Universidad de Málaga

Escuela Técnica Superior de Ingeniería de Telecomunicación

Master Thesis

Differential Robot for Table Surfaces Disinfection using Hi-NW Technology

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July 2, 2019

Declaration of Authorship

I, Daniel Rodríguez Criado, declare that this thesis titled, " DIFFERENTIAL ROBOT FOR TABLE SURFACES DISINFECTION USING HI-NW TECHNOLOGY" and the work presented in it are my own. I confirm that:

- This work was done wholly or mainly while in candidature for a research degree at this University.

- Where any part of this thesis has previously been submitted for a degree or any other qualification at this University or any other institution, this has been clearly stated.

- Where I have consulted the published work of others, this is always clearly attributed.

- Where I have quoted from the work of others, the source is always given. With the exception of such quotations, this thesis is entirely my own work.

- I have acknowledged all main sources of help.

- Where the thesis is based on work done by myself jointly with others, I have made clear exactly what was done by others and what I have contributed myself.

Signed:

Date: July 2, 2019

Acknowledgements

Abstract

UNIVERSIDAD DE MÁLAGA

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA DE
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Tecnología Electrónica

Master en Sistemas Electrónicos para Entornos Inteligentes

**Differential Robot for Table Surfaces Disinfection using Hi-NW
Technology**

by Daniel Rodríguez Criado

Recently, there has been significant concern regarding the widespread proliferation of biological hazards and thus, it is necessary to adapt novel solutions to this matter. This project has developed a differential robot for simultaneously performing automatic cleaning and disinfection on table surfaces. This system has a body with two motion wheels and a castor wheel what allows it to move in any direction. Also included are IR sensors to detect the edges of the table, and an obstacle detecting sensor facing forward for detecting an object located ahead of its travelling direction. The microcontroller system located within the robot controls all of its movements, which allows for a safe path to be navigated on the table surface when combined with the mentioned sensors. The disinfection system is made up of three LEDs (two blue light sources and one UV emitter) that eliminate pathogens or microbes from the irradiated surface. Finally, the robot includes a broom at the rear in order to sweep the dust and waste from the table.

Abbreviations

Hi-NW	Hight intensity-Narrow Wavelength
PCB	Printed Circuit Board
CAD	Computer-Aided Design
CAM	Computer-Aided Manufacturing
CBE	Chemical and Biological Egineering
HKUST	Hong Kong University of Science and Technology
UMA	Universidad de Málaga
UV	Ultra Violet
UVC	Ultra Violet C
UVGI	Ultraviolet germicidal irradiation
HAI	Hospital Acquired Infections
LED	Light Emitting Diode
IR	Infra-Red
PLA	Poly-Lactic Acid
RGB	Red, Green and Blue colour mode
BLE	Bluetooth Low Energy
RISC	Reduced Instruction Set Computer
DC	Direct Current
ADC	Analog to Digital Converter

LiPo	Lithium Polymer
LiIon	Lithium-Ion
PSD	Position sensitive device
I/O	Input/Output
MCU	fMicro Controller Unit

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Part I

Introduction

Introduction and general vision

Contents

Synopsis

This is an initial chapter that will explain the way to understand and navigate through this document and also a brief description of the content and the purpose of the project.

In goals section you can find the main aim of the project broken down in different objectives to be achieved.

The term "state of the art" refers to the highest level of general development, as of a device, technique, or scientific field achieved at the particular time when the project is made.

Fields of knowledge section is focused on the different technologies and researching fields used to carry out this master final thesis. It also describes procedures and guidelines followed during the project.

At the end,there is the memory organization that describes the chapters, appendix and additional information and the content that you can find in each of them.

Goals

The main purpose of the present work is to design and create a little differential robot that is able to disinfect flat surfaces[1] using Hi-NW technology. This robot must be able to avoid edges and objects located ahead of its travelling direction. For this reason, it must include sensors and actuators in order to interact with its surrounding environment. This principal aim can be achieved by resolving the following objectives:

1 First step is the seek of information about related works in order to set a background for the development of the project. This searching also include the state of the art of this kind of technology.

2 Design of different test benches in order to check the right working mode of the different components.

3 Then, the design of the robot is started. This must be carried out in different steps or smaller objectives:

- Study of the control systems that must be applied to the robot.
- Design of the electronic system consisting of the controller, sensors and actuators, battery and the connections among all components using a customized PCB.
- Design and manufacture of the robot's body using CAD and CAM software. The pieces of the robot will be printed using a 3D printer.
- Design and implementation of the microcontroller firmware.

4 Some additional features are proposed for the final design such as:

- A friendly appearance to make it attractive for commercialization. Try to make it as small as possible.
- Wireless connection with a smart-phone in order to control different functionalities and states of the robot.
- Addition of special sensors to interact with users such as a microphone for voice commands recognition or illumination sensors that detect if the lights of the room are on or off.

At the end of this document, there is a chapter of conclusions and future work III that explain the objectives achieved from the ones of above and which ones will be proposed for future work.

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[1]It has been designed mainly for tables but can be tested in other flat surfaces.

State of the art

Before starting to solve the problem, it is important to see what has been done before and what are ideas that could be worked with. This project starts as an application of Ni-NW technology in an small robot for the disinfection and cleaning of flat surfaces such as tables. High intensity narrow wavelength method has been studied and successfully implemented by Chemical and Biological Engineering (CBE) department in Hong Kong University of Science and Technology (HKUST) in previous works [23] under the supervision of professor King Lun Yeung. In the same department have been carried out several projects of different applications, for example, a hand-held device and a *Deebot* accessory with UV and blue lights, developed in [15].

This project has been developed within the environment of a robotic team in CBE department composed by four mechatronics engineers and supervised by professor Yeung. All the members of this team have made similar works concerning robots that include the light disinfection technology. The main researching lines of this group has been: a robot for vertical surfaces, another one for soft surfaces, an Android application for the disinfection of the smart-phone screen and the one developed in this work.

In the next two subsections we will talk about the disinfection technology and the market environment of similar products.

Light disinfection technology and Hi-NW

Recently, there has been significant concern regarding the widespread proliferation of biological hazards and Hospital Acquired Infections (HAI) specially in intensive care units. That is a major cause of morbidity and mortality worldwide affecting to hundreds of millions of patients each year [19]. For this reason, there are many studies about developing new disinfection and effective techniques for disinfections. Nowadays, researching in non-invasive methods using light for disinfection are getting more popular.

UV light has been used for germicidal purposes since it was discovered by Arthur Downes and Thomas P. Blunt in 1878 when they published a paper describing the sterilization of bacteria exposed to short-wavelength light [6]. From now on, the references to this disinfection method will be Ultravilolet Germicidal Irradiation (UVGI). The first evidences of this application in health care, date from 1903 when Niels Finsen was awarded with the Novel Price for medicine for his work using UV light against lupus vulgaris, tuberculosis of the skin [22]. Since then, UVGI has

been used for air and water disinfection, waste-water treatment, food and beverage protection and it is widely included in biological laboratory hygiene. However, the efficiency of UVGI depend of the penetration of this radiation into the cell in order to reach its DNA, for this reason the Hi-NW is developed and it will be explained hereunder.

It isn't within the scope of the project the understanding of UVGI technology. Nevertheless, it is necessary a brief description of how it works in order to introduce the Hi-NW technology. UV light has a big spectrum between 10nm and 400nm but in this project the range used for disinfection is the denominated UV type C (UVC) with a wavelength between 100nm and 280nm that is considered as germicidal, specially the range between 260nm-270nm. This radiation can break molecular bonds within microorganismal DNA, producing thymine dimers that leads to the cell death or inactivation. In figure 1, you can see an scheme of that process.
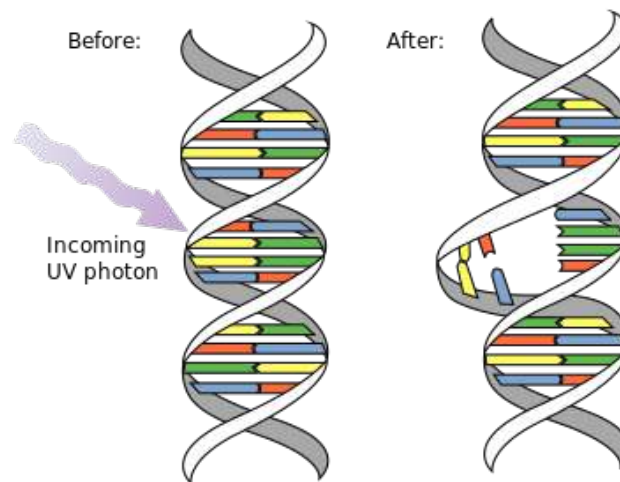
Figure 1: Formation of thymine dimer lesion in DNA.[2]

On the other hand, there are several studies about the use of visible violet-blue light in the range of 400nm to 500nm of wavelength as bactericidal technique. For example, in [12] is carried out an experiment that consist in exposing *staphylococcus aureus* and *escherichia coli* bacteria to light radiation in that range of wavelengths in increments of 5nm each time. The experiment concludes that there is a significantly inactivation of this bacteria cells in the range of 400nm-420nm with a maximum in 415nm. It also affirm that each bacteria is more sensitive to different wavelength radiation. Cell exposure to these wavelengths light causes the photoexcitation of porphyrin molecules, which leads to the production of Reactive Oxigen

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[2]https://en.wikipedia.org/wiki/Pyrimidine_dimer

Species (ROS) inside the cells, causing oxidative damage to the cell membrane and consequently the cell death [7].

Finally, high-intensity narrow-wavelength (Hi-NW) technique is a genuine method of killing bacteria using a combination of UV and visible blue light mentioned before. It is proven that the mixing of this two radiation have a better performance. As mentioned before, this has been investigated in CBE department in HKUST. In this final master thesis, the technology developed in [15] will be added to the robot for a real application in flat surfaces. In particular, this method uses the combination of three different lights: 405 nm, UVC (270 nm) and 470 nm. The visible light waken the cell membrane and thus, UVC radiation can easily hit the DNA and kill the bacteria. This process is represented in 2.
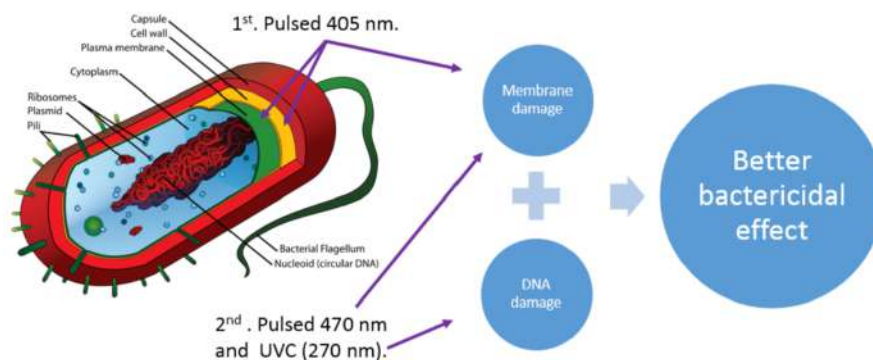
Figure 2: Lightning system mechanism over a eukaryotic cell. *Source:[15].*

In current times, there has been a big progress regarding the miniaturization of light emitting diodes (LED) technology. They also allow to emit light in many different wavelengths of the visible and invisible spectrum. At the beginnings, UGVI was produced by mercury lams which needed a feeding period before being used and they reached extremely high temperatures, besides the toxicity of the mercury. Nowadays, the same results can be achieve with LED technology as small as it can be seen in 3. This light emitters can give the same power or even more reaching less temperatures and with a reduced size what is ideal for this project.
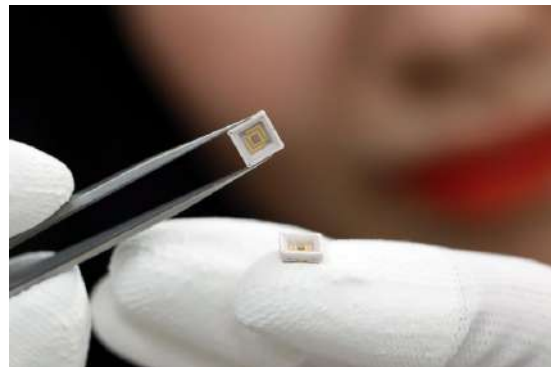
Figure 3: UV-C LED of 100 W

Robot technology

After a previous research about what kind of robot would fit better for the project purpose, it has been found that the differential robot are used for most of these kind of applications. Their functionality is easy to understand and they only include two wheels with motors and one castor wheel just as a support. One of the most important requirements for this project is the reduced size and this can be made with the differential mechanism due to its simplicity.

For mentioned reasons, differential paradigm is widely used in many applications specially for robots that are able to follow a path avoiding obstacles. It is possible to see an example in [11], here, it is developed a reduced size robot that is able to detect and avoid obstacles and cliffs using infra-red (IR) and sonar sensors. Furthermore, it has been done a research about the situation of commercial small robots that includes several sensors embedded for the detection of obstacles or lines underneath. Hereunder, it is shown three robots that will help as inspiration for this project:

- **Ozobot**[3]**:** This robot is capable to follow a drawn line in a flat surface. It can also differentiate among several colours and undertake different task depending of the color code. In principle, the colour recognition is not interesting for this project. Nevertheless, it is one of the smallest robot in the market and as mentioned before, that is a main goal to achieve.

Figure 4: Ozobot differential robot.

- **Ringo 2 Robot**[4]**:** It is an Arduino based, hackable, open source robot. Includes programmer hardware directly on the robot so no external programmer

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[3]You can find the reference in: `https://ozobot.com`
[4]You can find the reference in: `http://www.plumgeek.com`

or ribbon cable is required. This robot includes a big amount of sensor in a reduced space witch can give some ideas for the implement it in the project of the disinfection robot for tables.

Figure 5: Ringo robot version 2 with remote control.

- **Vortex**[5]**:** This is also an Arduino based and programmable robot made as a toy for kids. That is the one with the biggest size of the three mentioned robots, though, it is small enough to fit the project requirements. The interesting characteristic of this robot is the skill to recognize nearly objects with a proximity sensor.

Figure 6: Pair of Vortex robot.

All these robots have been disassembled during the project in order to perform reverse engineering and take some ideas for the robot of this project. Although, any part of the design of the robots has been copied.

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[5]You can find the reference in: `https://www.dfrobot.com/product-1314.html`

Material and methods

This project cover several technical and scientific fields. Making and designing a robot require the knowledge of the new technologies. Nowadays, this process is easier due to the computer assisted design and manufacturing (CAD and CAM) and rapid prototyping machines. Moreover, the size reduction of the electronic components allow the integration of more and more functionalities of a particular device. Hence, the three main disciplines of this project are the electronic, design and mechanical engendering.

Two prototypes has been developed during this final thesis, adding more features and improvements to the second one. For the design of the body of these prototypes it has been used the 3D printer *Ultimaker 3* that is shown in 7. The material used for printing the pieces has been polylactic acid (PLA), this is a biodegradable and bioactive thermoplastic derived from renewable resources. After solidify, this material has the enough strength and resistance to fulfil all the requirements of the project.
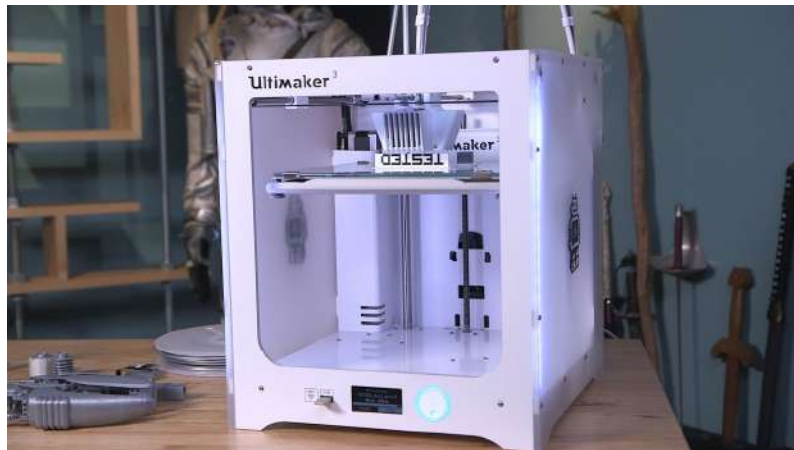
Figure 7: 3D printer Ultimaker 3.[6]

On the other hand, talking about the electronic part, the different components have been purchased from electronic companies that will be duly referenced in next sections. For the connection among the electronic parts, a custom printed board (PCB) has been designed in this project for the second prototype of the robot. For the first prototype, the connections have been done with a prototyping board.

CAD software used for the design of the body parts is *Fusion360* and *Eagle* for

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[6]Reference for these device and CURA software: `https://ultimaker.com/en/products/ultimaker-3`

the PCB design, both applications from Autodesk.[7] Must be also mentioned, that *CURA* is the CAM software used by this particular 3D printer. You can find more information about this software in its website. It is really intuitive and easy to use.
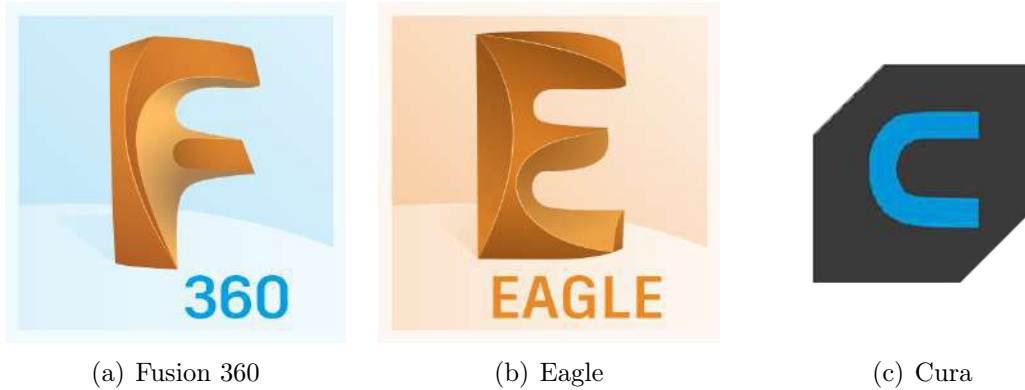
(a) Fusion 360   (b) Eagle   (c) Cura

Figure 8: Software used for design and manufacturing.

