Bachelor's Thesis

Grau en Enginyeria en Tecnologies Industrials

Rediscovering the experimental robotic platform MASHI

THESIS

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REDISCOVERING THE EXPERIMENTAL ROBOTIC PLATFORM MASHI

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Abstract

This Bachelor's Thesis about robotics works in the experimental robotic platform MASHI, created by the PhD student Dennys Paillacho, ESPOL, Ecuador. He designed and built a social robot for studying proxemics interactions between people and robot. The platform became an interesting opportunity as a robotic platform for another theses, and this is a clear example.

In this thesis a new computational unit for the platform has been installed and programmed to replace the initial one without interfering negatively in any of its functionalities. During a semester, the robot has been analysed and reconstructed from almost the beginning, and a new implementation has been developed.

The main objective is to improve easiness and accessibility to the platform such that future students will use the same platform to make research and to implement new subsystems and functions. The robotic platform has been designed with commercial components, so there is a huge number of ways of improving it.

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Acronyms

AI	Artificial Intelligence
AP	Access Point
CPU	Central Processing Unit
DHCP	Dynamic Host Configuration Protocol
DNS	Domain Name Server
DOF	Degrees of Freedom
ESPOL	*Escuela Superior Politécnica del Litoral*
GPIO	General Purpose Input/Output
HDMI	High-Definition Multimedia Interface
IP	Internet Protocol
LCD	Liquid Crystal Display
QR	Quick Response
OS	Operating System
PC	Personal Computer
PLA	Polylactic Acid
PWM	Pulse Width Modulation
RPi	Raspberry Pi
SCEWC	Smart City Expo World Congress
SD	Secure Digital
TTL	Transistor-Transistor Logic
TTS	Text-To-Speech
USB	Universal Serial Bus

1 Introduction

This Bachelor's Thesis focuses on experimenting with the educational robotic platform MASHI and each of their derivative systems. The educational robotic platform called MASHI is a project elaborated by the ESPOL's PhD student Dennys Paillacho [7]. In collaboration with the UPC he built the robot with the main goal of perform research in human-robot interaction. The thesis started when Dennys came back from Barcelona to Ecuador to finish his PhD. He brought with him the developed head and arms of the robot, and he left in Barcelona all the motion stuff.

The main goal has been to use the platform MASHI to be a good point for making future research and studies. The first step is to reconstruct the platform to have a starting point. After that, it will be a reference for students and future researchers to make implementations and improvements to the platform.

During the execution of the project there has been the opportunity to attend with the robot the Smart City Expo World Congress (SCEWC 2016), held from November, 14th to 16th 2016, where it has been possible to further analyse how the robot works and interacts.

It is intended to dedicate a career to robotics once the Industrial Engineering Degree has been finished. This Bachelor's Thesis is also an opportunity to check whether robotics is a good way for specialisation, as well as to get a first contact into this world. Writing the thesis will be of great help to determine future studies and career prospects.

By the start of the thesis there were two subjects left to study, and it is expected to pass them in order to start a Master program the next semester, in February 2017. For this reason, the thesis is being done in parallel with these two subjects.

1.1 Objectives of the project

The main objective of this thesis can be defined as twofold:

- Reconstructing the platform in Barcelona with all the documentation that Dennys could provide, in order to create a new functional MASHI.
- Analysing the platform and developing an implementation to improve its functionality.

1.2 Scope of work

The time for the project is estimated to last a four-month academic period. However, the thesis actually started in summer 2016 and it is pretended to be finished in January 2017.

The first phase of the project will be completed in collaboration with Joaquín Cortés, an ETSEIB student whose Bachelor's Thesis is also about this platform [1]. As far as there are two people working in the same theme, using the same robotic resources, reconstructing MASHI will be performed as part of a team. In the meanwhile, every particular implementation will be developed working in parallel.

The second phase of the thesis focuses on changing the processing unit of the platform in order to make the platform more efficient, affordable, and comfortable to use. As it will be seen in the following chapters, this task will involve some additional changes in associated elements. Power supply must be redesigned a bit, but the aim is to make the new implementation the less intrusive, the better.

The delivery of the thesis will be done in January 2017, from 12nd to 18th, and the oral presentation will be done the first week of February 2017.

2 MASHI, the working platform

The working robotic environment for the project is the social platform MASHI. MASHI comes from the Quechua and it means *friend*. It is also the acronym of *Multipurpose robot for Social Assistance Human Robot Interaction*.

The mobile robotic platform was started by Dennys Paillacho, who designed the original platform and thought of a function in order to work in his PhD, *An Exploratory Study of Group-Robot Social Interactions in a Cultural Center* [7].

The first part of this Bachelor's Thesis focuses on analysing and reconstructing the platform as it was incomplete at the beginning of the project. To cover as many aspects as it is possible, the analysis has been structured in three main points:

- Structure: it will be explained from physical, electric/electronic and computational point of view.
- Functionality: it will be explained which role does the platform perform.
- Interaction: it will be explained how the interaction with the user and the environment is managed.

For further information, in the annex there are the data-sheet and manual for each of the components mentioned below.

2.1 Structure

Taking a look at the platform, it can be seen that the platform can be classified in three independent sections: head, arms and mobile base.

Each section can be easily determined from three points of view:

- Physical.
- Electrical/electronic.
- Computational

As there are sections which combine electronic devices, some of them will be explained together.

2.1.1 Physical structure

The MASHI platform skeleton is composed almost entirely of 3D PLA plastic.

Most of designs for the 3D printed pieces were proportioned by Dennys at the start of the project. However, there is a number of them that have been redesigned to adapt joints, articulations and mechanisms more appropriately.

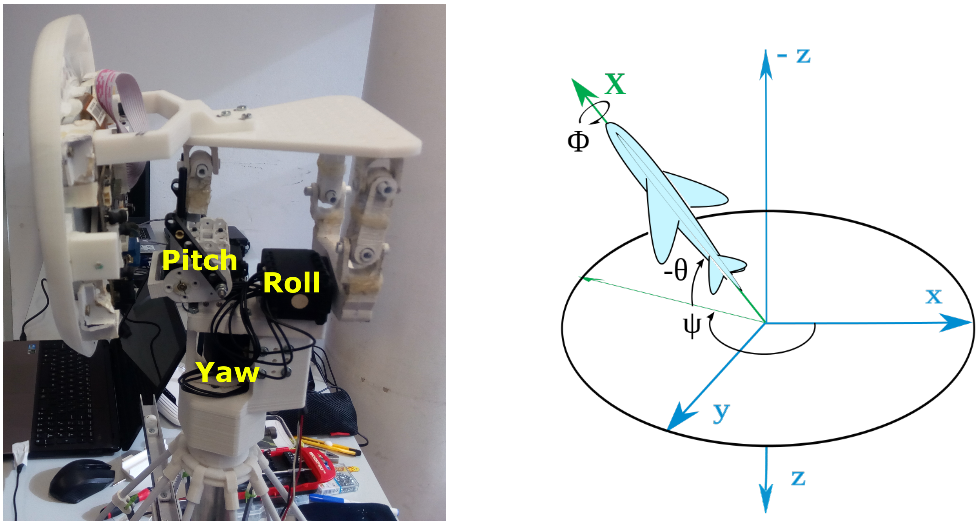
Printing the parts from 3D models has given versatility to the project, because it has been possible to make prototypes quickly and easily.

