repetitions. The movement starts as shown in Fig. 5.4a and ends as shown in Fig. 5.4b. In Tab. 5.2 the joint values for each position are reported.



(a) Starting position



(b) Ending position

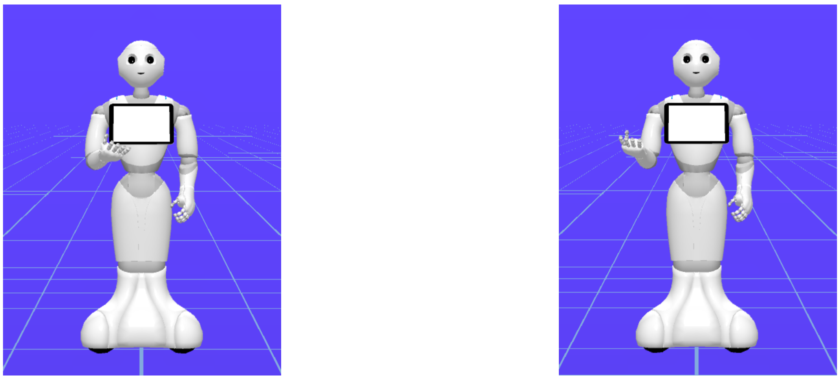
Figure 5.4: Andare starting and ending position

Starting position						
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	41.2°	-0.5°	62.1°	75.5°	20.5°	0.98*
Left	72.5°	0.5°	-39.1°	-77.8°	-31.5°	0.98*
Ending position						
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	16.2°	-0.5°	72.5°	18.8°	20.5°	0.98*
Left	72.5°	0.5°	-39.1°	-77.8°	-31.5°	0.98*

*0.98 = opened, 0.59 = normal, 0.02 = closed

Table 5.2: Andare starting and ending position joints

- "Che/Come?" (What/How?), this sign is performed with one arm, the left arm is left in the standing position, the movement is repeated twice. The movement starts as shown in Fig. 5.5a and ends as shown in Fig. 5.5b. In Tab. 5.3 the joint values for each position are reported.



(a) Starting position (b) Ending position

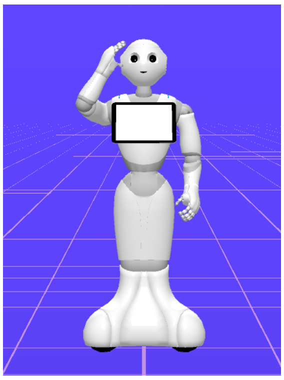
Figure 5.5: Che/Come? starting and ending position

Starting position						
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	78.8°	-6.6°	68.4°	87.6°	81.7°	0.98*
Left	90.5°	6.7°	-69.8°	-29.7°	-1.8°	0.59*
Ending position						
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	78.8°	-6.9°	104.9°	87.6°	81.7°	0.98*
Left	90.5°	6.7°	-69.8°	-29.7°	-1.8°	0.59*

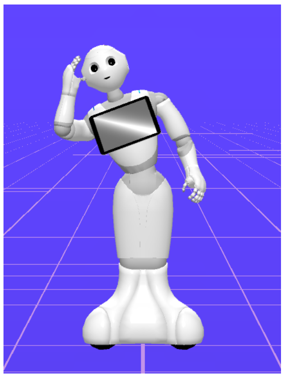
*0.98 = opened, 0.59 = normal, 0.02 = closed

Table 5.3: Che/Come? starting and ending position joints

- "Dormire" (To Sleep), this sign is performed with one arm, the left arm is left in the standing position, and this sign is the only one among the implemented signs that required also a body movement. The movement starts as shown in Fig. 5.6a and ends as shown in Fig. 5.6b. In Tab. 5.4 the joint values for each position are reported.