Finally, about the methods used to do this project, every subsystem of the robot has been design, tested and finally implemented in this robot. During this document, these three stages are explained in different chapters. There is a final chapter where is explained all the test carried out during the project.
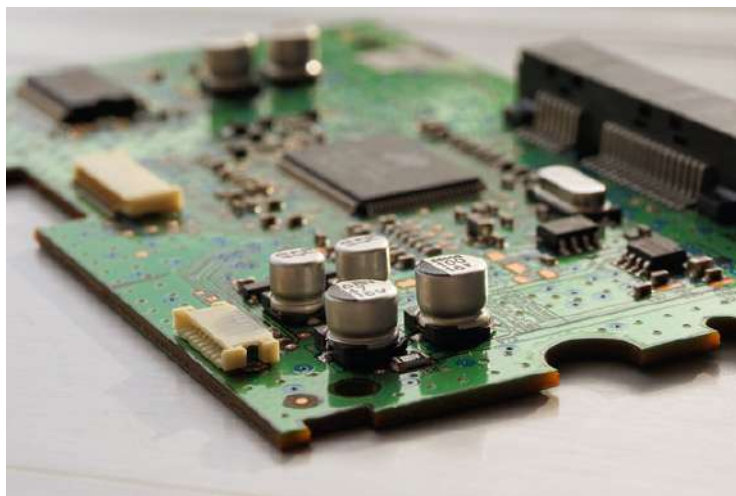
Figure 9: Example of a PCB.

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[7]You can find information about these two software form the website of Autodesk: `https://www.autodesk.eu`

Memory Organization

This section is necessary for the proper navigation through the document and it gives a better understanding of the structure. This work is divided in three main parts:

- **Part I:** This first part is an introduction that give a context for the situation of the project and the goals to be achieved.

- **Part II:** This part contain the bulk of the information about how the robot is made and design.

- **Part III:** In this final part you can find the results and conclusions. Besides, what is proposed for future work and with goals have been achieved.

Due to the second part is the most important, here under, the chapters of the memory will be briefly explained one by one:

- **Chapter 1:** In this first chapter, there is an analysis of the technology and the structure of the robot. What materials and components will be required and

- **Chapter 2:** In this one, it will be solved the problem concerning to the kind of sensors used for the obstacle and cliff avoidance.

- **Chapter 3:** This chapter describe de process of selection and design of each electronic component of the robot and the connection among all of them.

- **Chapter 4:** This one shows how the robot body is design and how all the components are mounted and placed in it.

- **Chapter 5:** Here will be detailed the algorithm used for control the functionality of the robot.

- **Chapter 6:** All the test performed during the developing of the project are explained in this chapter.

At then end of this document there is an appendix part were are included all the electronic and robot planes, the programming code and the budget of the project.

Part II

Content of the project

Chapter 1

Previous research

Contents

Synopsis

This chapter tells about a previous analysis of the work to do. It will briefly explain how the differential robot works. Furthermore, the similar robot mentioned in the introduction will be analysed in order to have a background of this kind of technology and what are the most common electronic components used for this applications.

At the end, there is a conclusion section where is introduced the technology that will be used in the robot based on this previous research. The analysis of the robots made in this section, has been carried out taking the needed information from their websites.

1.1   The differential drive robot

As mentioned previously, the differential robot seems to be the easiest and most interesting design for this kind of application. It is based in two active wheels and one passive that can turn in any direction. This allows the robot to rotate about itself, which is necessary in order to achieve a fast movement response to reach all the corners of the table. Furthermore, one of the most important advantages of this kind of robots is the simplicity of its kinematic equations. That allows to know the position of the robot in each instant of time if the speed of the motors is known and in absence of slippage. This might be necessary to implement a navigation algorithm because, it is mandatory to know the position of the robot in each instant of time.
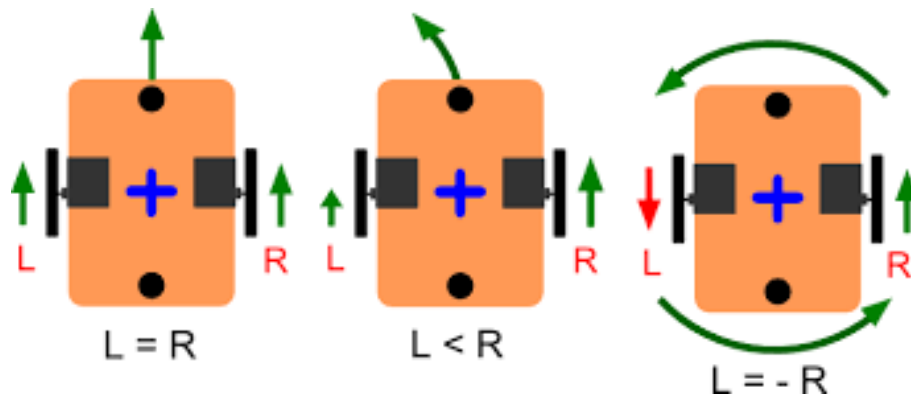
Figure 1.1: How the differential robot works.

In figure 1.1, it is possible to see the different movement possibilities, this can be achieve with the difference between the velocity vector of the two actives wheels:

- Robot will move straight, forward or backward, when both wheels are spinning at the same speed and in the same direction.

- To make the robot turn in one or the other direction, both wheels have to spin in the same way but with different speeds. The robot would turn to the direction of the slowest wheel. Thus, for example, if the right wheel is spinning faster than the left one, the robot will turn left.

- If the two wheels are spinning with the same speed, but in opposite directions, the robot will rotate in place, spinning around the midpoint between the two wheels.

As you can see, a lot of possibilities of movement can be accomplish by this robot. This allow the robot to adapt to any table shape.

1.2 Analysis of similar robot in the market.

For this analysis, all the robot mentioned in the presentation will be disassembled and studied in order to determine their components. That is a work of reverse engineering and nothing of what isn't published in the documentation of the robots will be revealed here.

1.2.1 Disassembling of the Vortex robot.

Along this section, you can see the different step to disassemble the Vortex robot. This doesn't pretend to be a manual of disassembling, so this process won't be fully detailed.

In 1.2 it is possible to see two images of the robots in different play modes. In 1.2a you can see them playing football, both are controlled remotely by a smartphone app that allow the user to totally control the movements of the robots. On the other hand, in 1.2b the robots are in the sumo mode. This mode can be also activated from the same application. However, in that case, the robots are not controlled by the user but they use their sensor to find the other one and push it out of the circle. All of this behaviour is stand alone, what means that the robot can be autonomous and make its own decisions what is interesting for implementing in the final robot of this project.

All the photos and information from [5] that is the website of the manufacturing company (DFRobot).

(a) Playing football.   (b) Sumo mode.

Figure 1.2: Different play modes of *Vortex* robot.

The first step was to remove the top cover of the robot. It is just fixed with magnets and can be easily remove with the hand as shown in the figure 1.3:

Figure 1.3: Robot without top cover.

Once the top cover is removed, the battery and the programming connections can be accessed. The robot use four alkaline normal batteries that can be changed whenever they run out of energy by removing the lid manually. The programming connectors are in the back of the robot and the lid must be remove by unscrewing it. In figure 1.4b the connectors are shown. The main one is the micro USB connector which allow to access the microcontroller from the computer and program it. The normal user is supposed to disassemble the robot just until this point.
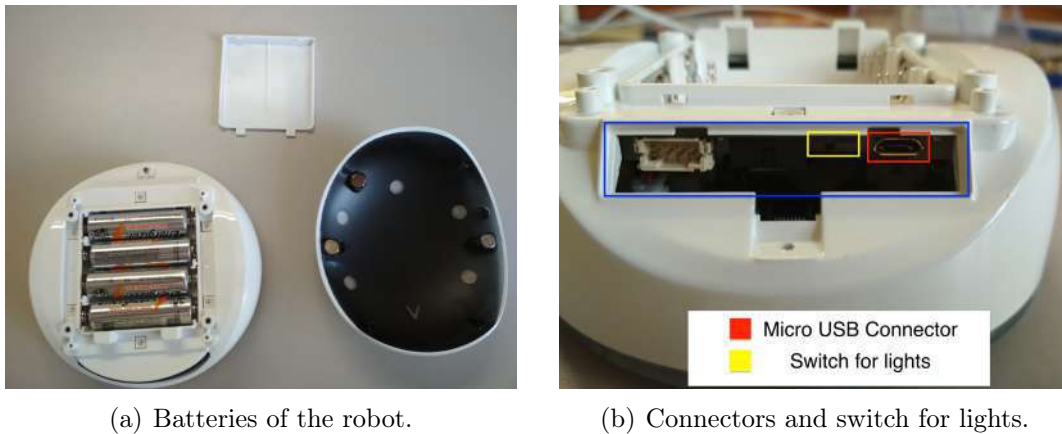
(a) Batteries of the robot.

(b) Connectors and switch for lights.

Figure 1.4: Connections and batteries of the robot.

Next is to remove the bottom cover of the robot. For this, it is necessary to

remove four screws and disconnect the speaker from the main PCB. In figure 1.5a
it is shown the bottom view of the robot and the IR sensors are circled. In 1.5b the
lid has already been removed and it is possible to see the main electronic board of
the system and the connection with the speaker that is in the cover. Bolted with
the board, there are two castor wheels in order to give the robot all the degrees of
freedom in the movement plane.
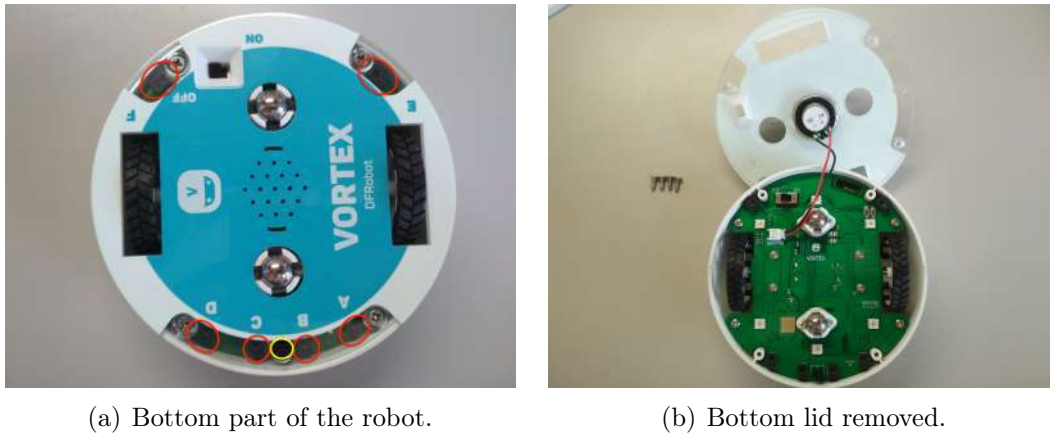
(a) Bottom part of the robot.   (b) Bottom lid removed.

Figure 1.5: Removing the bottom cover.

Finally, to complete disassemble the robot, it is necessary to remove the four
screws that fasten the electronic board to the plastic case. That can be seen in the
next picture:
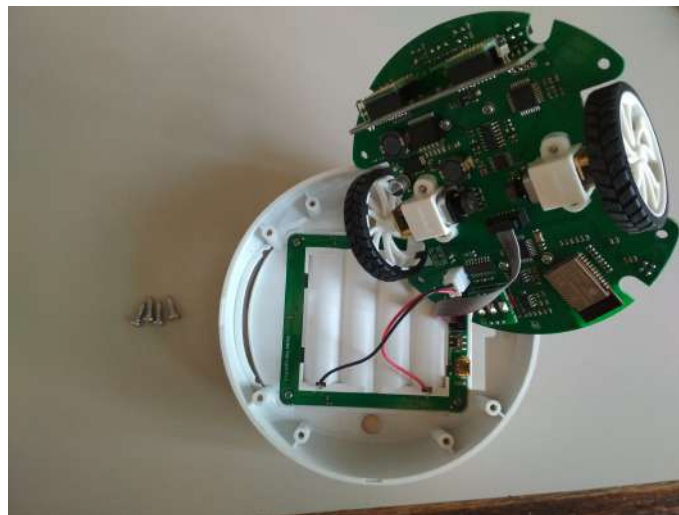
Figure 1.6: Removing the electronic board out of its case.

In 1.6 is shown the disassembling of the electronic boards. It is connected to another board with two buses. On the one hand, there are a black and a red wire that is connected to the battery and supply power to the board. On the other hand, the other bus used to send the information to the board from the connectors placed in the other one, that is the information bus. The little board that contains the connectors and the batteries is also removable but it is not necessary for this analysis.

Robot components

As shown in the previous section, the robot is easily demountable. Now, the main components of it will be commented. In the figure 1.7, taken from [5], you can see a summary of all the components.

CPU:	Atmega 328
Size:	120x120x64mm
Power:	4xAA Battery
Duration:	40-90 mins
Ground Clearance:	3mm
Light:	12 Independent RGB LED
Display:	32 Vivid Eye Expressions
Communication:	Bluetooth 4.0/USB/I2C
Sensor:	2 Infrared Proximity Sensors
	2 Encoders/Speed Control
	6 Ground/Line Following Sensors
Sound:	MP3 Sound Player with 8M Memory (Customizable)
Support Software:	Arduino IDE/WhenDo/Ardublock/Scratch
Expandability:	Temperature, Sound, Accelerometer, GYRO, Ultrasonic, Touch sensors and much more via I2C socket

Figure 1.7: Main electronic characteristics and components of the robot.

Main electronic board

The most important part of the robot is the main electronic board (PCB) located in the middle of it. Its function is both connect and control all the electronic devices and serve as fastener structure of the robot. The "brain" of this board is the microcontroller *Atmel ATMega328* that is the same one used in Arduino UNO board and it is a really often used microcontroller for this kind of application. This will be the controller used in the final robot of this master thesis, its characteristics will be detailed in the electronic chapter.

Figure 1.8a shows the main PCB of the robot whereas the 1.8b zoom in to see the microcontroller that is circled in yellow. As it is possible to see, surrounding the microcontroller there are several resistors, condensers and integrated circuits that work as peripheral supply as indicated in the data-sheet of *ATMega328*.
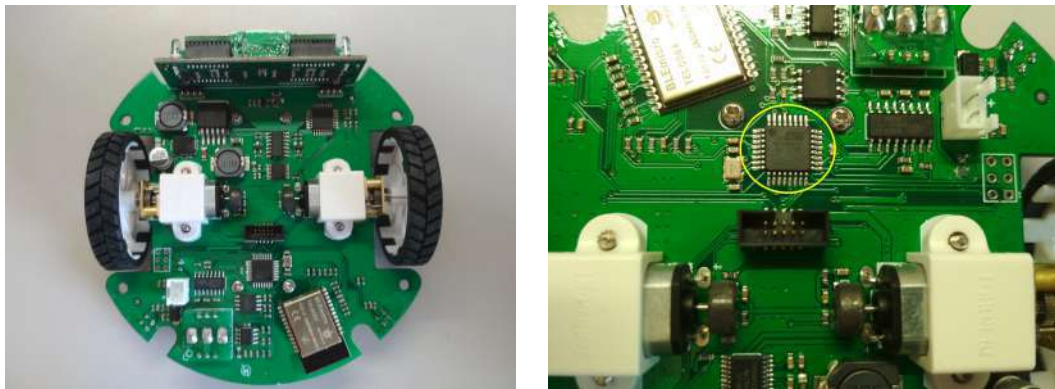
(a) Top view of the electronic board.   (b) Microprocessor.

Figure 1.8: Main electronic board and microprocessor.

This board also include a Bluetooth module in order to connect with a smart device such as a table or a smart phone. Thus, the robot can be controlled remotely. That is one of the additional features that want to be added to the robot developed in the present work as is mentioned in the goals section.

Robot motors

Since it is a differential robot, Vortex has two motors in the same axe and the wheel directions are parallel. This motors are directly welded and bolted with braces to the electronic board. Both of them have a counterweight to reduce the vibration and they are also serve as reference for the encoders. This device will be explained in the next subsection.

This motors include their own gear train to reduce the speed and increase the torque. Their size are quite small, taking into account that they have a reduction system. For this reason, it is a great option for be used in the robot of this project. Figure 1.9 shows how are the motors fixed to the PCB.
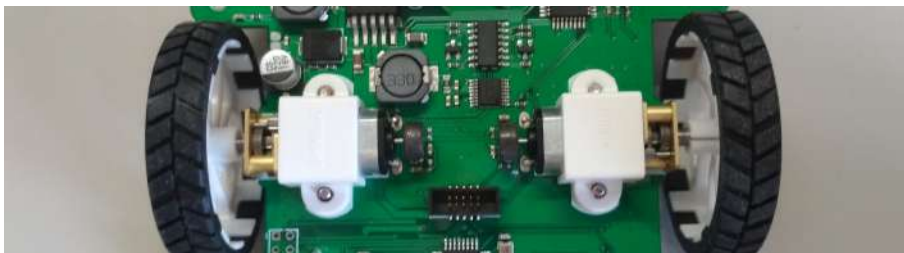
Figure 1.9: Motors of the robot.

Sensors and actuators

As shown in 1.7 the robot has six ground/line following sensors, two infrared proximity sensors and two encoders/speed sensors. Down below, each one is explained.
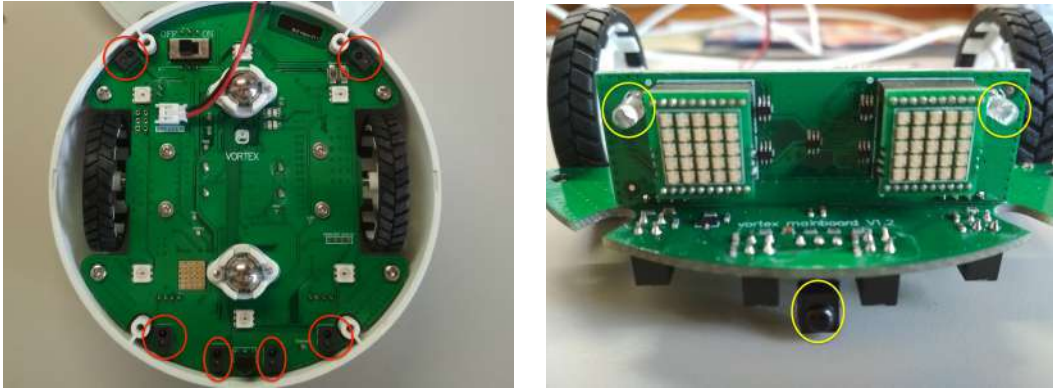
(a) Bottom view of the electronic board.   (b) View of the "face" of the robot.

Figure 1.10: View of the sensors included in the robot.

- **Infra-red proximity sensors:** They are circled in yellow in 1.10b. The robot use it to detect objects in front of it.

- **Encoders:** They are sensors integrated in the motors for measuring the turn speed. Thus, the robot can either detect if an user is pushing it with the hand and forcing it to move or if the motors are forced to stop, for example when the robot is stuck in front of an object.