2.1.1.1 Head

The head is 3 DOF element which coincide with the nautical angles, also known as Tait-Bryan angles. The Tait-Bryan angles are a particular case of the Euler angles, which rotations are (see Figure 1b):

- *Yaw*: rotation around the OZ vertical axis. It allows the robot to rotate the head around the neck.
- *Pitch*: rotation around the OY axis. It allows the robot to nod.
- *Roll*: rotation around the own face axis, perpendicular to the screen.

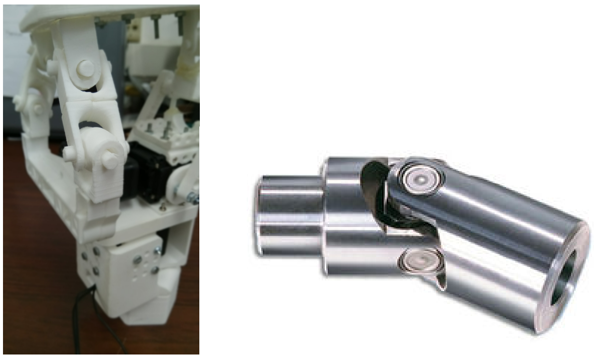
Every head rotation is executed by a Dynamixel AX-12A servomotor (from now on *servos*), as it can be appreciated in Figure 1a.



(a) DOF in MASHI (b) Example in a plain case

Figure 1: *Yaw*, *pitch* and *roll*

The most fragile movement of the head is the *roll* movement. The torque is transmitted from the motor to the head by some articulations similar to Cardan joints, as it can be seen in Figure 2.



(a) MASHI joints (b) Cardan joints

Figure 2: Comparison between MASHI joints and Cardan joints

The face of the robot is displayed using a LCD 7 inch screen that fits in a 3D printed support (see Figure 3).

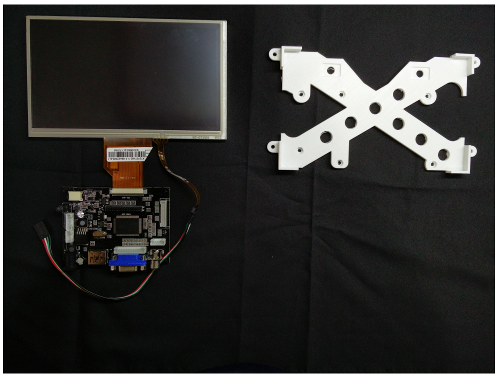


Figure 3: LCD screen and PLA support

The robot acts like a tele-presence robot commanded by an external operator. Hence, it also includes a camera and a microphone that allows the operator see and hear what is in front of the robot. In the forehead there are a web-cam and a microphone, as displayed in Figure 4.

All the structure of the head previously explained is surrounded by a PLA 3D printed case which, apart from giving the whole head a more human-like 'head' appearance, it also gives the head more robustness.

2.1.1.2 Arms

The left and right arms are different. The left arm is a 2 DOF articulation which correspond to the shoulder rotation and the elbow rotation of the robot's arm. However, the right arm has only 1 DOF that corresponds to the elbow rotation. The shoulder rotation has been eliminated because it was not necessary for the programmed functionality.

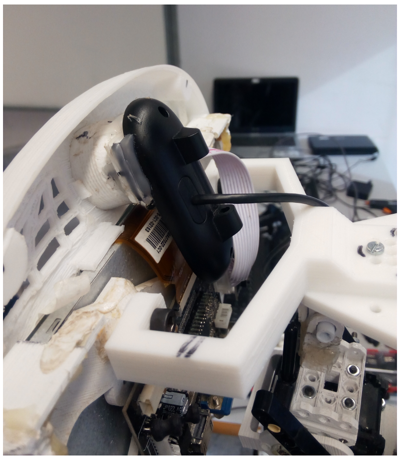


Figure 4: Frontal web-cam in MASHI

The shoulder is constructed with an U shape aluminium profile and a squared $3,5 \times 3,5$mm aluminium rod. Articulations has been implemented with VEX Robotics' plastic gears. An example is displayed in Figure 5.

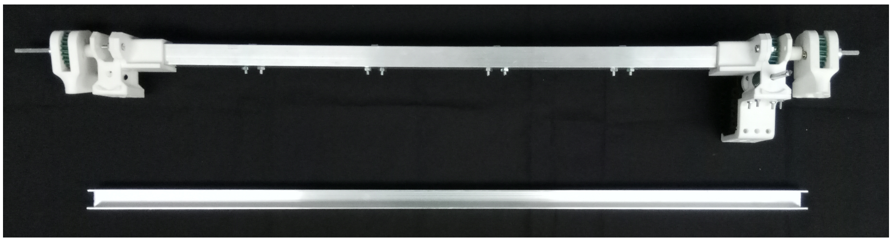


Figure 5: Aluminium profile and gears

In order to join the shoulder with both elbows and hands there are long plastic gears (see Figure 6). As an additional element, in the end of the left hand there is a web-cam for the *selfie* feature.

2.1.1.3 Base

The wheels for the robot navigation are fitted in a circular wood base (see Figure 7). On the base it starts the trunk and there are also the control elements of the wheels and the processing device, a laptop.

The wheels are PWM servos model Parallax 27971 which are controlled by an Arduino Mega 2760 board and a Parallax HB-25 (see Figure 8).

2.1.1.4 Body

All the elements explained above have been connected through a large metal pole which simulated the trunk (see Figure 9).

Figure 6: Partially assembled arms

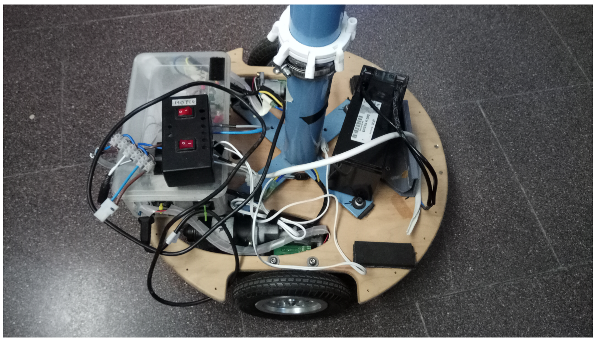


Figure 7: MASHI's base

To make the platform more friendly and human-like, an exoskeleton has been built with the same type of plastic gears used in the arms section, and all the visible wiring parts have been covered by blue foam rubber.