(a) Starting position



(b) Ending position

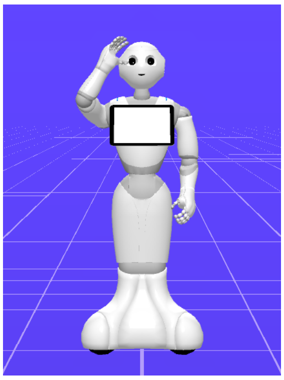
Figure 5.6: Dormire starting and ending position

Starting position									
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand	HRoll	HPitch	KPitch
Right	-16.4°	-20.3°	59.5°	87.2°	36.0°	0.98*			
Left	90.5°	6.7°	-69.8°	-29.7°	-1.8°	0.59*			
							-20.5°	-2.3°	-0.6°
Ending position									
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand	HRoll	HPitch	KPitch
Right	-16.4°	-20.3°	59.5°	87.2°	36.0°	0.98*			
Left	90.5°	6.7°	-69.8°	-29.7°	-1.8°	0.59*			
							0.0°	-2.3°	-0.6°

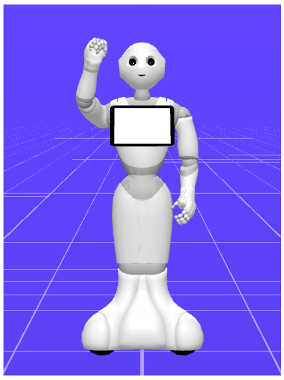
*0.98 = opened, 0.59 = normal, 0.02 = closed

Table 5.4: Dormire starting and ending position joints

- "Università" (University), this sign is performed with one arm, the left arm is left in the standing position, the movement is not repeated. The movement starts as shown in Fig. 5.7a and ends as shown in Fig. 5.7b. In Tab. 5.5 the joint values for each position are reported.



(a) Starting position



(b) Ending position

Figure 5.7: Università starting and ending position

Starting position						
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	-25.3°	-17.9°	54.6°	78.7°	2.5°	0.98*
Left	90.5°	6.7°	-69.8°	-29.7°	-1.8°	0.59*

Ending position						
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	-25.3°	-17.9°	54.6°	46.0°	2.5°	0.02*
Left	90.5°	6.7°	-69.8°	-29.7°	-1.8°	0.59*

*0.98 = opened, 0.59 = normal, 0.02 = closed

Table 5.5: Università starting and ending position joints

Chapter 6

Automating sign creation

6.1 Characteristics

The main idea on which this code is based is finding a way to automate the creation of the signs without having to manually adjust the joint values at each timestep. The code was realized to mimic the Animation Editor options: it is possible to set the time interval between consecutive movements and it is possible to use the mirror option. While developing the signs, they were built almost always only on the right arm, and used many times the option mirror that mirrors the joint configuration on the other arm, the code was developed so that it focuses on the computation of the right arm joints and mirrors the configuration on the left arm if needed. For this developing choice, 10 signs that required different movements for left and right arms or body movements could not be automated. The code is written in Python [25] language and makes use of the MATLAB engine API for Python [26] to call a MATLAB [27] function that uses a numeric solver for finding the joint values.

6.2 MATLAB function

This function is written in MATLAB language and admits 5 parameters: an array containing the 3D coordinates of the points to reach (3 values for each point, x,y,z coordinates), an array with the hand orientations (3 values for each point, x,y,z angles), an array for the hand configurations (one string for each point, opened, closed or normal), a flag that triggers the copy of the movements for the left hand, an array containing the weights to be used in the computation.
The function receives the parameters, checks their correctness, then a for cycle for each point begins and computes the right arm joint values. To perform this computation a numeric solver, from the Robotics System Toolbox [28], is used: first an inverse kinematic solver is created from the robot model by means of the *inverseKinematics* system object; then this solver is used to calculate joint configurations for a desired end-effector pose. The solver receives some parameters: the end-effector to be placed, the end-effector pose as a 4-by-4 homogeneous transform matrix, an array of 6 elements containing the weights

for pose tolerances, a struct array for initial guess of robot configuration. The end-effector is always the right hand, the end-effector pose is computed at each cycle with the 3D point coordinates and the orientation, the weights are fixed for each cycle, the initial guess is updated at each cycle as the configuration of the previous cycle.
A numeric solver was used since inverting the kinematics equations by hand was too complex. Furthermore, the inverted equations that can be found online [29] were obtained by making some simplifications that are not manageable in this case. The urdf robot model used in the numeric solver was adapted from the urdf file containing the robot kinematic and dynamic parameters, developed by [30]. The modified urdf file contains information on the torso and the right arm only.
Once computed, the values are checked to be inside the joint limits and are transformed into the relative left values if needed. The hand configuration is set at this point on the basis of the string received. Then the function ends and returns the joint values of both arms.