- **Ground/line following sensors:** They are circled in red in 1.10a. The robot used it for follow lines or detect edges. They also use infra-red technology.

1.2.2 Ringo robot 2

Before start the analysis it has to be mentioned that all the photos and information in this section has been taken from the website of the supplier (Plum Geek Robotics)[18]. Everything is at sight in this robot so there is no need to disassemble it. In 1.11 there are some images of different views of that robot. Next, the main characteristics and components of Ringo robot are explained. This is the robot out of the three ones that have more variety and number of sensors. It is design for table surfaces what makes it attractive for this project.
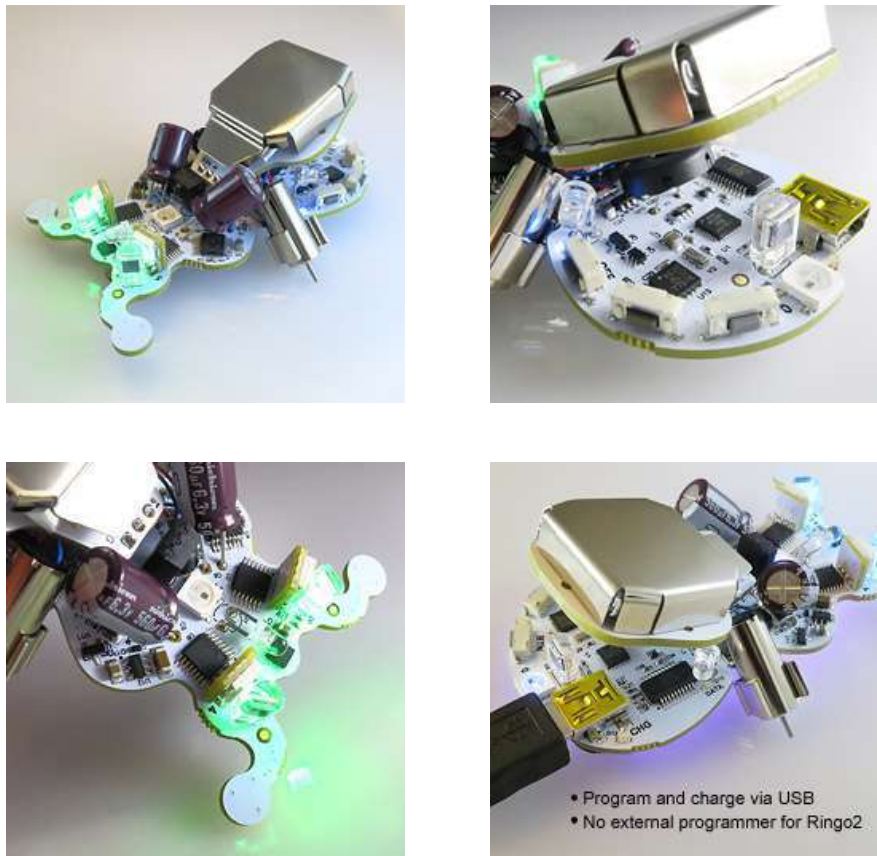
Figure 1.11: Different views of Ringo 2 robot.

- **Based on Arduino UNO:** Like Vortex robot, Ringo uses the same microprocessor as the Arduino UNO, this allows to use the same programming IDE used tu program Arduino boards.

- **3-Axis Accelerometer:** This sensor can measure and detect movement in all threw axes of the space as well as the orientation. It can also detect vibrations

on the table what is useful for interaction with people. It can be used to know the acceleration and velocity of the robot, hence the distant that the robot travel.

- **3-Axis Gyroscope:** A gyroscope is able to determine the rotation in the tree axes. Can be used to determine which direction Ringo is facing. Although, the most interesting axe is the flat one because is where the robot will move.

- **Six RGB LEDs:** This si an additional feature to give it a more friendly appearance. The colour of the LEDs can be programmed.

- **Sound Element:** That is another additional functionality to give some personality to the robot.The piezo-material sound element can create any sort of pings, tones, and chrips you can think of.

- **Light Sensors:** This robot includes three of these sensors capable of measure the ambient light. Interesting for the interaction with the users.

- **Infrared Light Sources:** As Vortex robot, Ringo use IR sensors for the detection of objects located ahead of its travelling direction. However, these sensors can be also used in this robot as a wireless input and output comunication. For example, it is possible to control Ringo bot with a TV remote.

- **Edge Sensors:** This robot also use the IR technology for edge detection and avoidance. They are situated under each of Ringo's feelers and also at the rear of Ringo.

- **Pager Motors:** The tips of the motors contact the running surface, allowing Ringo to skate around the table. Both motors can be controlled independently. They can run forward or backward at variable speed with the configuration of differential drive.

1.2.3 Disassembling the Ozobot robot.

In this section, the disassembling of the *Ozobot* robot has been accomplished. As in previous sections, most of the information required for this analysis is take from the supplier [17]. In 1.12 you can see both the top and the bottom side of the robot while it is switched on. First of all, it has to be mentioned that the attractive characteristic of this robot is that is one of the smallest in the market. In the bottom view (1.12b) it is possible to appreciate the five LEDs that the robot use for following the lines and will be described below.

(a) Top view.

(b) Botton view.

Figure 1.12: Different views of the *Ozobot* robot.

The first step was to remove the top cover of the robot. It use a little screw in the back part to fix the cover. Once you remove that scree the robot looks like in the figure 1.13:

Figure 1.13: Robot without top cover.

Next step is to disassemble the electronic board which use two screws to fix it to the body structure. Once the PCB is unlocked it is possible to notice the different connections as shown in figure 1.14a.

(a) Wire connections.

(b) Components of the robot.
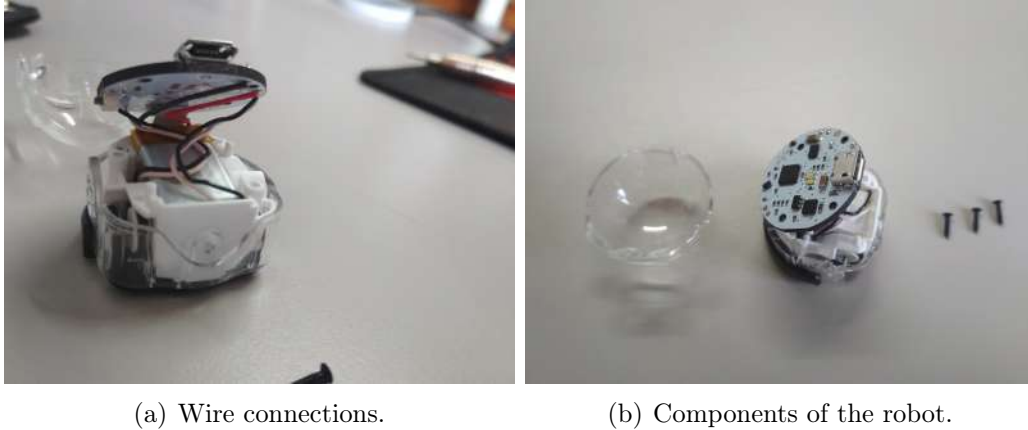
Figure 1.14: Disassembling the electronic board.

There are three pair of wires and an array of wires to connect the LEDs with the PCB. The red and black pair is used for the power supply from the battery, on the other hand, the black and white pairs are used for power and control the two motors of the robot.

(a) All the components.

(b) Completely disassembled.
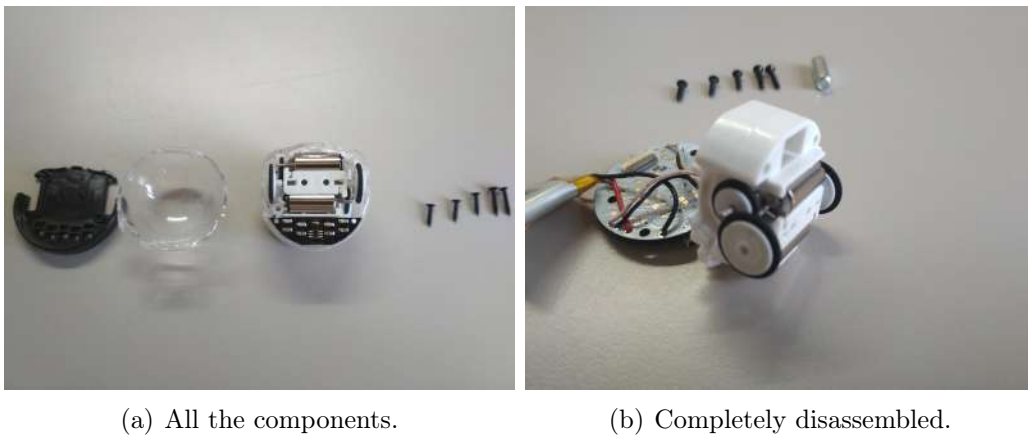
Figure 1.15: Removing the bottom cover.

Next is to remove the bottom cover of the robot. For this, it is necessary to remove two screws and the disconnect the LEDs board from the main PCB. In figure 1.15 you can see the result and the robot completely disassembled. Should be

mentioned, that the robot use a counterweight shown in 1.15b in order to remain the front part of the robot (LEDs board) close to the floor surface.

Robot's components

Once the robot is completely disassembled, it is time to describe the different components of it. A process of reverse engineering has been accomplished in order to try to determine how the robots works.

PCB components

The most important part of the robot is the main electronic board (PCB) located at the top of it. The other electronics components are directly connected to it as described previously. It also provides a micro USB connection to charge the battery and programme the microcontroller.

The microcontroller used in this robot is the *Atmel ATMega328* that is the same one used in Arduino UNO board and it is a really often used microcontroller for this kind of application.

Battery

The power supply of the robot is also a critical element in the design. It must be as small as possible and also have the enough capacity and energy to feed the motors and the disinfection LEDs. This robot use a single Li-Po cell with a capacity of 70 mAh. This provide the enough voltage for the microcontroller and the size is minimal as shown in figure refbattery. However, the power consumption of the disinfection LEDs is quite high consequently, a higher capacity will be needed for the final design battery.
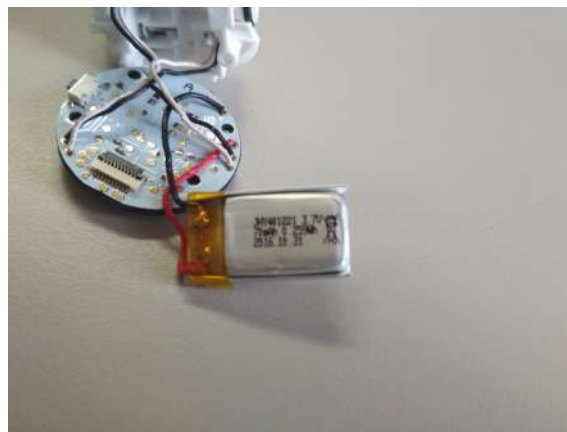
Figure 1.16: Robot's battery.

Line detection and rgb LEDs

The robot have an electronic board with five pairs of emitter and photoreceptor LEDs in the bottom part. It use that LEDs to detect a line drown in a surface and follow it. The central led is a rgb detector what means that can difference among colors (circled in red in the picture). The other ones (circled in blue), can differentiate between dark or light areas and in that way can follow a line. Two lines of sensors has been implemented in case the first line fail.

(a) LEDs board conection.   (b) Bottom view of the board.

Figure 1.17: Different views of LEDs electronic board.

Robot's motors

The main characteristic of the motors is the reduced size and the low consume. As shown in figure 1.18, they take the minimum possible space and use a little gear system to transfer the movement to the wheels.

Figure 1.18: Robot's motors.

1.3 Conclusions

After the previous analysis of these three robots, there are some conclusions that can be point out:

- All of the robots use the same microcontroller, Arudino based. This allows to use all the libraries from Arduino and the same programming interface.

- Most used technology is the infra-red one because the size is usually smaller than sensors for similar purposes. This question will be deeply studied in the next chapter.

- All robots use DC motors and usually is necessary to use a reduction gearbox. Motors used in Vortex robot includes their own gear reduction system what avoid a custom design of a gearbox for the robot of the present project.

Finally, it can be said that each robot hight light for one unique condition. The Ozobot robot is because its reduced size, the Vortex robot is its robustness and the geared motors and the Ringo 2 robot because of its variety of sensors. It is possible to take ideas for each one in order to build the first prototype of the disinfection robot for tables surfaces. The first approach may have a size between Ozobot and Vortex and step by step adding new sensors and features after testing each one.

Chapter 2

Obstacle and cliff detection problem

Contents

Synopsis

This chapter will solve the problem concerned to the kind of sensors used for the obstacle and cliff avoidance. It explains the current sensor technology used for solve this matters. To carry out this task, there will be a first classification of proximity sensors followed by an analysis of the problem to determine which technology fits better for the mentioned purpose.

It could be included in the electronic chapter but due to the extension of the problem, it has been decided that it must be written in a separate chapter.

2.1   Definition of the problem

As mentioned before, the final robot must be able to perceive two major characteristics from the surrounding environment. These are: the obstacles in its way and the edges of the table. There is an additional feature that is also explained here that is the dirty areas detection.

2.1.1   Object detection

Could be some obstacles in the table such as bottles of water, mugs, books, laptops or somebody's hand for example. The disinfection robot should be able to detect and evade all of this objects. For this reason it is necessary a sensor that can detect every type of material in the surroundings. In this chapter, it will be analysed what sort of technology could suit for this purpose. In the next video you can see a differential robot using a ultrasonic sensor to detect the obstacles in the distance: `https://www.youtube.com/watch?v=Zi0jvXwwdAQ`

2.1.2   Cliff detection

Since the robot is going to work over a table, it must be able to avoid the edges to not fall in the ground. The sensors that can be used for this function will be also analysed later. They must be looking downward and have a small size because they will be placed under the robot where the available space is reduced. The robot in the next video uses IR digital sensors for cliff detection: `https://www.youtube.com/watch?v=Da-y5ALE4vg`

2.1.3   Dirtier parts detection

The only technology that can accomplish that task is the photoelectric one. That is because optical sensors are the only ones that are colour sensitive. There are RGB colour sensors that can distinguish among the wavelengths of the different colours, however, it is possible to differentiate between dark and light areas with a simple IR sensor what it is probably enough for this application. This functionality will be implement in future versions of the robot, due to that, there is not a deep study of this kind of sensors in this document.

2.2   Classification of proximity sensors

The task of this section is to seek information about the different sensors that can works as proximity and edge detection system.

Firstly, it is necessary to carry out a preliminary sort of proximity sensors in order to clarify witch one can be useful for this kind of application. Hence, it is possible to find in the market this kind of sensors based on the classification made in [9]:

Inductive sensors

These sort of proximity sensors detect ferrous targets, normally it is use for steel plates or object thicker than one millimetre. They are based in the induction principle and consist of four components: a ferrite core with coils, an oscillator, a Schmitt trigger, and an output amplifier. It generate a magnetic field and when a ferrous object enter in this field a small induced current is generated in the object. Thus, the frequency of the oscillator change and that can be detected by the sensor. This devices are not attractive for the purpose of this project because the final robot should be able to detect obstacles made with any materials and not only ferrous ones.

Capacitive sensors

Capacitive proximity sensors can detect both metallic and non-metallic targets in powder, granulate, liquid, and solid form. The composition of this sensors is very similar to the inductive sensors. It have the same components but use two conduction plates at different potentials and the near materials change the capacitance of the system which is detected by a comparator electronic circuit (Schmitt trigger) and generate an output. The problems of this sensors is that the scope is too small. It has a really precise range from 3 to 60 mm but a larger ranger is needed for the robot of this project.

Photoelectric sensors

Mainly there are three types of photoelectric sensor for proximity detection: through beam, retro-reflective and diffuse. This three configurations will be explained in the next section. However, all photoelectric sensors consist of a few of basic components: each has an emitter light source (Light Emitting Diode, laser diode), a photodiode or phototransistor receiver to detect emitted light, and sup-

porting electronics designed to amplify and improve the quality of the receiver signal. The emitter, sometimes called the sender, transmits a beam of either visible or infra-red light to the detecting receiver.

This kind of technology usually has several problem with transparent surfaces because they are sensitive to light reflection. One of the main advantages of this sensor is the possibility of distinguish between different colour zones. That capability can be useful for dirtier zone detection of the table.

Ultrasonic sensors

Ultrasonic proximity sensors are used in many automated production processes. They employ sound waves to detect objects, so colour and transparency do not affect them (though extreme textures might). This makes them ideal for every kind of object detection.The most common configurations are the same as in photoelectric sensing: through beam, retro-reflective, and diffuse versions.

Bump sensor for cliff detection

The mechanism of this kind of sensor is very simple, it consist in a switch that when it is pushed, generate an output that can be either 0 or 1 depending of the configuration (pull-up or pull-down). This sensors can be used for contact detection in order to avoid obstacles and cliff detection. The possible solution will be analysed in conclusions section.

(a) Push button mechanism   (b) Commercial sensor
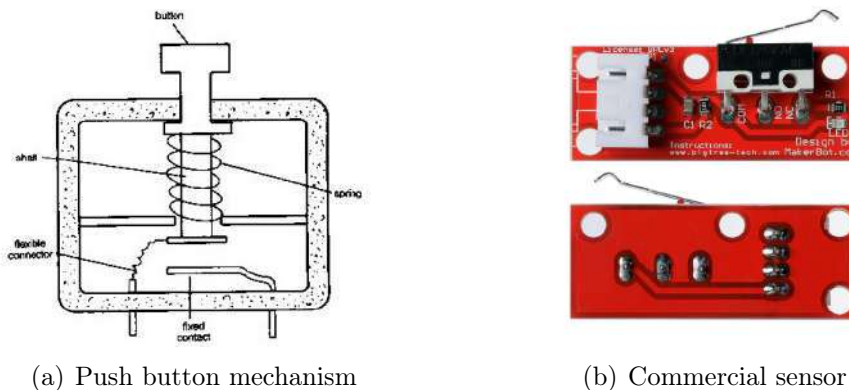
Figure 2.1: Bump sensor mechanism.

In 2.1 (a) it is possible to see the mechanism and in the 2.1 (b) there is an example of a commercial solution.

2.3   Ultrasonic and infrared technology

In view of the above, the most suitable technologies for proximity object detection for this project, are the photoelectric and ultrasonic sensors, in order to achieve the desired functionalities of the disinfection robot. For this reason, the will be deeper analysed in this section.