Visually speaking, the final structural result is depicted in Figure 10.

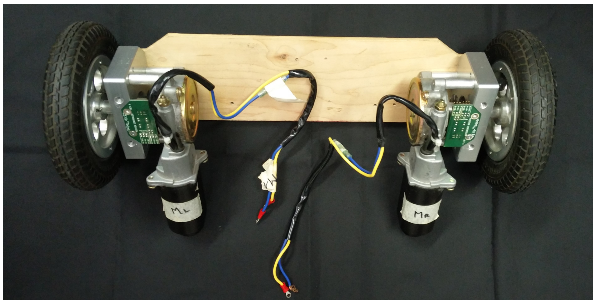


Figure 8: MASHI's wheels

Figure 9: MASHI's vertebral column

2.1.2 Electrical/electronic structure

As it has been done in the physical structure part, each section will be explained from the electrical and electronic point of view, specifying which components are used and which purpose do they accomplish.

2.1.2.1 Head and arms

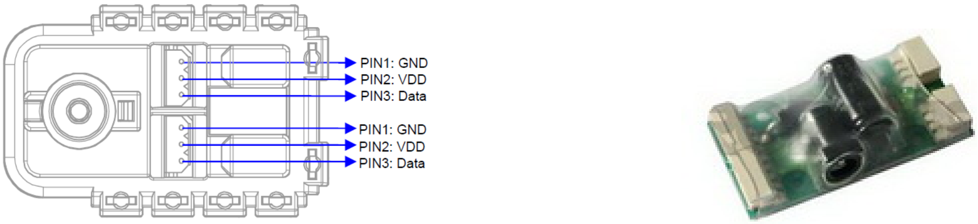
In the head and arms section there are only Dynamixel AX-12A servos connected to a Robotis OpenCM 9.04A controller. The TTL connection mode is used because it is comfortable and versatile: it is very simple to connect servos in parallel because the user only should connect them one to another and provide power supply. Each servo is attached to an ID, this distinguishes one from another.

The OpenCM 9.04A TTL bus (see Figure 11a for an example) does not provide power supply to the servos. For this reason it has been necessary to include a SMPS2Dynamixel Adapter (see Figure 11b). Powering one servo is enough if TTL bus connection is used.

The TTL connection of the whole head and arms section is displayed in Figure 12.

(a) Partially assembled MASHI (b) Assembled MASHI, in *SCEWC 2015*

Figure 10: MASHI



(a) TTL bus example (b) *SMPS2Dynamixel*

Figure 11: TTL and power supply

2.1.2.2 Base

In the base there is the electronic connection between the wheels and the Arduino board. The power supply is provided by the Parallax HB-25 and the DATA commands are provided by the RX and TX GPIO Arduino pins. The schematic is in Figure 13.

The diode included is a Zener diode model 1N4004 that helps the RX and TX serial communication. M_R and M_L are encoders used to read position, speed or other parameters of the wheels.

At the beginning of the thesis the base was supposed to work as a system in feedback, which read the velocity from the wheels' encoders and recalculated a new parameter of velocity to write to the motor. But, actually, the encoders suddenly broke in November and the system had to be read-

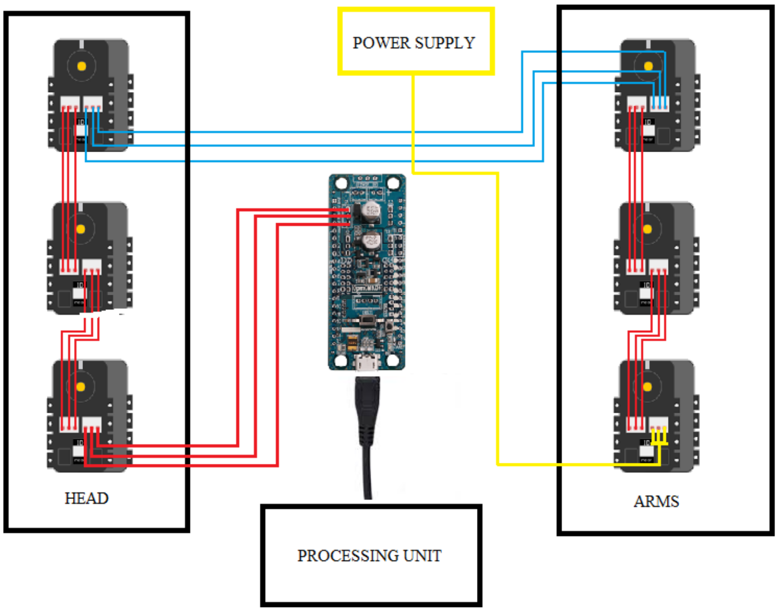


Figure 12: Head and arms schematic

justed to work in open loop. Consequently, the RX and TX serial connection wouldn't be necessary if the system worked in open loop.

2.1.3 Computational and processing structure

Once it has been defined separately each of the sections that compose the robot, it's worth explaining how all of these elements are combined to provide a whole robotic platform.

All the systems explained previously in Section 2.1.2 are connected to a computational unit that collects them and allows to work accordingly. The processing unit used is a laptop with all the controllers and peripherals connected. All this processing unit is called from now on as *Robot*. Another computer will be used as an *Operator* to control the robot separately.

The amount of devices connected to *Robot* are:

- An Arduino Mega board (Section 2.1.2.2).
- The Robotis board (Section 2.1.2.1).
- A microphone.
- A speaker.
- 2 web-cams.