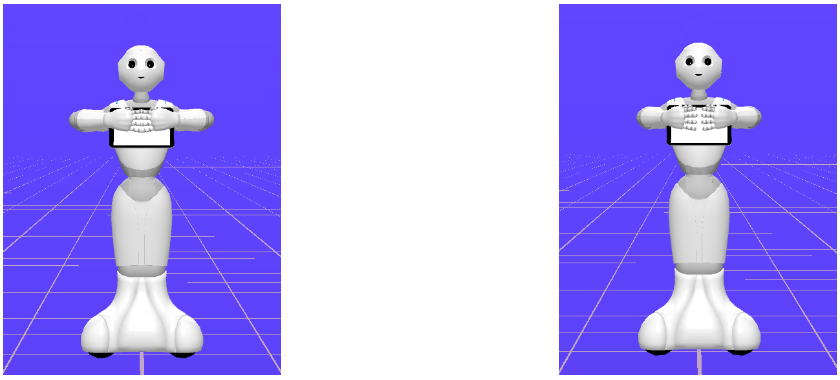
6.3 Python script

This script is like a wrapper: it collects the inputs, transforms them into suitable types, calls the MATLAB function and uses the returned values to write the animation file. The script accepts more inputs than the MATLAB function does since there are also parameters related to the animation timeline that are not interesting for the joint computation. The inputs are passed as arguments on the command line when calling the script. The possible inputs accepted are the following: time interval between movements and between starting/ending position and the movements, a path to the folder into which save the animation file, the name to give to the file, points to be reached, orientations and hand configurations, the weights for the solver and the mirror option. The data to be passed to the MATLAB function are transformed into suitable types and shapes for the function, the other data are used to create the animation file following these aspects.
After preparing the data, the MATLAB engine is started and the function is called, then the engine is shut down and the joint values returned from the function are used to write the animation file.
The animation file requires, besides the joint values, the abscissa and ordinate values of the Bezier tangent points. These values are computed based on the trend of the joint values, each joint can be seen as a curve linking the dots represented by the values at certain timestep. This file has an XML format and is organized as following: first the Animation tag is written, then each joint is reported as ActuatorCurve tag and inside the values it assumes are written as Key tags. Each Key tag has Tangent tags reporting the tangents values.
The final output of this code is an animation file, *.qianim* extension, saved in the specified folder or in the working folder if it is not specified and named as specified or "Animation" otherwise. This file can be opened in the Animation Editor tool and can be used to make Pepper perform some movements.

6.4 Results

The object was to recreate the signs previously hand-made. For the characteristics of the code, 10 signs cannot be automated, these signs need different arm movements and body movements. The signs not replicated are: *andare, bilancia, buongiorno, comunicare, dirigente, diventare, dormire, dubitare, raccontare, shampoo.*
The other 42 signs are realizable but it was not possible to create 4 of them (*aria, insegnare, montagna, rimanere*). The 3D coordinates can be reconstructed but it was not feasible to find a working combination of hand orientation and weights: either the points are reached but the movements are weird or the points are not even reached.
In general there were some troubles with the elbow in each sign. Many signs developed by hand had the elbow staying still and moving the arm around it, in the automation phase this was difficult to achieve and some movements involve the movements of the elbow too. A similar analysis can be made on the elbow position that results different from the hand-made signs. An advantage of this method with respect to the hand implementation is the higher simplicity in creating circular movements. To sum up, even though this automatic procedure achieves useful results, some manual adjustment might still be necessary if one wants to deploy the sign and use the robot in a real environment.
In the following figures, 3 automated signs ar displayed (*Amare, Che/Come?, Università*) in details and compare them to the ones realized by hand.

- "Amare" (To Love). Comparing figures 5.3 and 6.1 we can see that the movement is similar even though not equal, there is a difference in the elbow position. This difference leads to different joint values as shown in tables 5.1 and 6.1. Despite this diversity, the movements are similar and the meaning of the sign is still understandable.