2.3.1   Different configurations

Firstly, it is necessary to explain the different configurations for ultrasonic and photoelectric sensors in order to chose the best one for this case. In 2.2 taken from [9], a scheme of how these different configurations work, for both technologies, are shown.
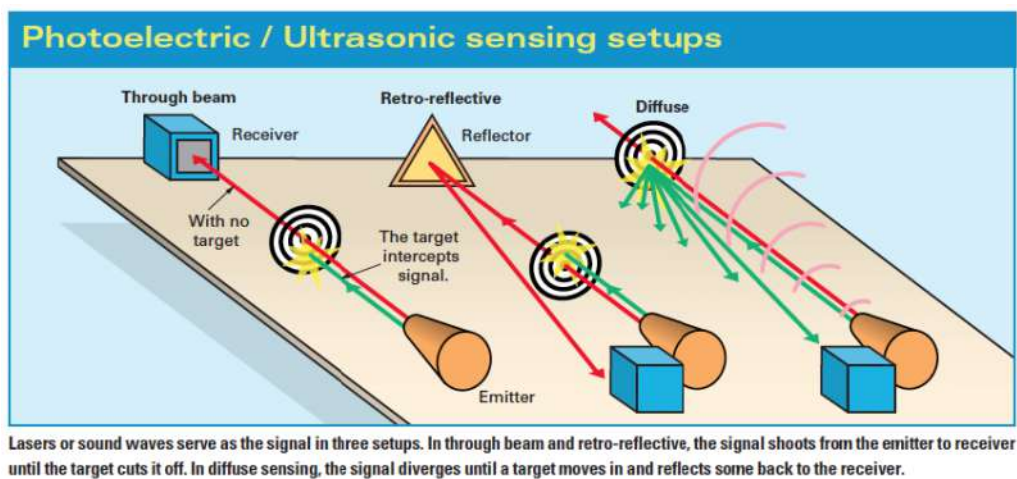
Figure 2.2: Different configurations for the ultrasonic and photoelectric sensors.

Each configuration will be explain hereunder:

- **Through beam:** This is the simplest and also the most reliable configuration. The emitter and receiver are in separated housing, the emitter provides a constant beam of light and detection occurs when an object passing between the two breaks the beam. This configuration is really often in security systems in the door of elevators. However, it is not suitable for mobile devices such as a robot, consequently, it is not a possible solution.

- **Retro-reflective (digital detectors):** The operation of this configuration is really similar to the though beam one. The only difference is that the emitter

and receiver are in the same housing. The emitter produces a laser, infrared, or visible light beam and projects it towards a specially designed reflector, which then deflects the beam back to the receiver. For this configuration the reflector must be at the same distance of the sensor, then, it can be used for cliff detection as it is explained in the next section.

- **Diffuse (analog rangers):** As in retro-reflective sensors, diffuse sensor emitters and receivers are located in the same housing. But the target acts as the reflector, so that detection is of light or sound waves reflected off the disturbance object. This method is aimed at distant measure applications. Using the angle of reflection in the case of photovoltaic technology and the response time in the case of ultrasonic sensor. This disposition can be used for distant object detection and it will be the chosen for this project.

2.3.2   Photoelectric and ultrasonic sensors comparison

A brief description of the operation mode of both sensors will be explained here. The operation mode of each sensor will be important for the way they are programmed and how the data from them are processed.

Infrared sensor operation

IR sensors can be classified mainly in two categories attending to their output: analogical rangers and digital detectors. The first ones are capable of measure the distance to an object. Whereas the second ones, provide a digital response, in other words, a hight or low signal depending if they detect or not an object.
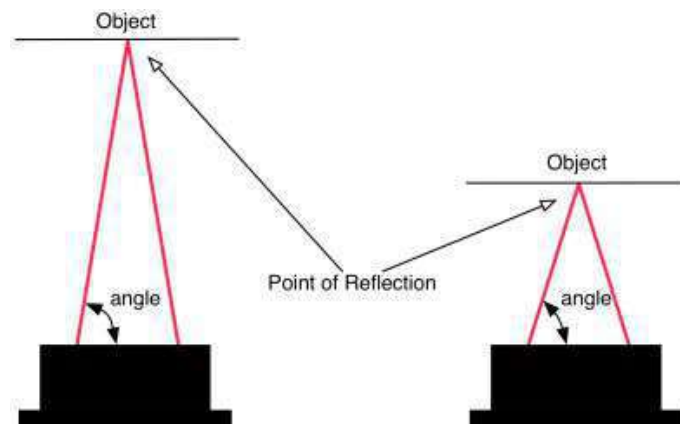
Figure 2.3: Operation of infrared ranging sensors. *Source: [1]*

Both of them use the diffuse configuration explained before, hence, they are able to detect object at different distances. Rangers use triangulation to calculate the distant to the object. For this, the sensor is composed of the emitter and a little array of photoreceptors. The triangulation process consist in a light beam sent by the emitter travels through the field of view and either hits an object or just keeps on going. If there is not an object ahead, the light will be never reflected and the sensor will not detect anything. On the other hand, if there is an object, it returns to the detector forming a triangle as shown in 2.3. Knowing the angle of reflection given by the array of sensors it is possible to compute the distant to the object.

On the other hand, infrared sensors with digital output will give a hight output just when any beam is reflected to the receptor, otherwise the output will be low.

Ultrasonic sensor operation

Ultrasonic diffuse proximity sensors employ a sonic transducer, which emits a series of sonic pulses, then listens for their return from the reflecting target. Once the reflected signal is received, the sensor signals an output to a control device. The distance to the object is computed based on the time-span between emitting the signal and receiving the echo.
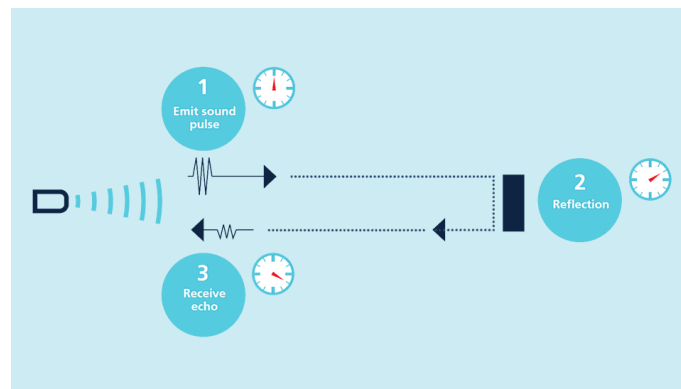
Figure 2.4: Operation of ultrasonic ranging sensors. *Source: [14]*

As the distance to an object is determined by measuring the time of flight and not by the intensity of the sound, ultrasonic sensors are excellent at suppressing background interference. Virtually all materials which reflect sound can be detected, regardless of their colour. Even transparent materials or thin foils represent no problem for an ultrasonic sensor.

Figure 2.4 shows a scheme of the operation of ultrasonic sensors.

Performance comparison

In [2] a performance analysis of HC-SR04 Ultrasonic Sensor and SHARP GP2Y0A21YKOF infrared sensor has been done with these materials as obstacles: Cardboard, Paper, Sponge, Wood, Plastic, Rubber and Tile. Table 2.1 shows the main characteristics of each sensor:

Table 2.1: Main characteristics of the sensors.

Parameters	IR sensor	Ultrasonic sensor
Range	10cm-80cm	2cm-10cm
Beam-width	75 Deg.	30 Deg
Beam Patern	Narrow (line)	Conical
Frecuency	353 THz	40 KHz
Unit Cost	750 INR	130 INR

The most interesting material for this project is wood because it is the material that most of the table are made of. Hence, figure 2.5 shows a graph with the results using a wooden object as target.
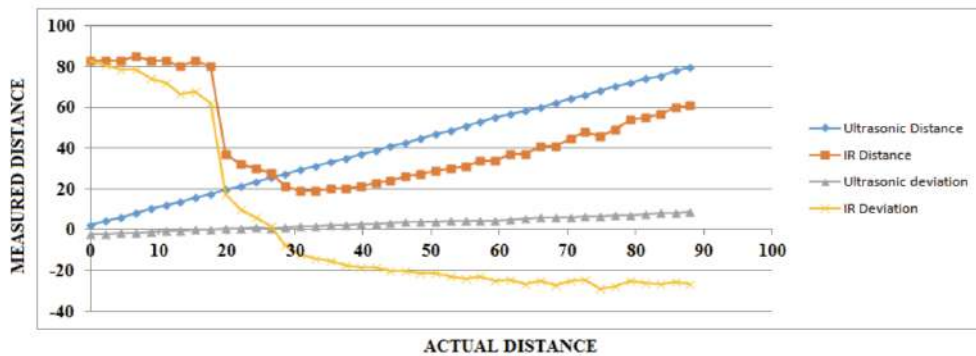
Figure 2.5: Performance comparison for obstacle material: Wood.

As it is possible to see, the results for ultrasonic sensor are better than the IR one. Both has a linear response from 30 cam and on. However, ultrasonic technology in that case is more accurate since a short range of distance. This is because, at lower range, the IR sensor reflection is taken for a large distance in this material.

In table 2.2 is possible to see the different results for all the materials used in the mentioned paper. The correlation coefficient (r) was estimated between measured and actual distance values as well as IR-US sensor readings for the analysis. The standard deviation parameter (for individual sensor data set) also considered, to check the consistency of the sensor measurement for a specific type of obstacle.

Table 2.2: Final table with the result of each material.

Material	Ultrasonic Sensor		Infrared Sensor		(r) (US-IR)
	Std. Dev	*r*	*Std. Dev*	*r*	
Cardboard	9.3	0.9879	10.6	0.91089	0.88424
Paper Sheet	37	0.2611	20.2	0.97866	0.20663
Sponge	5.8	0.9868	21.6	0.78774	0.72976
Wood	10	0.9999	36.5	-0.3291	-0.3285
Plastic	4.3	0.9995	25.1	0.78681	0.78767
Rubber	4.6	0.9988	58.3	0.90998	0.9216
Tile	11	0.9952	23.8	0.73032	0.73085

2.4 Conclusions

In conclusion, the ultrasonic sensor has better performance than infrared sensor in most of the materials for distant measurement. Paper sheet is the only material where infrared sensor get a better result and anyway it is similar to ultrasonic sensor result. However, it is important to take into account that for large ranges both sensors have similar performance. For this reason, either IR or ultrasonic technology can work as object detection in front of the robot.

On the other hand, for cliff detection, ultrasonic sensor is better in principle due to the lower range. Nevertheless, the output of the cliff detectors must be digital (cliff detected or not), so it doesn't matter the measured distance, hence, both sensors can be used.

Chapter 3

Electronic design

Contents

Synopsis

As its name indicate, this chapter describe de process of selection and design of each electronic component of the robot and the connection among all of them.

41

3.1   Microcontroller

The microcontroller is maybe, the most important element inside the robot, it may be said that is the brain of the robot. It coordinates and controls all the electronic subsystems in order to perform high level tasks.

A *Bluno Nano* board from *DFRobot*[1] company may suit for this project. The characteristics that make this board proper for this application, based on the goals specified in the introduction chapter are: the small size, the cheap price, the BLE (Bluetooth Low Energy) connection and that the microprocessor implemented in the board is the same one used in Arduino UNO board. This allow a easy programming and it is a known processor with a large background and documentation. In fact, it is used in all the robots analysed in the first section. BLE allows a wireless control of the devise and can be used to interact with the robot from a smart-phone or tablet device.

Figure 3.1a shows the *Bluno Nano* board and its size whereas Figure 3.1b shows the microprocesor used by *Arduino UNO* (Atmel ATMega328).
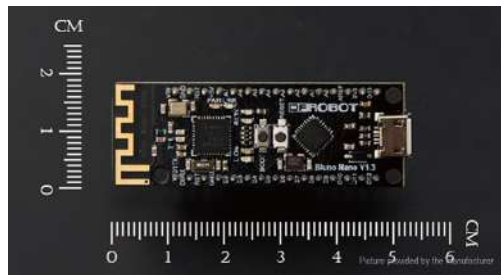
(a) Bluno Nano board.

(b) Atmel ATMega328 microcontroller.

Figure 3.1: Microcontroller and electronic used in this project.

The main and most interesting specification of this board are shown below, they have been taken from the website of the manufacturer (*DFRobot*):

- On-board BLE chip: TI CC2540.

- Transmission range: more than 20m.

- Wireless programming via BLE.

- Transparent communication through serial port.

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[1]More information in: `https://goo.gl/bCpWiP`

- Separated DC supply and USB powered.

- Microcontroller: Atmega328.

- Bootloader: Arduino UNO.

- Compatible with the Arduino Uno pin mapping.

- Size: 53mm x 19mm x 12 mm.

- Weight: 20g.

The electric characteristics are the same as *Arduino Nano* board[2] and the most important one for this project is the input voltage range: 7-12 V. This parameter is crucial for choosing the right battery.

It has to be taken into account some of the specifications of the microprocessor (Atmel ATMega328) as it will be useful for its programming. These characteristics has been taken from its data-sheet [4] and the most important ones are listed hereunder:

- **Advanced RISC Architecture:** It use the RISC processor instruction set, what is useful if it is necessary to program the microprocessor with assembly code.

- **Up to 20 MIPS Throughput at 20MHz:** This is the speed of the processor. It is enough to perform real time task such as detecting and avoidance of obstacles.

- **1KBytes EEPROM:** This memory can be useful if it is necessary to store any data received from the robot sensors.

- **Two 8-bit and one 16-bit Timer/Counter:** These peripherals components are very versatile and can be used for task such as: control of DC motors, control of LED illumination or control of periodic interruptions. Six PWM channels can be controlled with this timers.

- **ADC converters:** These are necessary to revive the data from sensors with analog output.

- **23 Programmable I/O Lines:** This feature allows to connect all the actuators and sensors implemented in the robot.

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[2]More information in: https://store.arduino.cc/arduino-nano

3.2 DC motors and drivers

From the analysis made in the first chapter and the tests performed in the last one it is possible to distinguish between two kind of motors. The first motors are the kind used in the Vortex robot which are bigger but includes their own gearbox, on the other hands, there are the kind of motors used in Ozobot and Ringo, they are very small but they need a custom gear system to reduce the rotation speed.

The test performed to this two motors shows that the bigger one need to be fed with a higher voltage and they consume a low current, while the other one have a high current consumption for low voltage levels. For this reason, besides the additional gear, this motors need a voltage regulator to be powered as opposed to the bigger motors that can be powered directly from the battery.

Taking into account all of the above, the bigger motors kind will be used for this project and it is proposed for future work the implementation of the small ones in order to reduce the size of the robot.

3.2.1 Motor specification

As to the details of the motor, the chosen option for the supplier has been *Pololu*.[3] They offer a wide variety of DC motors and electronic components. The model used in this project is the one shown in figure 3.2.

www.pololu.com

Figure 3.2: Pololu motor with gearbox included.

They come with their own mounting brackets to fix them to the design and also their own wheels. These elements will be shown in next chapter.

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[3]More information about its products in: `https://www.pololu.com`

Next are listed the most interesting specifications for this project that will be useful to integrate this element to the system:

- Gear ratio: 297:1

- Stall torque at 12V: 3.3 kg·cm

- No-load speed at 12V: 110 rpm

- No-load current at 12V: 0.06 A

- Stall current at 12V: 0.75 A

- Max output power: 1.0 W

- No-load speed at 6V: 55 rpm

- Stall torque at 6V: 1.7 kg·cm

This motor can be fed between 12V and 6V, although it is intended for operation at 12V, what is suitable for LiPo batteries with two cells (everything about batteries will be explained in next section). These batteries give an average voltage of 7.4 V.

The specification of the motor are given for 6V and 12V power supply, then the real behaviour will be between that two working modes. Hence, it will have a non-load speed between 110rpm and 55rpm but in any case it can be precisely controlled by a PWM signal generated by the microcontroller that will be explained in the programming chapter.

The final stall torque will be between 3.3Kg·cm and 1.7Kg·cm what is more than enough for this project because the robot will have two of these motors and the total weight of the robot won't be higher than 1Kg.

3.2.2   Motor driver

In order to control the direction and spinning speed of the motors, two different technologies will be combined. An H-bridge circuit is integrated in the motor driver, it helps to control the direction of the motors just with two microcontroller I/O pins for each motor (four pins in total), besides, this circuit also isolate the microcontroller from the power circuit to protect it from short circuit currents or any other accident. The other technology is the PWM signal that will be generated by the microcontroller in order to control the speed of the motors and it will be explained in chapter 5.

In figure 3.3b, it is possible to see the motor driver PCB that will be used in this project. The used model is *DRV8833* from Pololu supplier, the same one implemented in Vortex robot. Searching in the data-sheet of this driver [8], it is possible to determinate how the connection must be made with the battery, the motors and the microcontroller. Figure 3.3a shows a scheme of how the connections are made. This image is taken from the website of the supplier.

(a) Circuit schematic.

(b) DRV8833 Dual H-Bridge motor.
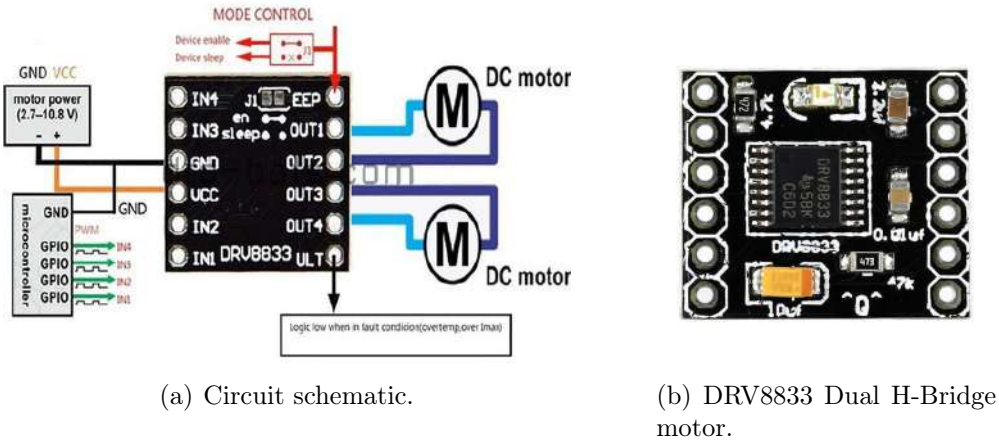
Figure 3.3: H-Bridge electronic circuit.

How the motor driver separate the control signal from the power supply? The behaviour of an H-Bridge is so simple. It uses four transistor in order to change the paths the current follow to feed the motors. In 3.4 you can see that the direction of the current through the motor changes when the signal in the transistor gates is different. Once it the motor will turn in one direction and then in the opposite one. This transistors also works as the isolation system mentioned before.