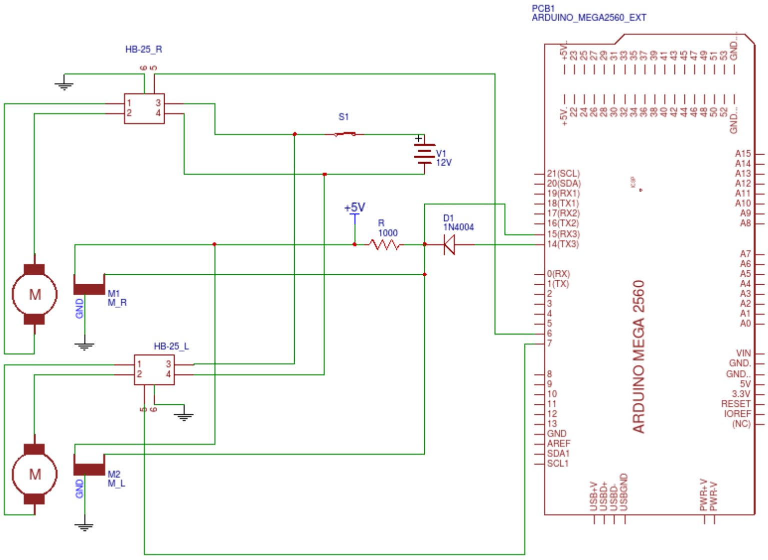


Figure 13: Base schematic

2.2 Functionality

The main feature of MASHI is that it is tele-operated. This means that it has been designed to be controlled from another site. The possibilities that allow tele-operation for a social robot of this kind are a lot, for instance:

- The robot can work for guidance purposes. For example: working as a tourist guide in towns' monuments.
- The robot can replace a person. For example: in some important meetings, when someone is not attending, he can be replaced by MASHI.

The main feature of the robot is that it fulfils a social goal. By social goal we could think about many types of actions, from making simple actions such as hugging a person to more difficult purposes such as taking care of elder people. The first function that has been designed to perform is the social convention called *selfie*. A selfie consists on taking a photo of yourself. In fact, it can be alone or accompanied. The photo is usually taken by the front camera of a mobile phone, but all the situations and devices are possible.

As it is said, MASHI performs selfies. It is actually thought to be installed in social centers, where making a selfie with people can make their visit more comfortable. And its human form makes MASHI to develop its function correctly: it doesn't cause social rejection; quite the contrary, it usually makes people smile. Once the selfie has been taken, it automatically uploads it in its Twitter profile, *@Mashirobot*, so people can see it and share it, like in the example in the Figure 14.

The robot also features text to speech (TTS) synthesis. This means that the robot can talk the way the operator wants. All that the operator has to do is typing what he wants to say, and the platform will interpret the words and

Figure 14: Example of a selfie

will play them using the speakers. It also has a microphone installed so that the operator can reproduce a conversation between the robot and a person.

The operator can see what MASHI is seeing because of the web-cam installed in its front-face. This also makes the interaction with the environment easier and more comfortable because the operator can handle the movement of the robot better.

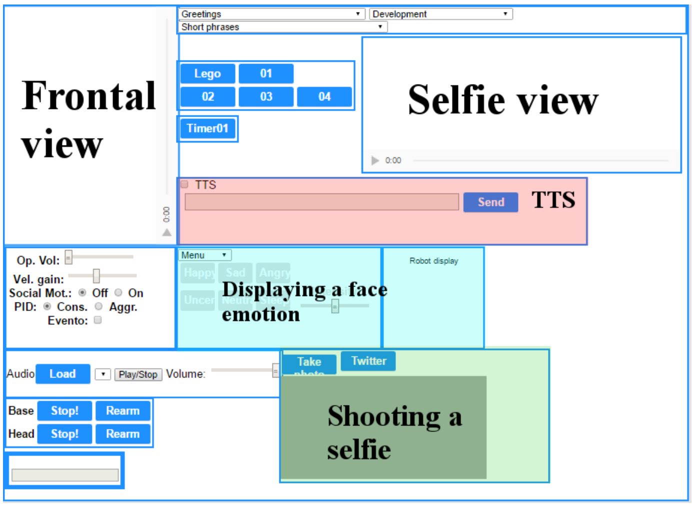


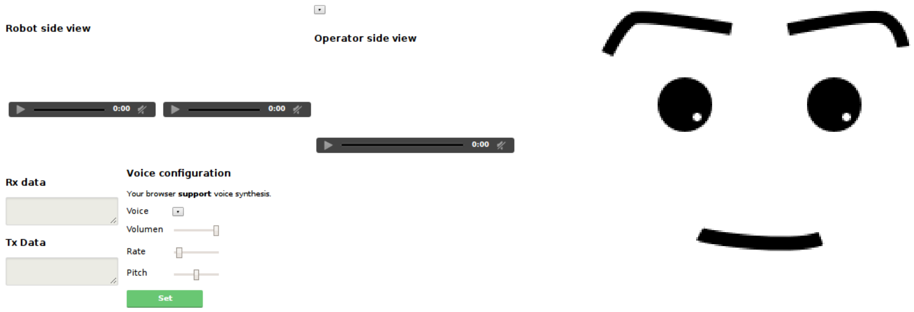
Figure 15: *Operator* web interface

2.3 Interaction. The Web-RTC platform

As it has been mentioned before, the main feature of the robot is that allows tele-operation. For that purpose, it has been created a Web-RTC environment that involves two parts, *Robot* and *Operator*.

Robot corresponds to the computational unit that takes care of all the processing of information and data. *Operator* corresponds to the computer that takes care of all the interaction between the robot and the environment. *Operator* is used to connect remotely to the robot and control it.

When we first start *Robot* interface we can check if the cameras and microphone are working, select the TTS language used and configure some other parameters (see Figure 16a). Once the language is set, *Operator* will be in charge of changing the interface to the face of the robot.



Your browser **support** voice synthesis.

(a) Setting TTS interface

(b) One example of the MASHI faces

Figure 16: *Robot* web interface

Operator interface has to be open after *Robot*, and it is where the user will be able to control MASHI. Using *Operator* the user will be able to do the following actions (see Figure 15):

- Moving the robot from one place to another.
- Moving the arms and head of the robot.
- Changing the face of the robot depending on the mood that the user wants to express (Figure 16b).
- Typing the words that the robot will say.
- Taking selfies and uploading them to Twitter.

3 Troubleshooting. Implementations and improvements

Once it has been explained the reconstruction process of the MASHI platform, the next goal is making an implementation to the robot.

As it is been mentioned in Section 2.1.3 all the processing and computational management is done by a laptop. The laptop creates a web environment via WebRTC (the *Robot* platform) and another PC connects to the environment and can control it via tele-operation. However, using a laptop as *Robot* involves some aspects worth improving.

- Physical space problems: there's no enough physical space on the base to place easily a laptop. Most of the times it is difficult to work with.
- Setting problems: setting *Robot* for the first time is lasting and uncomfortable. The WebRTC platform must run separately, all the peripherals need to be connected, and after it has been checked that it really works it must be placed on the base, being carefully not to disconnect a device.
- Energy drain problems: during all the time operation of MASHI the laptop must be turned on. This means that it can't enter in Sleep Mode and the screen has to stay always on, even if the lid is closed. In consequence, battery can drain faster than it is necessary.

This thesis deals with all these problems and proposes a solution to them.