(a) Starting position

(b) Ending position

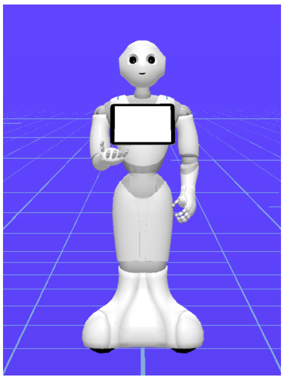
Figure 6.1: Amare automated starting and ending position

Starting position						
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	-1.6°	-26.8°	-0.8°	89.5°	100.4°	0.98*
Left	-1.6°	26.8°	0.8°	-89.5°	-100.4°	0.98*
Ending position						
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	-1.4°	-13.3°	-7.6°	55.6°	102.6°	0.98*
Left	-1.4°	13.3°	7.6°	-55.6°	-102.6°	0.98*

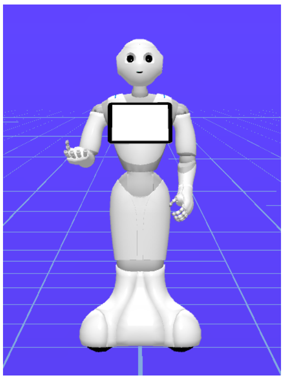
*0.98 = opened, 0.59 = normal, 0.02 = closed

Table 6.1: Amare automated starting and ending position joints

- "Che/Come?" (What/How?). In this case the comparison between figure 5.5 and 6.2 show very similar behaviors and tables 5.3 and 6.2 confirm this similarity also in joint values.



(a) Starting position



(b) Ending position

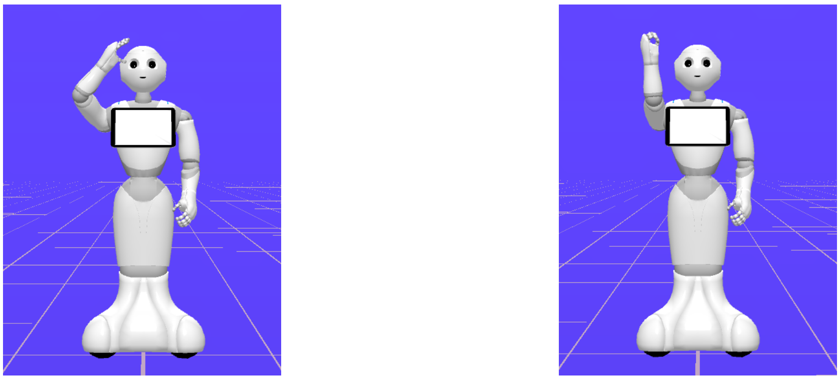
Figure 6.2: Che/Come? automated starting and ending position

Starting position						
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	77.9°	-0.5°	74.4°	80.2°	94.7°	0.98*
Left	90.5°	6.7°	-69.8°	-29.7°	-1.8°	0.59*
Ending position						
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	79.4°	-14.0°	96.4°	76.7°	102.1°	0.98*
Left	90.5°	6.7°	-69.8°	-29.7°	-1.8°	0.59*

*0.98 = opened, 0.59 = normal, 0.02 = closed

Table 6.2: Che/Come? automated starting and ending position joints

- "Università" (University). Figure 5.7 and figure 6.3 are pretty similar except for the hand rotation that is more emphasized in the first picture. The joint comparison, tabs 5.5 and 6.3, follows the same pattern.



(a) Starting position (b) Ending position

Figure 6.3: Università automated starting and ending position

Starting position						
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	-38.4°	-24.9°	36.7°	74.5°	51.1°	0.98*
Left	90.5°	6.7°	-69.8°	-29.7°	-1.8°	0.59*
Ending position						
	SPitch	SRoll	EYaw	ERoll	WYaw	Hand
Right	-26.0°	-0.5°	95.0°	54.6°	-2.0°	0.02*
Left	90.5°	6.7°	-69.8°	-29.7°	-1.8°	0.59*