Figure 3.4: Working mode of an H-Bridge driver.[4]

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[4]Source of the image: http://www.modularcircuits.com/blog/articles/h-bridge-secrets/h-bridges-the-basics/

3.3 Battery Selection

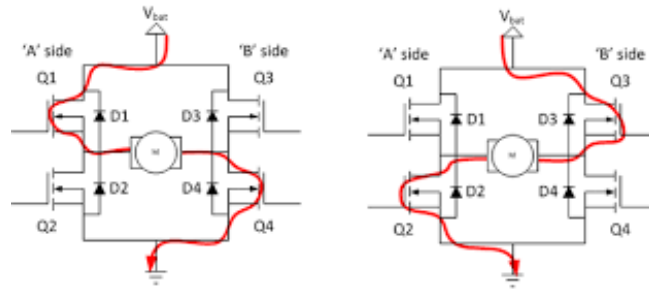Power supply is one of the most important element in the design, because of that, in this section there is an analysis of the different possibilities of batteries and its characteristics. At then end of the section it is possible to find the final solution for this project ad the specifications of this battery.

3.3.1 Batteries features

There are a few different ways to 'measure' batteries in order to choose the more suitable for the project. In this section, the most important measurable characteristic of the batteries will be explained. This analysis is based on the work done in [10].

Electronic features

Let's start with the electronic features, which probably are the ones to take in a higher consideration. These are the voltage, the power capacity and the power capability. The last two are closely related to one another, so they will be explained in the same subsection.

Voltage

This parameter only depend on the chemistry used inside the battery. How charged is the battery also affect to the voltage it can supply but in a little amount upper or lower to the average. For example, all Alkaline cells are 1.5V, all lead-acid's are 2V and all polymer lithium (LiPo) batteries are 3'7V. But if a LiPo batteries is totally charged it may supply 3,75 volts and on the contrary, if it is in low charge, it may supply around 3,6 volts.

Batteries can be connected in series in order to sum their voltages, in this way, it is possible to reach the desired voltage. Thus, in this project, microcontroller, disinfection LEDs and the motors can work in a voltage between 6V and 10V, so the battery used must supply a voltage in that range.

Power Capacity and Power Capability

These two characteristics are probably the most important and the most difficult

to understand, for these reason, they will be explained more in detail.

On one hand, **power capacity** is the amount of energy stored in the battery. The most used magnitude to measure energy are the Watt-hours (the symbol Wh). A Watt-hour is the voltage (V) that the battery provides multiplied by how much current (Amps) the battery can provide for some amount of time (generally in hours). However, since voltage is pretty much fixed for a battery type due to its internal chemistry, often the measurement of the energy in batteries is expressed Amps per hour, usually in Ah or mAh (1000mAh = 1Ah).
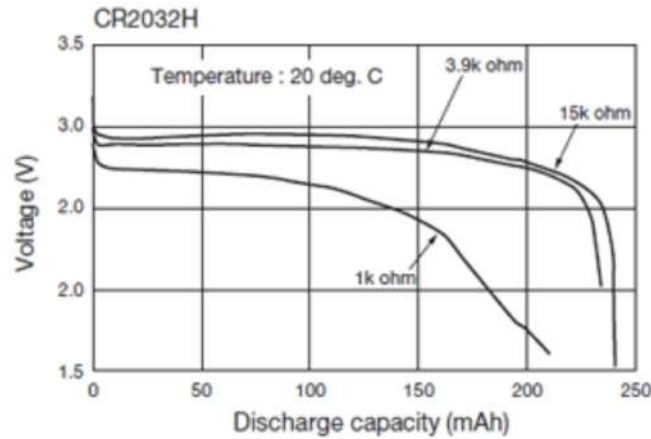

Figure 3.5: Representation of batterie capacity in function of the load. *Source: [10].*

On the other hand, the amount of current that the battery can really draw is called the **power capability**, and this is an important parameter to take into account because it is often limited. For example, a 1Ah coin cell has no problem providing a 1mA for 1000 hours but if you try to draw 100mA from it, it'll last a lot less than 10 hours. Figure 3.5 shows a coin cell that is able to drive a 3.9Kohm resistor and provide 230mAh (which is what its rated for) before dropping to 2V, but if its a 1Kohm resistor, it will only provide 125mAh.

The way the power capability is measured is in C's. A C is the Amp-hour capacity divided by 1 hour. So the C of a 2Ah battery is 2A. The amount of current a battery 'likes' to have drawn from it is measured in C. The higher the C the more current you can draw from the battery without exhausting it prematurely.

Other characteristics.

Although the characteristics mentioned above are the most important, there are others to take into account. These ones are mentioned hereunder:

Size

Depending on the battery technology, that is to say the internal chemistry, the size of them will be different. For this application, as mentioned in previous sections, the size must be as small as possible. However, the smaller size the lower capacity of the battery. For this reason, an arrangement between size and capacity must be made.

Weight and power density

This characteristic is also related with the size. Higher quality (and more expensive) batteries will have a higher power density. A battery with a high power density will have more capacity with a smaller size. Often this is expressed in Watts-hours per Kilogram. Thus, it must be a valance between the price and the quality of the battery.

Price

Price is usually proportional to power-density and proportional to power capacity . Since this project require a high capacity for a small size, the price for the battery will be high.

Re-usability

Some batteries are rechargeable and other can be used only once. Furthermore, there are some rechargeable batteries technologies with memory effect that will be mentioned in next section.

3.3.2 Different technologies of batteries in the market.

In that case, the technology of the battery means the internal chemical. This clasification has been based on [21]:

Lead acid batteries.

Lead Acid batteries are the most economical, rechargeable, and easily available. They are good for systems where a lot of power is needed and weight is a little

concern. The main problem of this batteries is that they are very heavy, batteries tend to be very large bricks because power density is very low. For this reason, they are not suitable for this project.

Alkaline batteries.

Alkaline batteries are the most common batteries you will come across. They have higher power density than NiCads and slightly better power density than NiMH. However, they are one-time use. They are non-rechargeable and his capability is quite low. It could be a possible solution because the required current from the robot is not too hight. It remains to be seen whether the battery must be rechargeable.

Ni-Cad and Ni-MH batteries.

Ni-Cad are the older rechargeable batteries that were popular for a long time. They come in standard small battery sizes like AA, AAA, C as well as rectangular shapes that make them easier to embed in an enclosure.

They are slightly cheaper than LiPo batteries but an important issue of this kind of batteries is that they requires "full discharge/recharge" cycles every once in a while to reduce 'memory effect' (the growth of crystals on the battery plates) what shorten the capacity.

Li-Ion and Li-Poly batteries.

These are the latest in rechargeable battery technology, and are quickly becoming the most common batteries for consumer electronics. They are very lightweight, don't mind high discharge rates, and have very high power density.

However, they are very sensitive and require special circuitry to keep them from exploding. This means that raw LiIon cells are very rare and very dangerous. Most li-ion batteries come with protection circuitry that keeps the battery operating safely. LiIon cels are around 3.6V so 3.6V and 7.2V are the most common battery voltages you'll see. They can easily provide up to 1C of current, some can go upper to 10C.

LiPo batteries have almost the same characteristics than LiIon but they can be shaped easily and they are usually slimmer.

Comparison table.

Table 3.1 shows the typical parameters of the technologies mentioned before which will help to take the final decision. This table has be taken from [21]:

Table 3.1: Comparison table of commonly used rechargeable batteries.

	NiCd	NiMH	Lead Acid	Li-ion	Li-ion polymer	Reusable Alkaline
Gravimetric Energy Density(Wh/kg)	45-80	60-120	30-50	110-160	100-130	80 (initial)
Internal Resistance (includes peripheral circuits) in mΩ	100 to 200[1] 6V pack	200 to 300[1] 6V pack	<100[1] 12V pack	150 to 250[1] 7.2V pack	200 to 300[1] 7.2V pack	200 to 2000[1] 6V pack
Cycle Life (to 80% of initial capacity)	1500[2]	300 to 500[2,3]	200 to 300[2]	500 to 1000[3]	300 to 500	50[3] (to 50%)
Fast Charge Time	1h typical	2-4h	8-16h	2-4h	2-4h	2-3h
Overcharge Tolerance	moderate	low	high	very low	low	moderate
Self-discharge / Month (room temperature)	20%[4]	30%[4]	5%	10%[5]	~10%[5]	0.3%
Cell Voltage(nominal)	1.25V[6]	1.25V[6]	2V	3.6V	3.6V	1.5V
Load Current - peak - best result	20C 1C	5C 0.5C or lower	5C[7] 0.2C	>2C 1C or lower	>2C 1C or lower	0.5C 0.2C or lower
Operating Temperature(discharge only)	-40 to 60°C	-20 to 60°C	-20 to 60°C	-20 to 60°C	0 to 60°C	0 to 65°C
Maintenance Requirement	30 to 60 days	60 to 90 days	3 to 6 months[9]	not req.	not req.	not req.
Typical Battery Cost (US$, reference only)	$50 (7.2V)	$60 (7.2V)	$25 (6V)	$100 (7.2V)	$100 (7.2V)	$5 (9V)
Cost per Cycle(US$)[11]	$0.04	$0.12	$0.10	$0.14	$0.29	$0.10-0.50
Commercial use since	1950	1990	1970 (sealed lead acid)	1991	1999	1992

3.3.3   Final Solution.

Due to the functionalities that the robot must have, there are some restrictions for the battery specifications. The main one is the size, then the dimension of the battery has to be the smallest that fulfil the electronic requirements. The voltage range of the components of the robots (motors and microcontroller board) is in between 6-10 volts so two cells of Li-Po would work for this needs. However, has to be taken into consideration that the more cells the more difficult is to control the charge of the batteries.

Once the voltage is define, let's talk about the other two electronic parameters according to the power needs. The time that the robot must be working without stop is about 40-50 minutes and the estimated average power consuming is around 1 ampere with maximum picks of 3 amperes because the disinfection lights has a high consumption. Then the value of the capacity of the battery should be in the range of 667-834 mAh accordingly with 3.1 and 3.2 respectively. On the other hand, it must have a capability of 3C (where C is the capacity) in order to support the current peaks caused by the disinfection LED system. As mentioned before, this two parameters are closely related so one depends on another.

$$Capacity(40min) = 1000mA \cdot \frac{40}{60}h = 667mAh \tag{3.1}$$

$$Capacity(50min) = 1000mA \cdot \frac{50}{60}h = 834mAh \tag{3.2}$$

It is possible conclude from the above analysis that the best and more used technology is the lithium made batteries. Alkaline batteries could also suit for that project because a high current is not required, the problem is that they are non-rechargeable and must be replace every time they run out of power.
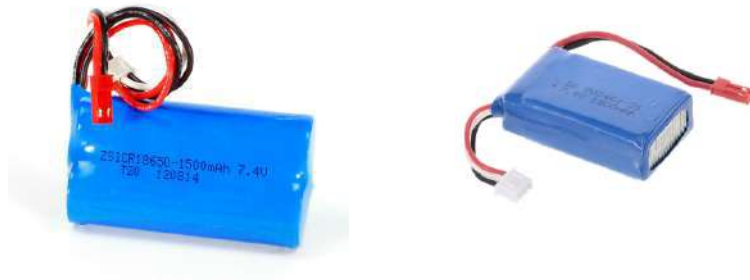

Figure 3.6: LiPo battery used in this project.

The advantage of Li-Po over Li-Ion is that they can be adapted to the desired shape and they have a sightly higher power density. For this reason, the chosen battery is LiPo kind and you can see it in figure 3.6. It is made of two cells, consequently it can provide 7.4V average, it has a capacity of 1500mAh and a capability of 5C. As you can see, these specifications are slightly higher than the required for the project but the price is reduced as you can see in the final price table.

$$Time = \frac{1500mAh}{1000mA} = 1,5h \tag{3.3}$$

With this battery, the robot will be able to work non stop for 1,5 hours as indicated in 3.3. The current consumption has been calculated considering that the microcontroller has a negligible demand so it is the sum of the motors and LEDs current needed supply.

This battery comes with a charger that can safely charge it without risk of explosion or damage. Figure 3.7 shows this device:

Figure 3.7: Comparison table of commonly used rechargeable batteries.

3.4   Sensors

This devices was deeply studied in chapter 2, as a conclusion it was said that it is possible to use both IR and ultrasonic technology for either obstacle detection or edge detection. In this project, due to the size requirement, it has been used IR sensors in both cases. Next, will be specify the model and characteristic of each sensor. It has to be mentioned that the processing speed of both sensors is enough for real time detection.

3.4.1   Obstacle detection sensor

The model of the IR sensor that will be used as obstacle detector is the *GP2Y0A51SK0F* from SHARP company. It is capable to measure distances based on the reflection principle that was mentioned in chapter 2. The basic specifications of this sensor are shown thereunder. These characteristics have been copied from the data-sheet [20] given by the manufacturer:

1. Distance measuring sensor is united with PSD, infrared LED and signal processing circuit.

2. Distance measuring range : 2 to 15 cm.

3. Compact size (27.0 x 10.8 x 12.0 mm)

4. Analog output type.

This model has three connections, two of them are used to supply the power and the third one generate the output signal. These connections are shown in 3.8.It can be powered directly from the microcontroller.

Figure 3.8: Three pins of the sensor.

The output signal generated by SHARP sensor is an analog voltage which depends on the distance to the reflective object. In the data-sheet it is possible to find a graph 3.9 that shows the relation between these two variables.

If you pay attention on that graph, the voltage before a distance of 1 cm drops abruptly. For this reason the sensor must be in a higher distance of 1 cm from the reflective surface.
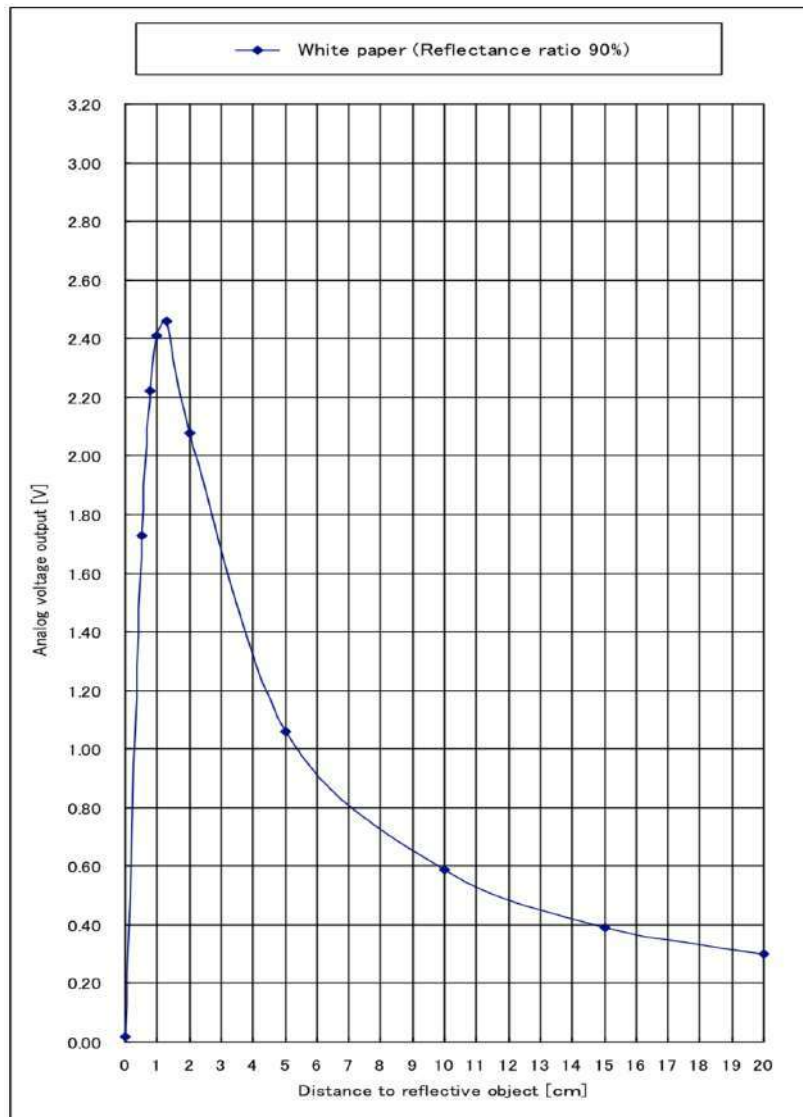

Figure 3.9: Relation between output signal and distance to object.

3.4.2   Edge detection sensor

The chosen sensor for edge detection is an IR module from Arduino with digital output. It will send a high signal to the microcontroller when no cliff is detected and a low one when the cliff is sensed.

The working mode of this sensor is quite simple. As you can see in figure 3.10, it is made with two LEDs. The black one is the receiver and the transparent one the IR emitter. It use a comparator to detect is any signal is received, in that case, a low signal is sent to the microcontroller. The sensitivity of the receiver can be controlled with a potentiometer in order to adjust the distant for the obstacle detection.

Figure 3.10: Infrared sensor with digital output.

This sensor is very common and easy to find from any supplier, in that case it has been purchased from *Taobao*. [5] The main charasteristic of this sensor are listed below:

- Can use 3-5V DC power supply for the module

- Digital output

- 3mm screw holes for easy mounting

- Circuit board size: $3,2cm \cdot 1,4cm$

---

[5]Here you can see the link of the product: `https://detail.tmall.com/item.htm?spm=a230r.1.14.8.1101a2d0xShZ6e&id=558968986174&cm_id=140105335569ed55e27b&abbucket=13`

3.5 Printed circuit board (PCB)

The function of this element is to connect all the electronic components in a tidy and easy way. It contains the microcontroller, motors drivers, status LED and all the needed jumpers for the external connections. In the first prototype of the robot a prototyping PCB was used for the connections. Next prototype use a custom PCB designed with EAGLE software. Both of then are explained in this section. The schematic of these circuits can be found in the Appendix.

3.5.1 Prototyping PCB

This PCB consist in a plate with the holes already made. In this way, you can introduce the components and weld them together.
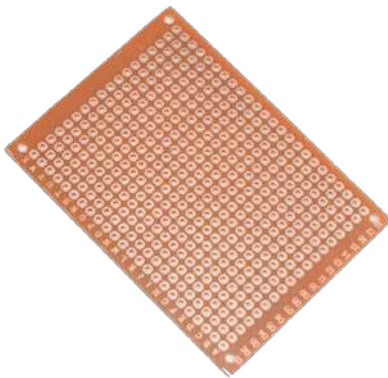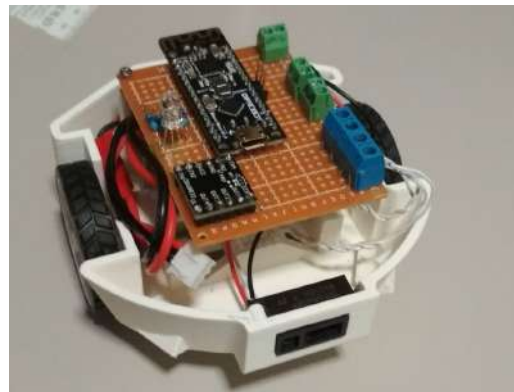
(a) Prototyping PCB   (b) PCB included in the robot

Figure 3.11: Prototyping PCB for the connections of the robot electronic components.