3.1 Decision point. Using a Raspberry Pi

It is necessary to implement a computational and processing platform that solves all the problematic expressed but without changing the way is is controlled and its functionality. Studying all the alternatives available in the market it has been found that there are a lot of different boards that can be useful. The range of prices is similar to all of them. The alternatives selected have been:

- Beaglebone Black[1].

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[1] `https://beagleboard.org/black`

- The Hummingboard family [2].
- ODROID-C2 [3].
- Orange Pi [4].
- Raspberry Pi [5].

For that purpose the selected device has been a *Raspberry Pi* (from now on *RPi*). The decision has been made in terms of:

1. Its community of users. It is the most extended.
2. Its market availability. As it is the most extended board, it is easy to achieve one.

Hardware has not been a decisive factor because all the alternatives selected have nearly similar specifications. Community and availability have been more determining.

Using a RPi gives some advantages:

- It is small. The Raspberry Pi is a credit card-sized board, smaller than a laptop.
- It is easy to use. It is very versatile and adapts perfectly to every situation and purpose.
- It is Open-Source code based. All the information and software is shared by the Internet community and it easily accessible.
- It is compatible with the WebRTC platform and all the programming environment of MASHI.
- It is cheap. Using a RPi instead of a conventional laptop will save some money.

Once a RPi is selected there are several points to take into account:

1. The RPi needs to be plugged in to the electrical grid to work.
2. The RPi needs to be plugged in to a mouse and a keyboard.
3. As we can associate a RPi as a PC, it needs to be connected to a display.

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[2] https://www.solid-run.com/freescale-imx6-family/hummingboard/
[3] http://www.hardkernel.com/main/products/prdt_info.php
[4] http://www.orangepi.org/
[5] http://www.raspberrypi.org

3.2 Setting up the RPi

The RPi used in this case is a RPi 3 Model B. For what is needed there is no difference between one model and another, but the 3rd version has been selected because one of its main features is that the Wi-Fi network adapter is built-in. As it is not necessary to use a Wi-Fi dongle we can use an extra USB port to connect peripherals.

Apart from the 802.11n Wireless LAN built-in adapter, other features of the RPi are:

- 1.2GHz 64-bit quad-core ARMv8 CPU
- Bluetooth 4.1 Low Energy
- 1GB RAM
- 4 USB ports
- 40 GPIO pins
- Full HDMI port
- Ethernet port
- Combined 3.5mm audio jack and composite video
- Camera interface
- Display interface
- Micro SD card slot
- VideoCore IV 3D graphics core

The OS used is Raspbian, the official supported RPi OS. It is a GNU/Linux distribution based on Debian. This is the official supported OS and the most used by the Internet community.

3.3 Interaction and usability

As it is explained before it is needed at least a display, a keyboard and a mouse to navigate through the OS and configure all the software and settings. The robot has already a screen display by itself but it is really uncomfortable to control the RPi through it because the display is too small to see things properly. However, the platform does not include a mouse and a keyboard by default, so including them would use at least an extra USB port that will be necessary to connect other peripherals. Furthermore, it also would not be handy because in case of turning the platform on, you would have to connect the keyboard and the mouse, set up the platform, and finally disconnect them.

As another computer will be used as *Operator* these issues have been solved using a Remote Control software, in this case we will use *TeamViewer*[6]. This software allows the operator to control *Robot* connecting directly to its OS. Only an Internet connection in both platforms will be needed. *Robot* acts as Host and *Operator* as Guest, and *Operator* will use its own keyboard, mouse and display to move through the RPi.

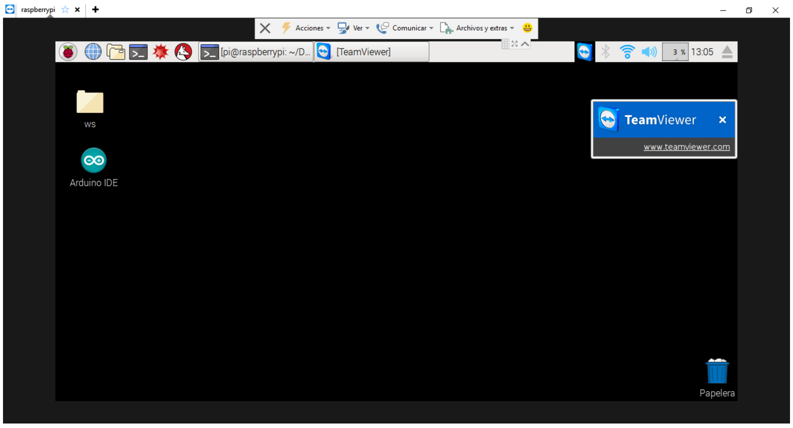

Figure 17: Using RPi in *Operator*.

Using Teamviewer the user will set up the robot remotely and, in case there's something that does not work, he will easily connect to *Robot* and fix it. The RPi uses Teamviewer 11 (the last compatible version for ARM-based devices) and *Operator* uses Teamviewer 12. After all the set up is done, the user will disconnect the remote control to use the platform via WebRTC.

3.4 Software included

The original WebRTC designed by the researcher Dennys Paillacho used Node.js v0.11.16 to create the web-based interface, but this version is not compatible with ARM-based devices such as the RPi. Fortunately, Node.js v0.10.29 is compatible with the RPi and with the modules used, which are:

1. Serialport. This enables Serial Port Communication between the interface and the USB devices.
2. Twitter. This allows the interface to make Twitter actions such as uploading a photo and tweeting.
3. Keypress. This allows to assign certain actions by the time that a key is pressed.

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[6] TeamViewer is a proprietary computer software package for remote control, desktop sharing, online meetings, web conferencing and file transfer between computers.

4. Atob

5. Socket.io[7]. This allows real-time bidirectional event-based communication.

6. Express[8]. This provides a set of features for web applications.

Other software program included which will be useful is *Geany*, the default text editor included in Raspbian, and *LXTerminal*, necessary to navigate through files and execute commands. Additionally it has been included the *Arduino IDE*, in case it is necessary to use it. The *Robotis OpenCM IDE* is not officially compatible with ARM-based devices.

MASHI needs an Internet connection to work properly. As WebRTC creates a web-based interface the DHCP mode connection has been disabled. This allows the RPi to use always the same IP address and make tests easier and faster. For that reason, every time that MASHI is connected to another Wi-Fi AP, or in case it is connected by Ethernet connection, the IP must be changed to correspond to the new configuration. In the annex there is a tutorial of the procedure used.

3.5 Power supply

Apart from needing a keyboard, a mouse and a display to work, the RPi also needs power supply. One option could be plugging in to a conventional electrical grid through a compatible AC/DC transformer. But this is not actually a solution because the robot will not be established in a fixed place, it will be moving.