*0.98 = opened, 0.59 = normal, 0.02 = closed

Table 6.3: Università automated starting and ending position joints

Chapter 7

Evaluation

7.1 Description

This last step aims at proving that Pepper is able to sign well and that its movements are intelligible. In order to validate the created signs, a questionnaire containing a set of these signs was made and it was submitted to people who know LIS, in order to evaluate Pepper performing signs. The questionnaire is made up of two main parts: there are 15 multiple choice questions and 2 open questions.
The first 15 questions show Pepper performing a sign and the person filling the questionnaire is asked to select which sign Pepper is making, among 4 possibilities: 3 of them are signs and the fourth option is a "None of the above signs" option. The signs shown are chosen both from the 5.3.2 section and the 5.3.1 section, the aim is to validate both right and wrong signs. The "None of the above signs" option should be the selected option for the signs belonging to the 5.3.1 section.
The last 2 questions show Pepper performing 2 of the implemented sentences and ask the subject filling the questionnaire to write down what he/she thinks Pepper is saying.
The questionnaire was fulfilled by a total of 12 people, most of them are deaf and use sign language on a daily base. They live in different regions of Italy so it is possible that they sign some signs in a different way with respect to Pepper, even if we tried to implement the most used version of each sign. The subjects are both females and males and they are from 18 to 40 years old. The only request they were made was to answer sincerely.

7.2 Results

From the questionnaire results it is clear that many signs are recognized correctly while some others are not so easy to understand. In general Pepper's movements are positively evaluated, thus supporting the thesis.
The results are analyzed in details in the following subsections.

7.2.1 Multiple choice questions

The signs submitted to evaluation are:

- "Acqua" (Water) : Recognition rate: 50%. Pepper is not able to perform this sign in the best way, the movements are similar to "Apple" and in fact 25% of the subject voted for this option. The other 25% selected the none of the others option. Considering the data and the comments just made, we can say that this sign is intelligible.
- "Antipatico" (Unpleasant) : This sign belongs to the discarded signs, so the right option should be "No option is correct". 58.3% voted for this option validating the non intelligibility of the sign, even though a 17% of the subjects voted for the "Antipatico" option recognizing the sign.
- "Capriccioso" (Capricious) : This sign again belongs to the discarded group but in this case the recognition rate was high 58.3% and the no correct option was voted by 33.3% of the people. In this case a *wrong* sign was validated as a *correct* one.
- "Che/Come?" (What/How?) : The recognition rate for this sign was very high, equal to 83.3%, thus validating the sign.
- "Chiedere" (To ask) : This case was difficult to determine, the right option obtained the majority of votes (41.7%) but also the "No correct option" was voted a lot gaining the 33.3% of the votes. The movements performed in this sign are similar to the "Insegnare" movements and this option was chosen by the 16.7% of the people.
- "Dimenticare" (To forget) : This case was very good, it reached 100% of recognition rate. Maybe this is due to the fact that this movement is iconic and so easy to recognize, but in any case Pepper performed it very well.
- "Doccia" (Shower) : Recognition rate: 66.7%. The percentage validates the sign. Furthermore this movement is similar to the "Idea" movement and 16.7% of the people voted for this option.
- "Finire/Fatto" (Done) : 100% of recognition rate in this case.
- "Idea" : Even though this sign belongs to the discarded set, its recognition rate is among the highest ones (91.7%) and only one person voted for the "No correct option".
- "Insegnare" (To teach) : This sign is very puzzling, only 33.3% of the voters recognized it. Another 33.3% voted for the "No correct option" and 25% selected the "To speak" option. This sign is the worst one in terms of recognition.
- "Libro" (Book) : This case is similar to the first one, the recognition rate is equal to 50%. Then the second most selected option is the "No correct option" and a 16.7% of the people voted for "Big". This sign is a problematic one because of the robot's limitation in movement: the tablet does not allow Pepper to put its hands attached

to one another at the front. The sign is thus difficult to understand, as the results show, and is similar to the "Big" sign.

- "Profumo" (Perfume) : This sign belongs to the discarded signs and the results confirm this choice. Even though the right option was "No correct option", every subject selected the "Good" option. "Perfume" and "Good" are similar in the movements but their starting position is different. Due to Pepper's limitations, the hand position is not correct and is more similar to "Good".
- "Shampoo" : Recognition rate: 100%
- "Spaventarsi" (To get scared) : 58.3% voted for the "No correct option" that, in this case, is the right one since this sign was discarded. 16.7% of the people recognized the sign but the overall result confirms that this sign is not intelligible.
- "Università" (University) : This is the last sign and it obtained 100% of recognition rate.