The dimensions of the used board is $5cm \times 7cm$, and it has four screw holes in the corners in order to fix it to the robot. The size of this PCB is pretty big considering that the robot has to be small, for this reason it is required a custom PCB in order to make it smaller.

All the connections among the components are made underneath by welding wires to the metallized holes. That is another reason to create a custom design for de PCB, the improve of the connections.

3.5.2   Custom PCB

In this subsection will be detailed the two custom PCB designed in this project. One is made for the connection of the electronic elements of the robot and the other one is a smaller design for the IR sensor for cliff detection but it won't be implemented in this project, although it is proposed for future works.

Main PCB

As mentioned before, the design of this printed circuit board has been made with *Eagle* software. Figure 3.12 shows the design made in this program:
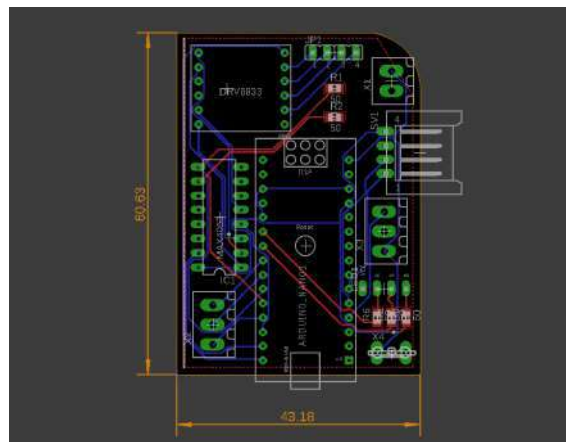
Figure 3.12: *Eagle* design of custom PCB.

Once the design is finished, *Eagle* allows you to generate the *Gerber* files that are sent to the manufacturer. The main specification of this board are the listed below:

- Two layers: Bottom and Top

- Clearance wire-wire: $8mil$

- Clearance other components: $6mil$

- Distance coper to the border: $40mil$

- Minimum wire width: $10mil$

- Minimum drill (for vias): $0,35mm$

As figure 3.12 shows, one centimetre in each dimension of the board has been reduced from the prototyping PCB. Other considerations have been taken into account in the design such as the lines do not cross in a perpendicular way from top layer to bottom one and has been used a wider wire for power supply lines.

Finally, figure 3.13a shows the custom PCB sent by the manufacturer and in figure 3.13b you can see this PCB mounted in the robot.
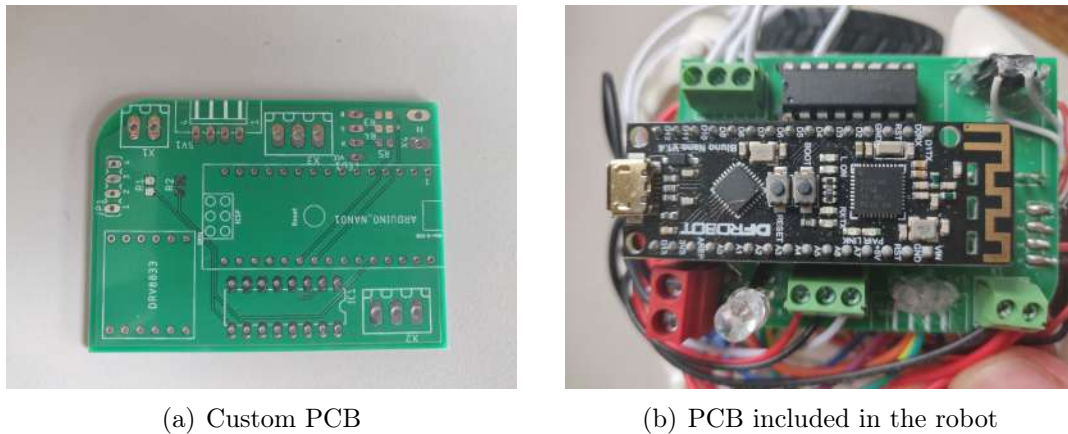

(a) Custom PCB

(b) PCB included in the robot

Figure 3.13: Custom PCB for the connections of the robot electronic components.

Custom PCB for IR digital sensor

This element has been designed but never included to any prototype of the robot. It is proposed for next work. In test chapter you can find how the circuit is made an how is tested. Figure 3.14 shows the PCB designed in *Eagle*.
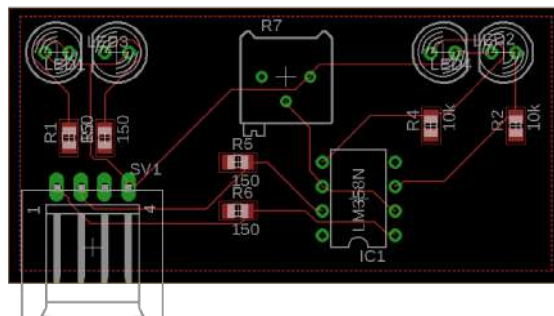
Figure 3.14: *Eagle* design of custom PCB for IR sensor.

3.6   Disinfection System

This system is made of the three LEDs needed for implementing the Hi-NW technology mentioned in then introduction chapter. The also include a power transistor and a power resistance in order to protect the LEDs:

- **Dissinfection LEDs**: Those are teh UV-C LED, 405nm LED and 405nm LED. The combination of this three lights in a particular duty cycle perform the disinfection.

- **Power transistor**: This element carries out the task of separating the control signal from the power supply. This LED's will be directly connected to the battery and they will be controlled by a signal generated from the microcontroller.

- **Power resistor**:That's element is required for regulating the voltage that will be supplied to the LED.

One PCB fore each LED has been created and designed by the members of the robotic team: Antonio Luis Velasco Martín and José Miguel Ríos Pérez. Each of them include the three elements mentioned before. They have three conections: control signal (from the microcontroller), voltage input signal (from the battery) and ground signal (from the battery).

After welding all the components, the disinfections LEDs look like shown in 3.15 in their printed circuit boards:
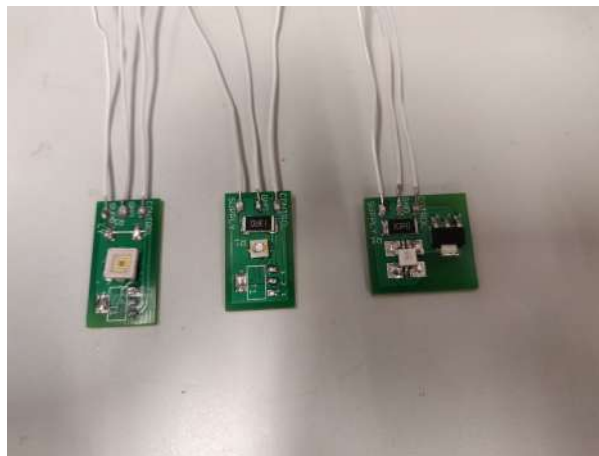

Figure 3.15: Real PCBs after welding the components.

3.7 Final connection

In 3.16 is shown the final connections among all the electronic components. The disinfection system is not included in the scheme in order to not overload the draw, but anyway all the connections are detailed hereunder.
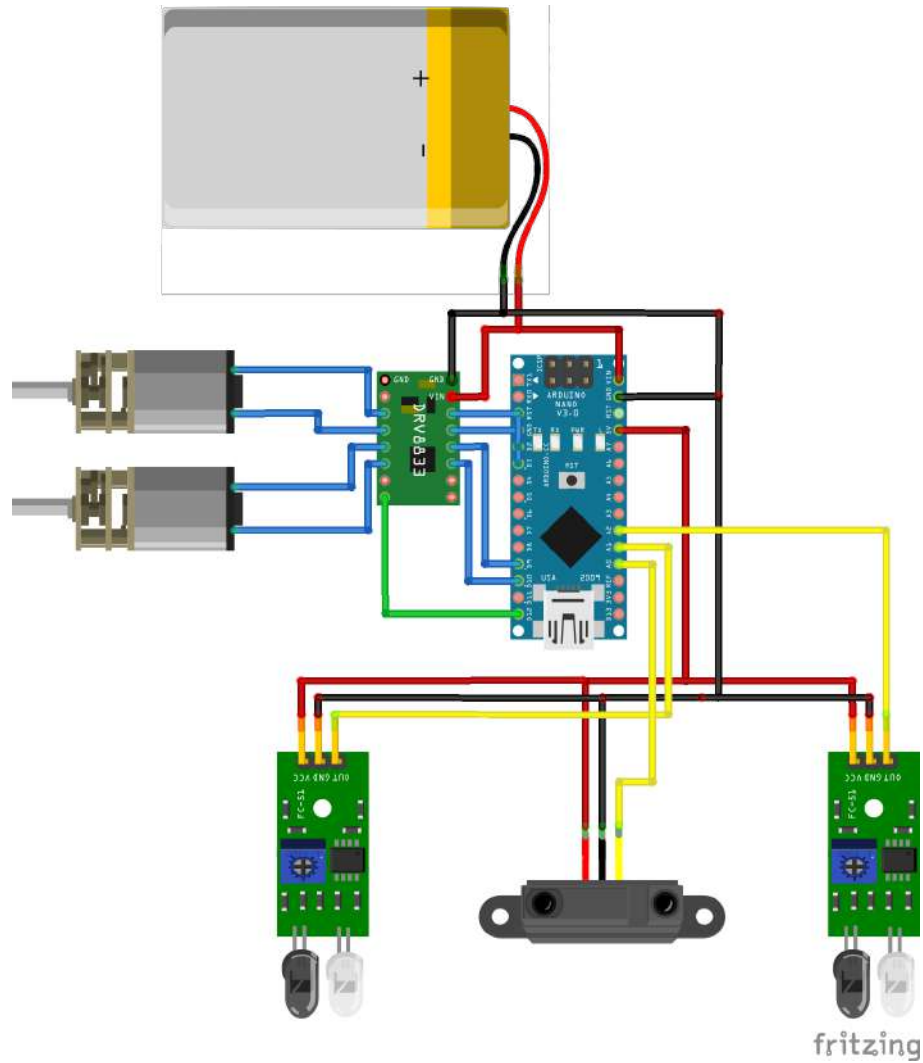

Figure 3.16: Final connections among all the electronic components.

Now, all the elements are listed one by one to specify the connections of their pins:

- **Battery**: Reference pin is connected to all the ground pins of each component of the system because all of them have a common reference. On the other hand,

the positive pole of the battery feed directly the micrcontroller (Vin pin), the motor driver and the disinfection LED circuits.

- **IR sensors**: All of them are powered by the 5V pin fo the microcontroller and the reference is directly connected to the battery. About the control signal pins are connected as follow: obstacle sensor detector is connected to the analog input pin of the microcontroller A0, the left cliff detector sensor to the pin A1 and the right one to the pin A2.

- **Motors**: They are connected to the output pins of the driver. Right motor to OUT1 and OUT2 and left motor to OUT3 and OUT4.

- **Motors driver**: The output pins are connected to the motors as mentioned previously. About the input port, they are connected to the microcontroller as follows:

  - Control of the right motor: IN1 to PWM pin 10 and IN2 to PWM pin 11.
  - Control of the left motor: IN3 to PWM pin 5 and IN3 to PWM pin 6.
  - Enable pin: it is connected to I/O pin 12 of the microcontroller.

- **Disinfection LED circuit boards**: The power pins are directly connected to the battery and the control signal are connected to the microcontroller as follows:

  - UV LED: digital I/O pin 6.
  - 405nm LED: digital I/O pin 5.
  - 470nm LED: digital I/O pin 9.

- **Microcontroller Bluno Nano**: All the connections to the microcontroller has been mentioned previously in the other components explanation. However, it last the wireless BLE antenna that will set a connection with a remote device.

It must be mentioned that there is a general switch that doesn't appear in the scheme. It is connected in the positive pin of the battery in order to connect or disconnect the power to the whole system.

Besides all this information, it is possible to find the schematics of the custom PCB where all the connection al detailed.

Chapter 4

Body robot design

Contents

Synopsis

This chapters shows how the robot body is design and how all the components are mounted and placed in it. As mentioned before, the CAM software used for this purpose is *Fusion360* from *Autodesk*.

4.1 Designing the parts of the robot

This section will talk about all the mechanical parts that the robot is made off. The planes of this parts can be found in the Appendix of the present work.

4.1.1 Main body

That is the main part of the robot and the one that will support all the electronic component inside. Figure 4.1 shows different views of this part that have been render with the CAD software *Fusion360*. That is the version used in the last prototype.
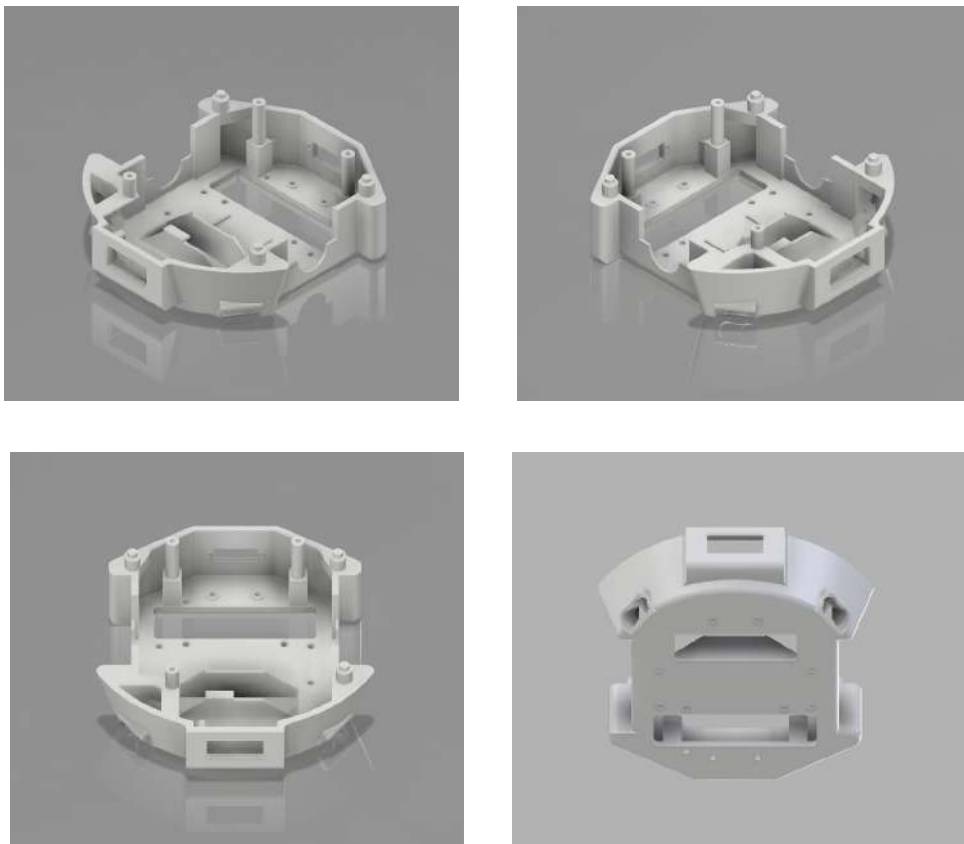
Figure 4.1: Different views of the main part.

Al the elements of this part are pointed in the two figures represented in 4.2 and also you can see the pieze once is printed in PLA. However, the gap for the disinfection LED will be explained in more detail.
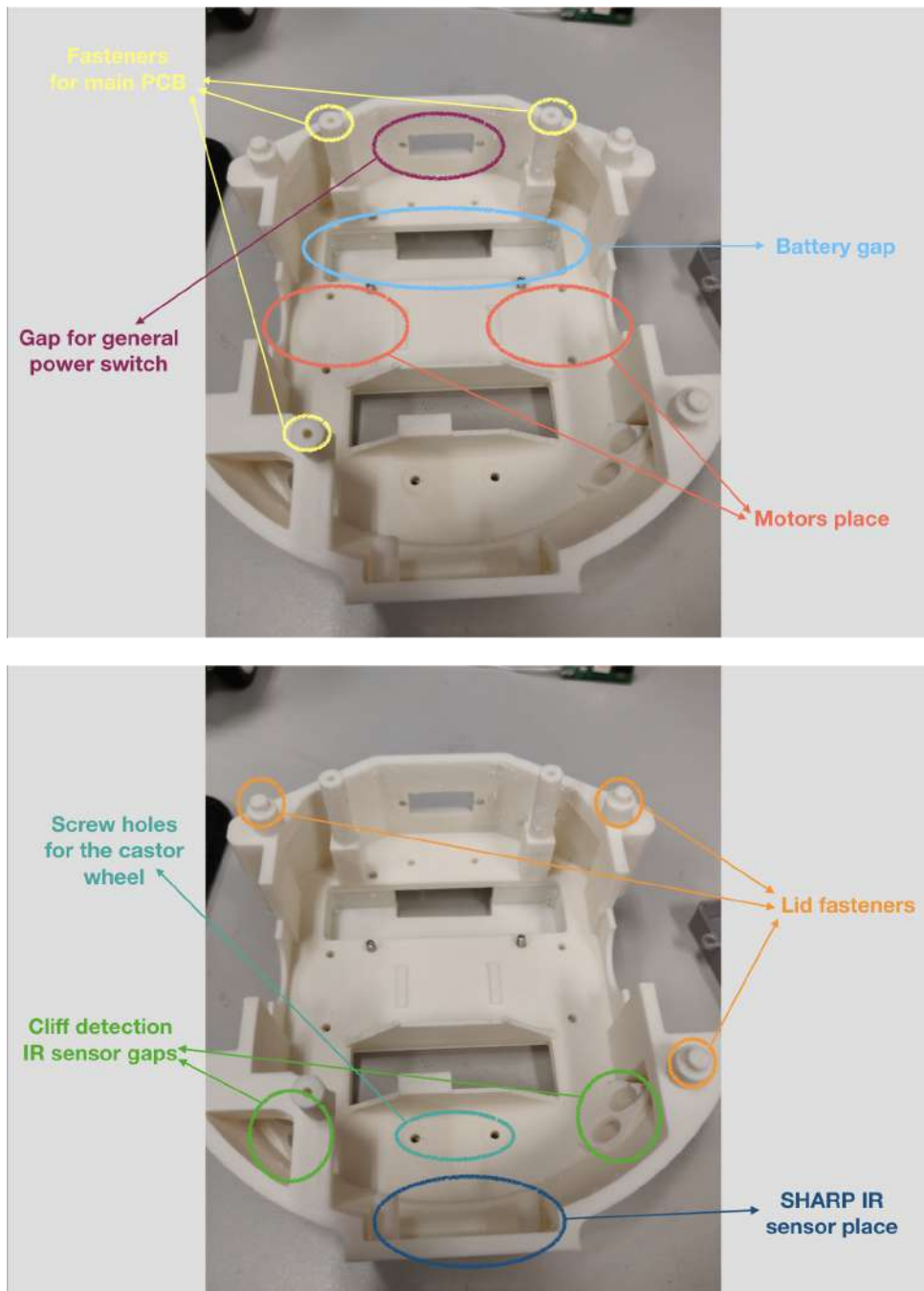
Figure 4.2: Elements of the main part of the robot.