Another solution could be using the 12VDC battery that power the wheels of the robot and some devices to power the RPi. But RPi only allows 5VDC as input to work, overfeeding the board will ruin it.

Finally, the solution that has been proposed is using a 5VDC battery to power the board. For that purpose, a simple smart-phone external battery is enough to power the RPi. This kind of batteries aren't heavy and voluminous, and as most of the smart-phones use them, they are affordable.

A 8000mAh battery will be used to power the RPi, and as we add a device to be on the base, the situation of both RPi and battery will be restructured to be easy to quit the battery in order to charge it.

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[7] For further reference visit `http://socket.io/`

[8] For further reference visit `http://expressjs.com/`

4 Testing MASHI. SCEWC 2016

Testing the RPi in the platform has been successful. All the functions explained in Chapter 2 worked well, respecting the previous configuration. In fact, future implementations will be easily adaptable to the new processing unit.

The only restriction that the RPi has is that as there are only 4 USB ports, it can only be connected to 4 devices without using a HUB. These devices are:

1. The front web-cam.
2. The selfie web-cam.
3. The Arduino Mega 2560 board in charge of controlling the base.
4. The Robotis OpenCM 9.04A board in charge of controlling the arms.

The speaker is connected to the RPi via Bluetooth, so a USB can be saved. Using a HUB will imply adding a new power supply to it because the RPi itself would not be capable of powering all the devices at the same time. The microphone can be connected using two ways:

- As it has been said, using an USB microphone connected to a powered HUB.
- Using a Bluetooth speaker with a built-in microphone.

The current configuration set in the RPi includes the use of a microphone, but this connection has not been included in the tests.

Due to the Smart City Expo World Congress 2016 celebrated in November 14th-17th, Dennys came to Barcelona to participate in it. MASHI was reconstructed with the pieces brought by him and the part that was in Barcelona as well. The Congress was full of people and that was an opportunity to analyse how MASHI works and how interacts with people.

During the setting of the robot the encoders suddenly broke and the robot couldn't move. For this reason the robot was established in *L'H Social Hub* stand, next to a model of the city, done by *Club Cortocircuito*.

It was really surprising how MASHI got people's attention. Although it was not the best robot of the Congress, nor the most modern, people from all ages were willing to take a photo with MASHI. Some people were really interested and wanted to know more about the project and the robot.

However, there were some people that didn't understand exactly the purpose of the robot and what was it doing. Sometimes people were staying in front of the robot, and someone had to explain to them what was it doing, and what did they have to do. This gives an idea that's worth taking it into account in future congresses, if the robot is exposed again.

Another issue that was detected is that most of the times it is very difficult to establish a conversation between the operator and the person standing in front of the robot. The operator had to be really fast with the TTS to catch people's attention and to chat.

After taking a photo with the robot they could read a QR code with their cellphone and they were redirected to MASHI's Twitter profile, where they could follow him and share their photo with all of their friends.

On the whole, spending 3 days in a professional congress like the SCEWC has been an experience not to be missed, and has allowed to see a lot of things that couldn't have been possible without the collaboration of *UPC*, *L'Hospitalet de Llobregat* and *Club Cortocirtuito*.

Figure 18: MASHI in SCEWC 2016

5 Suggestions for improvements

MASHI is an Open-Source platform and it is not perfect. Two implementations have been made by the way, but the intention is that this robot could be used for future students that want to work in their thesis. In fact, there are a lot of improvements that could be done in a future.

This Bachelor's Thesis has implemented a new computing processing unit for the robot so as to work better and efficiently. At the same time, a new motion control is been designing by Joaquín Cortés [1]. However, there are a lot of different fields of study, and these are some of the suggestions for improving the platform:

1. Mechanics:
    - Redesign of the head movement.
    - Change of the building materials.
    - Addition of DOF and improve of the range of movement.
2. Electronics:
    - Making the wheels work as a system in feedback.
3. Interaction and interface:
    - Installing a face recognition system to the selfie function.
    - Installing an AI system to the robot to take some autonomous decisions.
    - Installing a speech-recognition system that works with the TTS.
    - Improving the *Robot* and *Operator* interface: adding more faces to the robot, more preset phrases...

The experience in *SCEWC 2016* explained in Chapter 4 also gives a feedback from the people and there are some points explained that are worth thinking about in future thesis and projects of the platform. After all, the MASHI platform is experimental, and the more feedback it is given, the better for the project.

6 Time planning

This thesis started by the starting of the Autumn semester in September 2016.

As it is explained in Chapter 1, in this project there are two separate goals:

1. Reconstructing the robot.
2. Implement a new processing unit.

The thesis has been planned to last a semester, from September 2016 to January 2017. Most of the time has been devoted to the reconstruction of the robot in collaboration with Joaquín Cortés [1].

The last month of the thesis has been devoted to setting up the RPi and adapting all the processing part to the new way of working.

Due to the SCEWC 2016 (Chapter 4) a part of the time has been used to reconstruct the robot with Dennys's pieces, and it has been an opportunity to see how it works and find out some ways of improving.

On balance we can outline the time planning with a Gantt Chart:

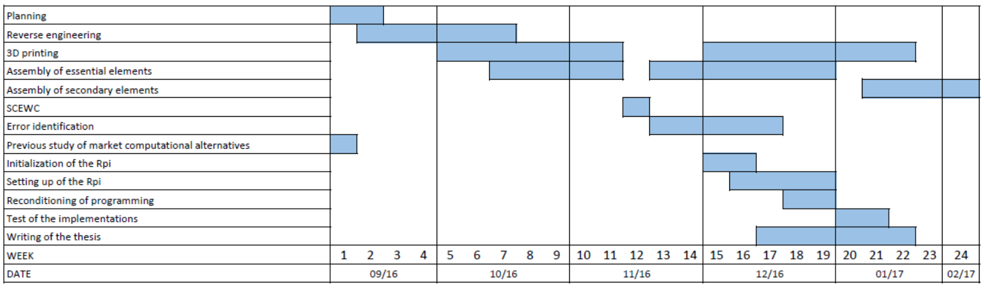


Figure 19: Gantt Chart of the time planning

7 Budget

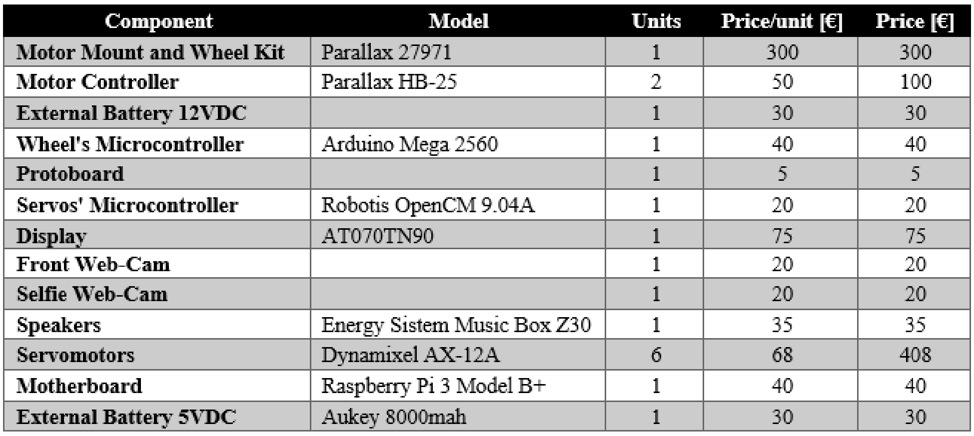
This chapter estimates the total cost of the project done, itemised in different parts:

- Electronic components.
- Materials.
- Other costs.