In general the results show that Pepper movements are understandable. The options were chosen to harden the game, placing options relative to similar signs in most questions. Considering the results of some signs in particular, we can say that this was the right strategy to follow.

7.2.2 Open questions

The two open questions did not obtain the same good results of the multiple choice part.

- "Ho mangiato una mela" (I ate an apple), realized as mela - mangiare - fatto (apple - to eat - done) : Because of the similarity between "Water" and "Apple" previously discussed, most subjects recognized the sentence as "Ho bevuto e mangiato" (I drank and ate). Only one person was able to correctly answer the question. Despite this misunderstanding, the question was answered by every participant and almost all of them gave a translation for each world.
- "Vado a casa a studiare" (I go home to study), realized as casa - studiare - andare (home - to study - to go) : This sentence has a very low recognition rate, most participants were not able to understand the words. One person correctly answered the question, another one answered almost correctly, a third person understood the world "Studiare" and 2 more participants recognized "Andare". All the other subjects answered with very different sentences and sometimes directly wrote that they were not able to understand. A probable cause of this lack of recognition is the "Casa" sign: Pepper makes a big movement in this sign that is different from the real movement that it should perform but it cannot be done in another way due to its limitations.

Chapter 8

Conclusions and future works

The conclusion is that Pepper is able to sign well many of the realized signs and this result is supported by the presented questionnaire. Talking about the not well recognized set of signs, a possible development of this thesis is to modify these signs in order to make them more intelligible, always asking for support to the deaf community. We believe that continuing working on this topic with the help of deaf people is the key for succeeding.
Another option to improve intelligibility is to use the tablet on Pepper's chest, we discussed about this idea with the human interpreter that helped us and she positively validated our proposal. Depending on the context, it is possible to use the built-in tablet but also an external monitor: considering a scenario in which Pepper is supposed to help people from behind a desk, one could place a monitor on the desk, near the robot, and use it instead of the built-in tablet. This option allows us to overcome a possible issue with the built-in tablet: most signs are performed in the space in front of the tablet, so some movements can prevent the screen to be seen. In any case, there are different alternatives to analyze: we can show an image representing the sign Pepper is performing (even if it is difficult to represent an action with an image) or we can show an avatar/human signer performing the same sign or else we can show a face making expressions and moving lips.
Reconnecting to this last point, one could point out that a robot with a human face or with a screen as head would be more appropriate. In this work we showed that making a commercial social robot able to communicate in sign language is possible, even though it is limited and cannot speak fluently. Pepper is very friendly looking and has a variety of skills since a lot of different studies have been conducted on it, but it is limited in physical movements. We understand that these issues are real problems and we hope that in the near future social humanoid commercial robots will be more advanced and will meet the necessities of the deaf community. A robot able to separately control each finger, having 10 fingers, and a human face able to express emotions and move lips, is the perfect robot for this task. Nowadays, technology makes progress at an amazing velocity, we are confident that will not be long before a suitable commercial robot enters the market.
The other main topic around which the thesis was developed is the script for automating the signs. We showed that it can effectively create most of the realizable signs but also that is has some limitations due to implementing choices. The development of the thesis on this topic can follow two different paths. The most similar one is to further develop

the code and implement the support for the left arm, and also a furthered study on the wrong realized signs can be conducted. The second possibility is to develop a new code based on neural network that can analyze a human's movement and convert it into joint values.
Once improved the code or created a new one, it will not be difficult to generate all the other signs that Pepper can physically perform. Furthermore, this method is preferable to the realization by hand for the signs containing a circular movement. The configurations are the same that are presented in this thesis, considering the hand opened or closed or a combination of both.
To summarize, we successfully implemented a set of signs, belonging to Italian Sign Language, on the social robot Pepper. We used two different methods to implement the signs: by hand and with the use of a specifically developed code. Eventually, we asked to some members of the signer community to evaluate the robot performance and the results were positive.
We believe that this work is very important under many points of view and we hope that this is just the beginning for further studies to help the deaf community.

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