As the disinfection LEDs are the main purpose of the robot it is important to calculate the incidence angle of then and design their props properly.
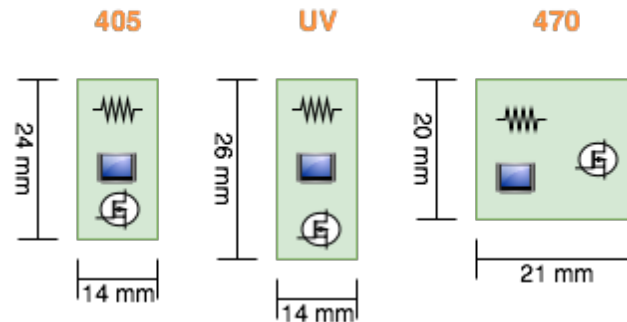

Figure 4.3: Scheme of the dimension of the PCBs for the disinfection LEDs.

They aim of this task is that all the three different lights irradiate the same area. The PCBs used for this purpose has been mentioned in chapter 3 and the dimensions are displayed in the scheme of figure 4.3.
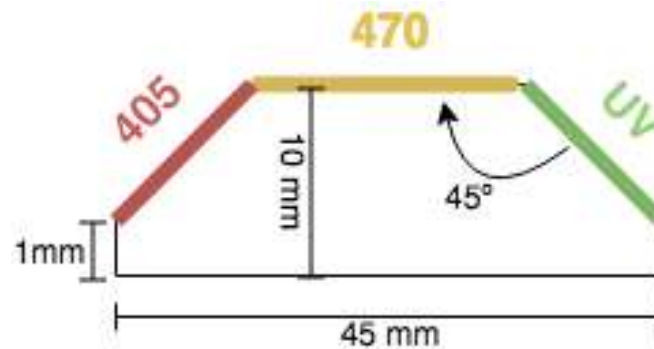

Figure 4.4: Representation of the PCBs disposition within the robot.

The PCB of 470nmLED will be placed on the top, facing downwards, and the other two will be placed in the sides because they have the same wide dimension so it will be symmetric. The LEDs on the sideways will be facing the table surface at an angle of 45° . Thus, the configuration of the lights would be similar to the one shown in the scheme of figure 4.4.

Figure 4.5 shows the gap made for the LEDs and a strip of blue tack in order to fix the PCBs. The assembling of this LEDs and the rest of the components will be explained deeper in the next section.

As shown, the mentioned LEDs will be placed in the front part of the robot. This PCB are quite big so they will be use in this prototype of the robot but for
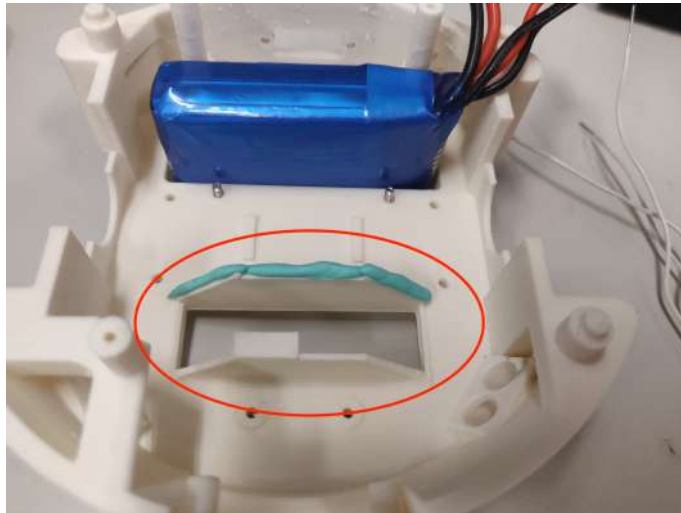
Figure 4.5: Gap for LEDs with a strip of blue tack.

further prototypes, a new PCB with the LED controllers will be design in order to make the robot smaller. This is proposed for future works.

4.1.2   Robot's lid

This very first design of the lid is based on a simple cover that protect the inner of the the robot from dust and bumps. It also has a little hole in order to show the light of the RGB status LED incorporated in the main PCB.

Figure 4.6: Render of the lid in Fusion 360.

In 4.6 you can see a render image of the lid made with the software *Fusion 360*. On the other hand, in 4.7 is shown the final printed result and a photo of the lid matched with the other part of the body:

Figure 4.7: Final result of the printed lid.

As you can see, the design also cover the wheel of the robot giving the appearance of a little turtle.

4.1.3   Design of the cover for the battery.

Due to the battery has a big size in comparison to the size of the robot, it projects beyond the body of the robot. For this reason, it is required to design a lid to cover it and make the battery easily removable for charging. Figure 4.8, shows the shape of the lid printed in the 3D printer. It will be screw to the body bottom of the robot.

(a) Top view.   (b) Bottom view.

Figure 4.8: Different views of the battery lid.

In figure 4.9 there are two pictures of the final assemble of the lid to the robot body. As you can see, it is easy removable as just unscrewing it. In that way, the battery can be easily extracted to be charged.

Figure 4.9: Battery lid assembled to the robot main part.

Next section will show how the battery is placed in that gap.

4.1.4 Additional parts

Two additional parts are the brackets for fixing the motors and the wheels of the robot. They both were included with the purchased of the motors from *Pololu* supplier. Figure 4.10 shows this two components.

(a) Mountin brackets   (b) Robot wheels 32×7

Figure 4.10: Battery lid assembled to the robot main part.

The fit perfectly with the used motors and the shape of the wheels have been taken into account for the main part design.

Another additional part is a broom at the back of the robot for sweeping away the soil of the table. It is just a brush tape glued to the robot body as you can see in figure 4.11.
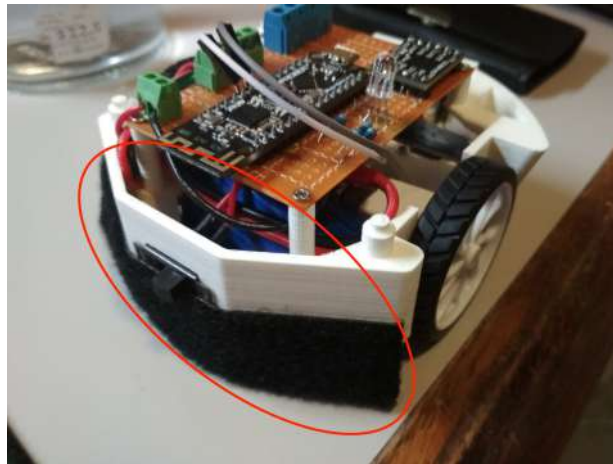
Figure 4.11: Broom at the back of the robot circled in red.

4.2 Assembling the robot

This section will explain step by step how all the components of the robot are assembled and mounted. Figure 4.12 shows a scheme of the assemble. It is made with *Fusion360* software.
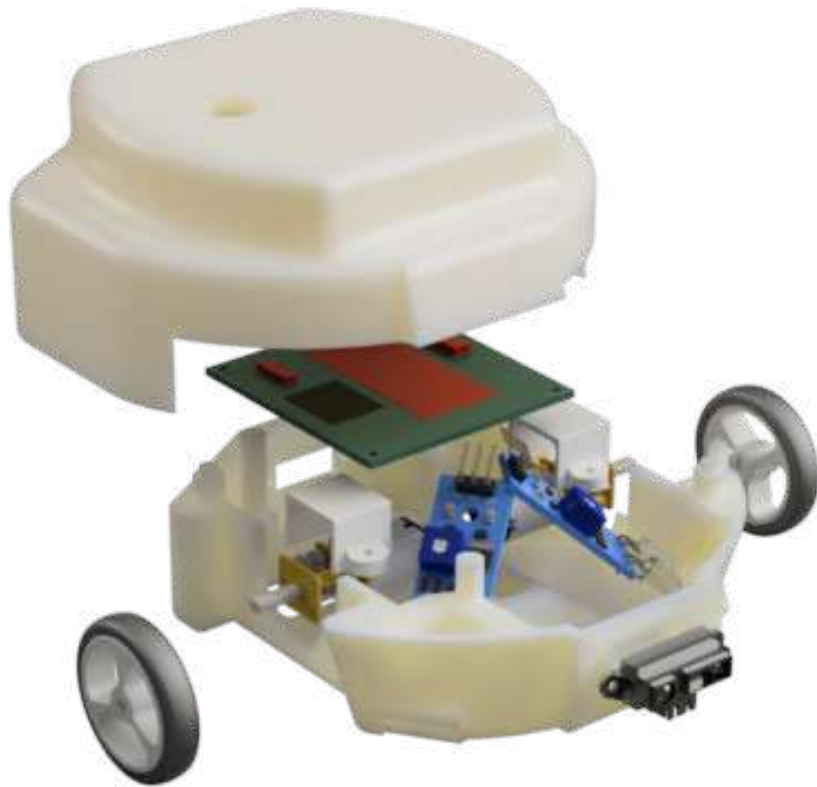

Figure 4.12: Assemble of all components of the robot.

The first step is to place the battery in its gap. As you can see in figure 4.13, it is at the back of the robot because it is the heaviest part and it gives more stability and makes that the broom exerts a bigger drag force. This broom, as mentioned before is just stuck to the robot with a special glue for plastic materials.
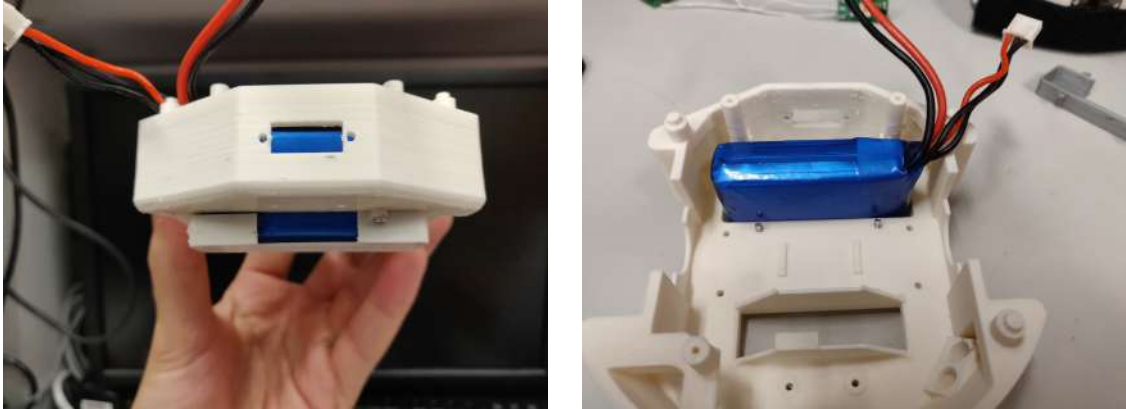
Figure 4.13: Battery placed in the robot.

Next step is to place the disinfection LEDs. After place the PCBs on their sites, more blue tack is used to fill the gaps among them and fix them better. The gaps are covered in order to focus all the light to the surface and do not allow outside light interfere with the disinfection lights. You can see the final result in figure 4.14:
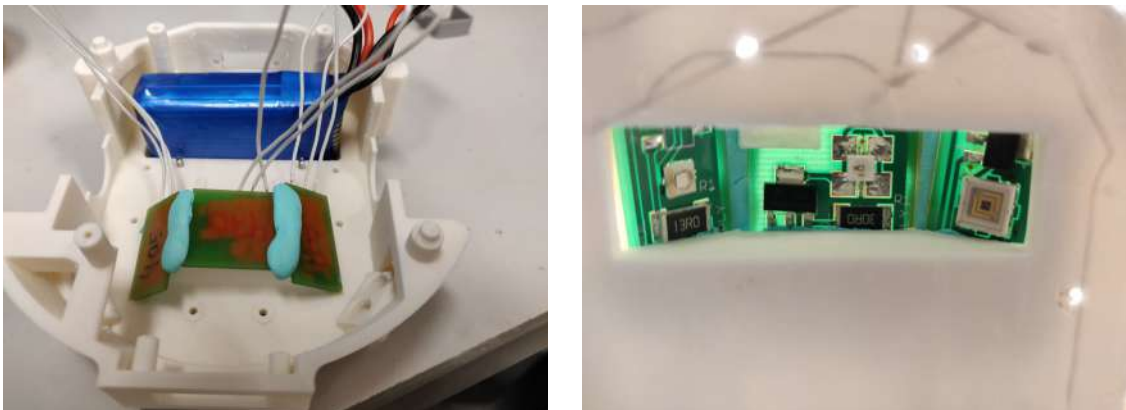

Figure 4.14: Placement of the disinfection LEDs in the first prototype.

Now it is possible to include the general switch and the motors. The general switch is placed at the back of the robot and connected to the positive borne of the battery, you can see that in figure 4.15.

Figure 4.15: Placement of the general switch.

On the other hand, the motors are placed in their gaps using the mounting brackets as shown in figure 4.16. This si a photo of an old prototype, nevertheless, the mounting process is exactly the same. This figure also shows the castor wheel in the front of the robot. It is bolted using the screw holes previously designed for it. There is no need of another wheel at the back of the robot because the broom acts as a prop.

(a) Motors fixed to the design.

(b) Caster wheel.

Figure 4.16: Placement of the motors with the mounting brackets and caster wheel.

Next, IR sensors are added to the robot. The cliff detectors are inserted in the gaps made in the bottom and sides of the robot and the obstacle detector is placed in the front as shown in 4.17. The first ones are circled in red whereas the range IR sensor is circled in yellow.
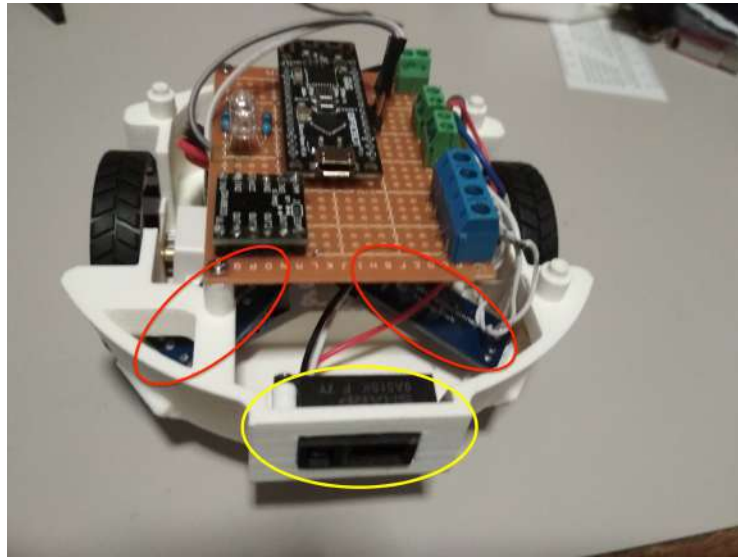
Figure 4.17: IR sensors placed in the robot.

In the two photos shown in 4.18 it is possible to see how the sensors looks outside the robot. Only the emitter and receiver LEDs can be seen from the outside. In one picture the robot is shown with the lid and the other without lid.
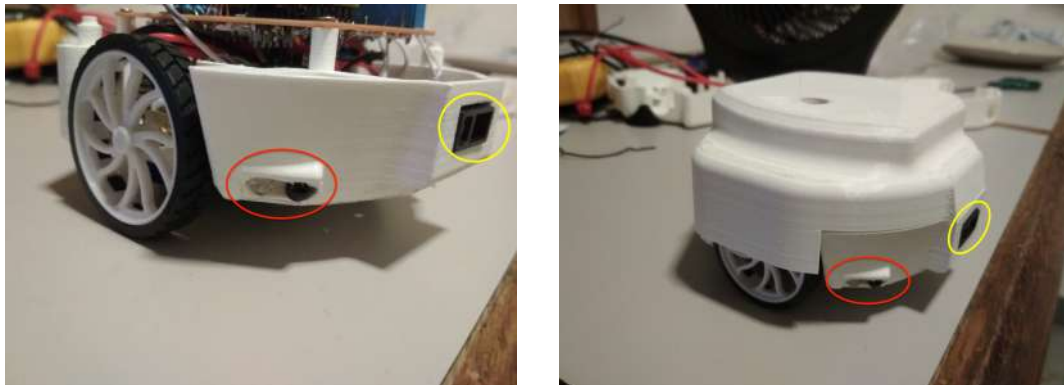

Figure 4.18: Outer part of the IR sensors.

Last step is to fix the main PCB to the design, made all the connections and add the lid of the robot. All of these can be also seen in the last three pictures.

Chapter 5

Program and algorithm design

Contents

Synopsis

Hereunder will be detailed the algorithm used for control of the functionalities of the robot. There will be also detailed the structure of the code and the main characteristics of it. You can find the full code in the appendixes.

5.1   Previous definitions

This section will explain two basic concepts that will be required for the programming of the robot. The first one is the PWM signal that is used for controlling the speed of the robot, the other one is the duty cycle that must be applied to the disinfection LEDs.