Each part will be quantified separately in order to make it clear.

7.1 Quantifying the electronic components

The amount of money corresponding to the electronic components is:



Component	Model	Units	Price/unit [€]	Price [€]
Motor Mount and Wheel Kit	Parallax 27971	1	300	300
Motor Controller	Parallax HB-25	2	50	100
External Battery 12VDC		1	30	30
Wheel's Microcontroller	Arduino Mega 2560	1	40	40
Protoboard		1	5	5
Servos' Microcontroller	Robotis OpenCM 9.04A	1	20	20
Display	AT070TN90	1	75	75
Front Web-Cam		1	20	20
Selfie Web-Cam		1	20	20
Speakers	Energy Sistem Music Box Z30	1	35	35
Servomotors	Dynamixel AX-12A	6	68	408
Motherboard	Raspberry Pi 3 Model B+	1	40	40
External Battery 5VDC	Aukey 8000mah	1	30	30

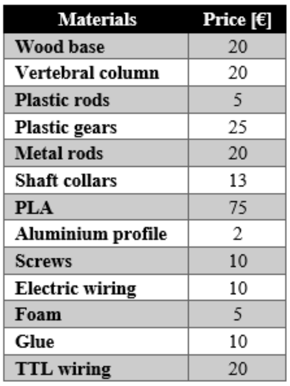
Figure 20: Electronic components costs

That makes a total cost of electronic devices of:

$\text{Subtotal}_1 = 1123$€

7.2 Quantifying the materials used

The amount of money corresponding to the materials used is:



Materials	Price [€]
Wood base	20
Vertebral column	20
Plastic rods	5
Plastic gears	25
Metal rods	20
Shaft collars	13
PLA	75
Aluminium profile	2
Screws	10
Electric wiring	10
Foam	5
Glue	10
TTL wiring	20

Figure 21: Materials costs

That makes a total cost of materials of:

$\text{Subtotal}_2 = 235€$

On balance, the total amount of money estimated to construct the platform is:

$\text{Subtotal}_1 + \text{Subtotal}_2 = 1123 + 235 = 1358€$

7.3 Other costs

7.3.1 Human resources

It has been supposed that the project has been made along 25 weeks as a part-time job for a company (in this case, we could suppose that we are working for the UPC). The human resources costs are:

$$20\frac{\text{h}}{\text{week}} \cdot 25\text{weeks} \cdot \frac{20€}{\text{h}} = 10000€$$

Transport costs are quantified in 284€.

7.3.2 Equipment

It has been used a 500€ PC redeemable in 3 years:

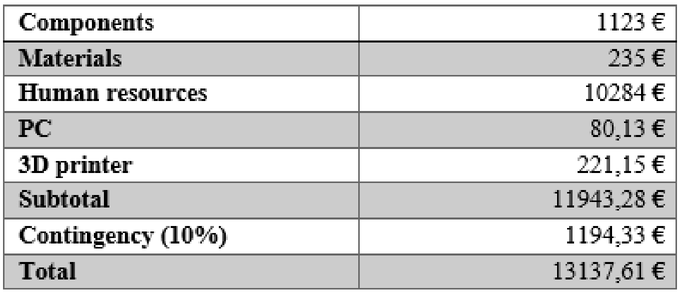
$$\frac{500€}{3\text{years} \cdot \frac{52\text{weeks}}{1\text{year}}} \cdot 25\text{weeks} = 80,13€$$

The 3D printer is redeemable in 5 years:

$$\frac{2300€}{5\text{years}\cdot\frac{52\text{weeks}}{1\text{year}}}\cdot 25\text{weeks} = 221,15€$$

7.4 Overview. Total costs

Using a 10% extra cost due to contingency costs and adding all the costs specified previously the total costs of the project are:



Components	1123 €
Materials	235 €
Human resources	10284 €
PC	80,13 €
3D printer	221,15 €
Subtotal	11943,28 €
Contingency (10%)	1194,33 €
Total	13137,61 €

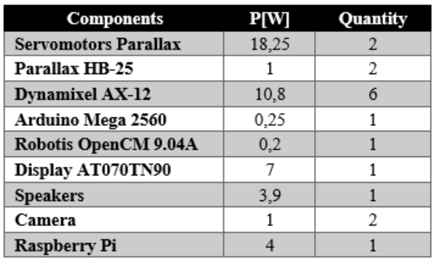
Figure 22: Total costs of the project

8 Environmental and social study

8.1 Quantifying the environmental impact

This chapter has been taken from [1] and adapted to the new use of a RPi.

In order to know the environmental impact of the project, it has been calculated the CO_2 footprint produced by the use of MASHI and all of its manufacturing process (in particular, the 3D printing). First of all we calculate how much does MASHI consume in high performance (supposing it is always moving at maximum speed and that all the devices are working). These results can be seen in the following figure:



Components	P[W]	Quantity
Servomotors Parallax	18,25	2
Parallax HB-25	1	2
Dynamixel AX-12	10,8	6
Arduino Mega 2560	0,25	1
Robotis OpenCM 9.04A	0,2	1
Display AT070TN90	7	1
Speakers	3,9	1
Camera	1	2
Raspberry Pi	4	1

Figure 23: Energy use of every electronic device

The total amount of consumed potency is:

$$\text{Total} = 120,65W$$

The total consume is used to calculate the amount of CO_2 emitted to provide this energy, using the procedure explained in [2]. The amount of CO_2 emitted is (t is expressed in minutes):

$$\text{gCO}_2 = 0,607\text{t}$$

It can be seen that the consume is relatively lower than other robots. The CO_2 footprint is not high.

Using a RPi has decreased the consume more or less the 47%.

However, MASHI has been constructed using PLA, a biodegradable material. It has been calculated the impact of the printing of the pieces, assuming that the 3D printer consumes 240W and that the total amount of working time has been more or less 50h.

$$gCO_2 = 0,24x50x302 = 3264g$$

This amount of CO_2 is low in comparison with other production process.

8.2 Quantifying the social impact

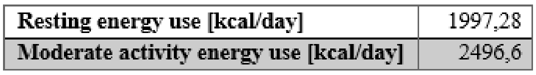
As it has been said when describing the platform and its functionality, MASHI is a robot that works tele-operated. The robot can act as a person in multiple social events, allowing presence although the person is not physically there.

Let's suppose that MASHI attends the *SCEWC 2016*. If a professional wanted to attend the conference but he is a foreigner and he can't be present there, he could use MASHI. He would save time because he is not travelling there and he would attend only the time he wanted. He would save money because transport and accommodation costs would be significantly reduced. And he wouldn't have to move while MASHI would be moving around the conference.

8.2.1 Energy use of a person

Supposing that MASHI is working an hour and it is only moving half of this time, let's calculate how much energy will a person use in this amount of time.

Using [5] we will calculate the energy use of a 70 kg, 180 cm person, aged 40. According to *Harris-Benedict (1990)* and using moderate activity and resting as an activity factor:



Resting energy use [kcal/day]	1997,28
Moderate activity energy use [kcal/day]	2496,6

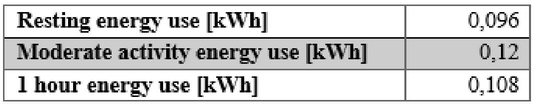
Figure 24: Energy use of a person in a day

Expressing them in *kWh*:

$$1997,28\frac{kcal}{day}\cdot\frac{1000cal}{1kcal}\cdot\frac{4,18J}{1cal}\cdot\frac{1day}{24h}\cdot\frac{1h}{3600s}=96,63W=0,096kWh$$

$$2496,6\frac{kcal}{day}\cdot\frac{1000cal}{1kcal}\cdot\frac{4,18J}{1cal}\cdot\frac{1day}{24h}\cdot\frac{1h}{3600s}=120,78W=0,12kWh$$

The energy use of a person will be:

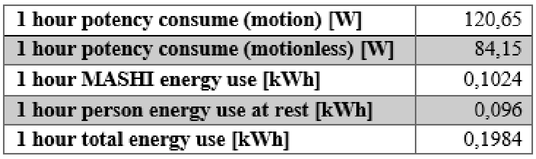


Resting energy use [kWh]	0,096
Moderate activity energy use [kWh]	0,12
1 hour energy use [kWh]	0,108

Figure 25: Energy use in working operation

8.2.2 Energy use of MASHI

Using the same time restrictions (1 hour of work, only moving half of this time) we will calculate the energy use of MASHI. Apart from the energy use of MASHI we should add the a 1 hour energy use at res from the operator:



1 hour potency consume (motion) [W]	120,65
1 hour potency consume (motionless) [W]	84,15
1 hour MASHI energy use [kWh]	0,1024
1 hour person energy use at rest [kWh]	0,096
1 hour total energy use [kWh]	0,1984

Figure 26: Energy use of MASHI in an hour

MASHI consumes $0,1984KWh$ in an hour of operation.

8.2.3 General evaluation

It has been calculated that a car with a gas consumption of $5L/100km$ uses $35,5kWh$ travelling at $80km/h$, according to [9].

We can conclude that in the congress MASHI will use more energy that a person who is physically there, working around. But if we take into account that travelling to the congress has also an energy use, it is clearly verified that a robotic platform like MASHI walking around the congress will be more profitable in terms of energy use. Even if the person has to arrive to the congress walking an hour more or less, it would also be profitable to use MASHI.

9 Conclusions

Once the platform MASHI has been reconstructed and explained, and once the implementation has been done, it is time to write conclusions about all the work done.

Taking a look to Chapter 1 and the objectives of the thesis, it can be said that the objectives of the thesis have succeeded. It has been possible to adapt a new computational unit to the MASHI platform, using a RPi and an external battery to power it. Using a RPi gives the platform the same functionality but it solves all the problems mentioned in Chapter 3: space, setting and energy drain problems.

Along this semester there were some troubles that have been solved. The most important was trying to know why the wheels didn't work properly. It took nearly a month to figure out that there was a problem with the encoders, and it was decided to make the system work in open loop. Nowadays the robot is working properly, but it would be a point if in a future there is a fix to the problem.

Another problem that is worth mentioning is dealing with the 3D printer. Having access to a 3D printer in the laboratory has been a really advantage because it has eased the production of material. However, it has been actually difficult to make it work properly. In fact, the printer had to be taken to technical support because the LCD broke and printing was really tough. Issues like stuck filament in the Bowden tube and loading filament were very common.

Working in that project has allowed to work with Arduino and RPi. Working with Arduino was familiar because it has been explained in a previous subject of the Degree, but working with a RPi was completely new. It has been a nice course to learn how a RPi works and how to adapt it to a robot. Both in RPi and Arduino, at first it is a bit confusing, but having the Internet community is a good advantage to learn. As Arduino is programmed in C code, which it has not been taught in the degree, sometimes it was difficult to understand how the code is written.

Working together with Joaquín Cortés [1] has been really helpful because as it is said, *four eyes see better than two*. There have been a lot of hours of work and spending them with a class mate has been really useful.

Having the opportunity to attend an International Congress like the *SCEWC 2016* has been very significant because on the one hand it has been an opportunity to know Dennys Paillacho in person, and on the other hand it has been an opportunity to test the platform in an appropriate environment. It has also been an honour to see how a professional congress is from the inside because nowadays attending it as a student is a bit unlikely.

Personally speaking, this project has been definitive to decide that robotics is the future field of study that it is wanted to specialise in. It was almost decided since the starting of the Degree, but the many approaches to the subject, the better. Working in that platform has made me realise that it is not enough to work from one point of view. An Industrial Engineer has to be capable of seeing things from multiple points of view and work to implement a way to comprise all of them.

Academically speaking, working in that project has made me realise that the next step to take is the double-master's course, the Industrial Engineering master's course and the Automatic, Control and Robotics master's course. The intention is to mix concepts and ways of working from the two courses to promote a good future and specialisation.

I would like to thank all the people that has accompanied me in this semester of work. First of all, Cecilio Angulo, the supervisor of the project, Joaquín Cortés and Dennys Paillacho, who have helped me in the process of reconstruction and testing. Jonas Londschien, who has helped me in the arduous process of the 3D printing. And I wouldn't forget my family and friends, who have always supported me every time I needed.

Finally I would like to conclude by saying that working in the robotic platform MASHI has been an experience not to be missed, and in a near future I wouldn't reject to work again with it.

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