5.1.1   PWM signal

This type of signals are so common for controlling the intensity of LEDs or the velocity of motors. It is digital square signal, while the signal can only be high (usually 5V) or low (ground) at any time, it possible to change the proportion of time the signal is high compared to when it is low over a consistent time interval (duty cycle). Depending on this duty cycle, the power given to the motors can be changed.
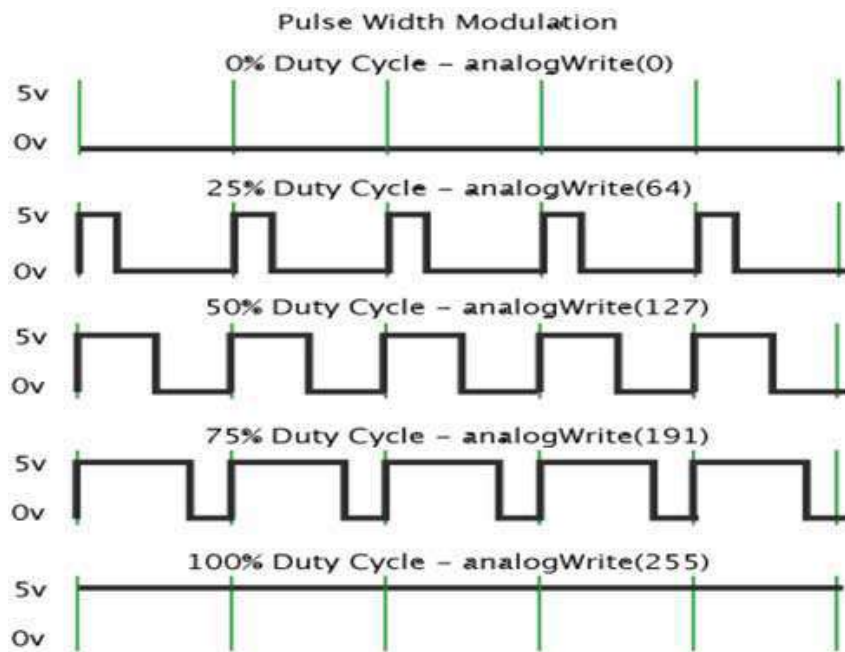

Figure 5.1: Example of PWM signal. *Source: [3]*

For example, figure 5.1 shows different duty cycles generated with the Arduino function *analogWrite()* that accept as a parameter a natural number between 0 and 255 to give a power from 0% to 100%. At a particular case, if the parameter is 64 the duty cycle will be the 25% and the average voltage generated by the microcontroller

1,25V. This signal will be taken by the motor driver and it will generate the proper signal for the motors using the power from the battery.

5.1.2   Program of the disinfection LEDs.

As mentioned previously, the light from the three disinfection LEDs must be combined in a specific cycle in order to inactivate the bacteria. This flashing rate has been studied by [15] and it will be used the same one in this project.

Without entering in deep details, after some test performed in the cited work, the best bactericidal combination effect is:

1   There is a previous exposure with 405nm light in order to damage the membrane of the cell and let the UVC light reach the DNA easier.

2   Then, the UVC and 470nm lights are alternative flashed causing the death of the bacteria.

The different timers of the microcontroller will be properly configured to achieve that task. They are able to generate a square signal from a digital I/O pin that is connected to the control signal of the LED printed circuit board.

5.2   Algorithm analysis.

In this section is explained the final algorithm implemented in the robot of this project. That is a first version with the basic functions so, it doesn't include an autonomous and smart navigation algorithm. That will be proposed for future work.

5.2.1   Finite states machine

Basically this program is based in a finite state machine. It is a computation model used to simulate sequential logic. The robot can be in a finite number of states and it will change among then under certain conditions. Particularly, figure 5.2 shows the state machine implemented in this robot.
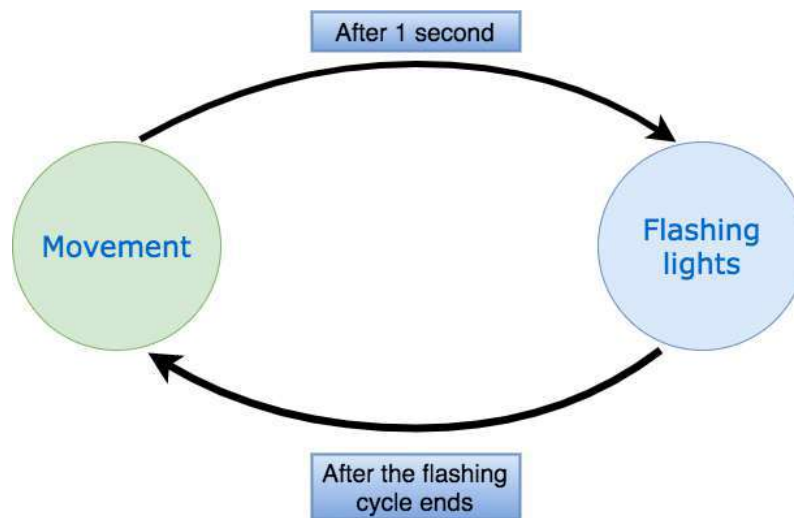

Figure 5.2: States machine

After a reset or when the robot is turned on, it will start in the *Movement* state, after one second it will change to the *Flashing light* state and once the cycle ends it will come back again to the previous state. Thus, this program will be in an infinite loop changing without stop between this two states.

Movement state is, in turn, is another finite state machine that is explained next. On the other hand, *Flashing light* state just will perform the cycle of the disinfection lights mentioned before.

5.2.2   Navigation algorithm.

As previously mentioned, this is another state machine. It is representated in the scheme of 5.3. The states are inside of orange rectangles and the conditions to change between states are in a red diamond.
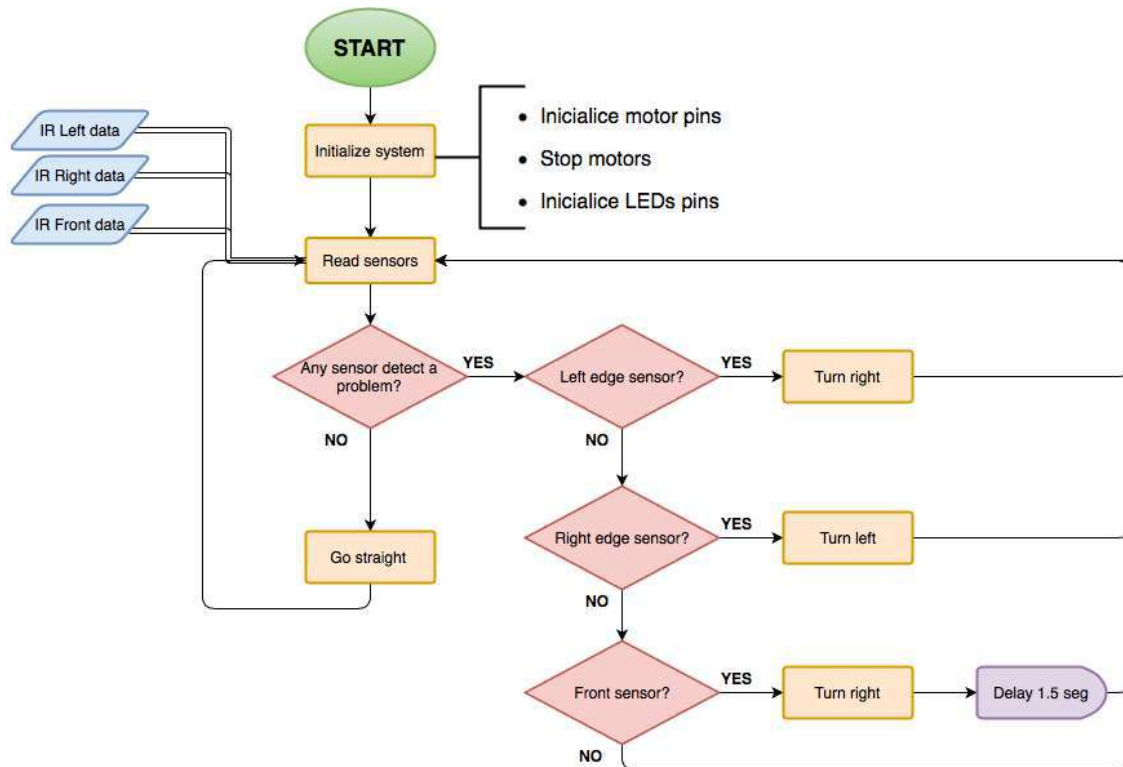

Figure 5.3: Flow chart that represents the algorithm of the program.

At the beginning, there is a initialization process when all the pins are settled, the motors are stopped and the status LED turned down. Then, the measured data from the three IR sensors in the robot are read. Next step is to make a decision with that acquired data. For example, if the left sensor for cliff detection find the edge of the table, the robot will enter in the *Turn Right* state until the sensor doesn't detect the edge any more.

5.3 Structure of the code files.

The code of the program is structured in five different files. All of them are included in the appendix. Hereunder, they are explained:

- **main.ino:** Main file with the behaviour algorithm of the program where are included all the libraries.

- **sensors.h and sensors.cpp:** Library with all the definitions and functions that control the status LED, the sensors and the disinfection LEDs of the robot.

- **motor.h and motor.cpp:** Library with all the definitions and functions that control the motors.

All of them are programmed using the Arduino IDE what allows to use C/C++ language and the native functions for controlling the peripheral and functions of the microcontroller such as: the I/O pins, the timers, the ADC converters, etc.

Chapter 6

Tests

Contents

Synopsis

This chapter shows all the tests performed during the project. For each of them it is explained the methodology and the results obtained.

6.1   Testing the two kind of motors

As mentioned in previous chapters, there are two kind of motors that have been tested in order to chose the more suitable for this projects. Those are the gear included motor *Vortex* robot kind and the small DC motor *Ozobot* and *Ringo* robot kind.

6.1.1   Voltage and intensity motors test

Once the two kind of motors are disconnected and ready for use, it is time to test it. The purpose of this test is to find the operating point, in other words, the electrical parameters (voltage and current) that they need for working with a good efficiency. The specifications of the smaller motors are unknown so it is necessary to try with different voltages. The two different sort of motors are shown In figure 6.1.

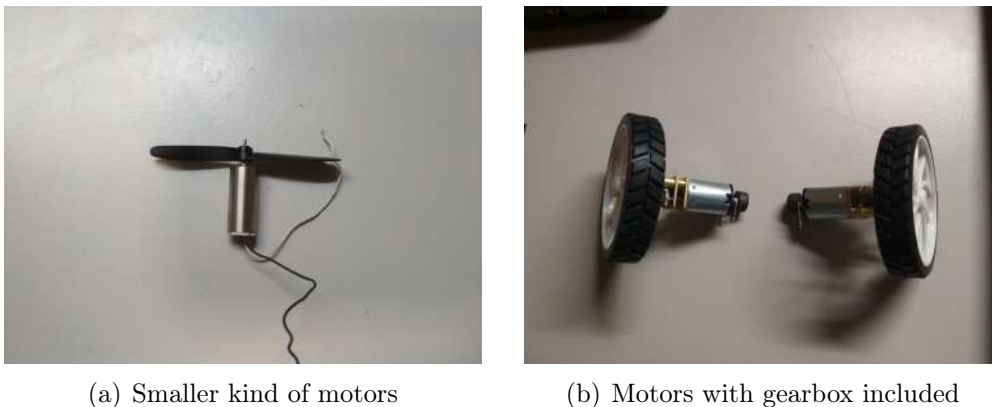(a) Smaller kind of motors

(b) Motors with gearbox included

Figure 6.1: Two kind of motors used for testing.

A simple test bed has been set in order to measure the electrical characteristic of these devices. It consists of a power supply and a multimeter all connected as shown 6.2a. Thus, the power source supply the energy and display the current that the motor is consuming whereas the multimeter display the voltage in between the motor terminals.

Several test has been performed: obviously they has been tested for different voltages but they have also been tested with and without load. That is made to know how they will behave once they are included in the robot. In 6.1, the results of the test can be checked for both motors.
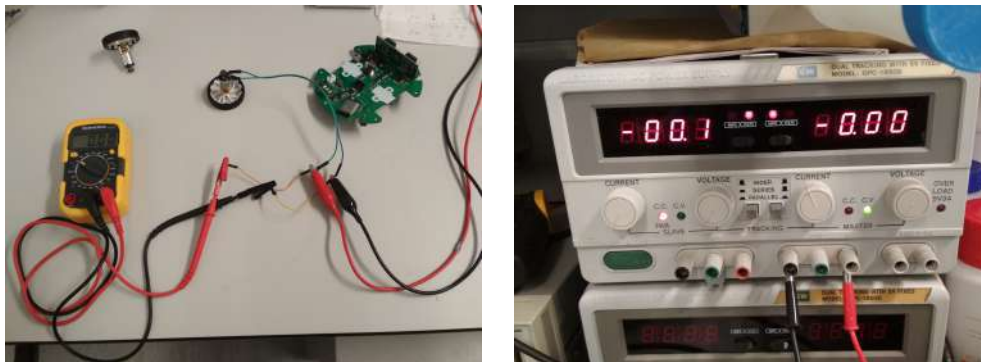
(a) Test bed.

(b) Power supply.

Figure 6.2: Test bench used for analyse the motors.

As shown, the smaller motors consumption is much higher than the other one. They can rotate faster and get a higher torque with the proper gears with a lower voltage what means that they can do the same with only one LiPo battery cell but with a higher consumption.

Table 6.1: Main electronic characteristics and components of the robot.

| Characteristics	Voltage (V)	Current (A)	Observations
Vortex Robot motor			
Movement starts	0,5	0,02-0,03	Low current even for high voltage.
LiPo voltage (3.7 V)	3,7	0,04	
High voltage	12	0,07	
Quadcopter motors			
With load (LiPo)	3,7	0,78	High current even for very low voltage.
Without load (LiPo)	3,7	0,1	
High voltage	5	1,3	

The advantages of using the *Vortex* robot motors instead, is that the step-down years has already been added and it is not necessary to build and design them.

6.2   Testing the SHARP IR sensor.

In order to test the sensor, the *Arduino UNO* board has been used . The sensor
can be connected directly to the board as shown in 6.3b. Red and black wires
are used for the power supply (5 volts and GND respectively) and the third one is
connected to an analog input of the microcontroller since it carries the output signal
of the sensor. Finally the board is connected by USB port to the computer. In 6.3b
is shown the final installation.
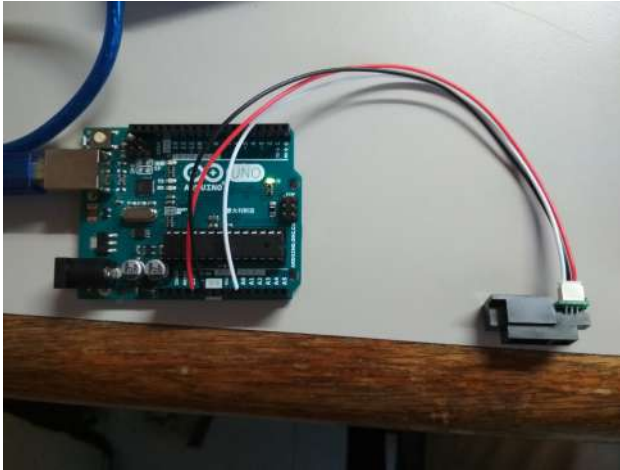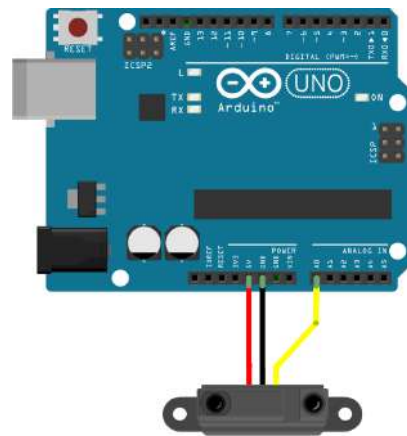

(a) Real connection.   (b) Scheme of the conection.

Figure 6.3: Circuit disposition for the test of SHARP IR sensor.

With a really simple code that is explained in 6.2.1, the data read from the sensor
is sent through the serial connection (USB) and displayed in the serial monitor on
the computer. The distance is shown in millimeters and when its value is bigger
than 30mm the word "OUT" is sent.

Knowing this, the test consist in holding the sensor facing the table with a little
angle and from a distance of 0,5-1cm approximately. Then, move the sensor until
the edge of the table. In 6.4 the results of the test is shown in four images. When the
sensor is over the table, the output data is about 5 mm that actually is the distance
to the reflective surface. However, when the sensor reach the edge, the OUT word
is display, what means that it has been detected.
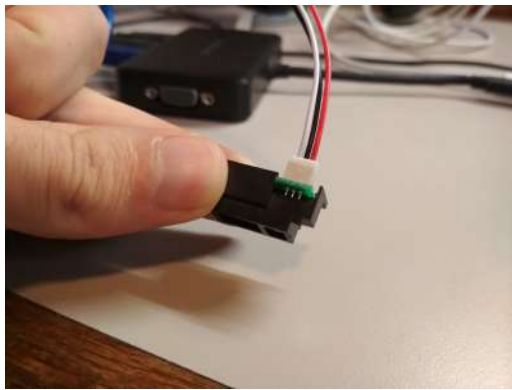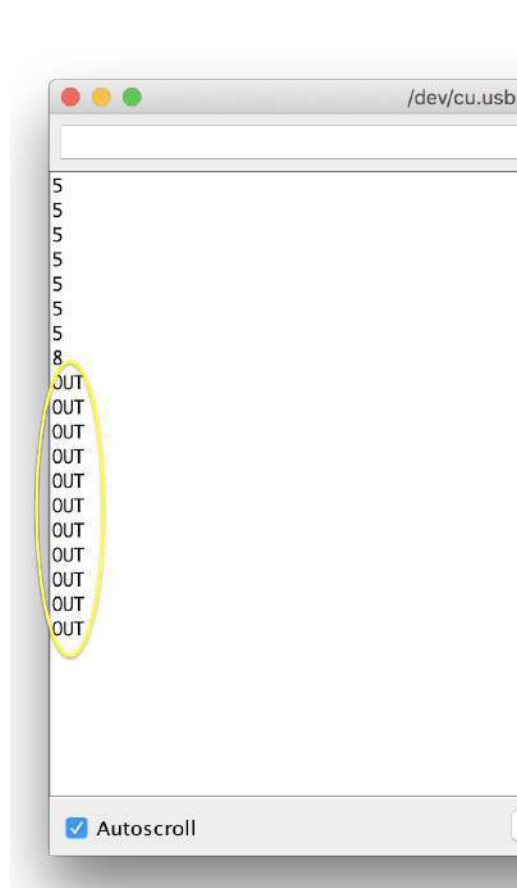
(a) Sensor facing the table surface.
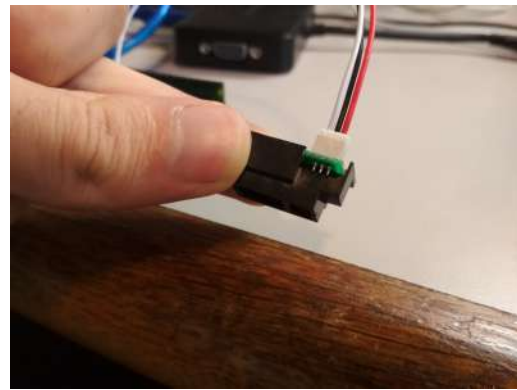
(b) Sensor reach the edge.
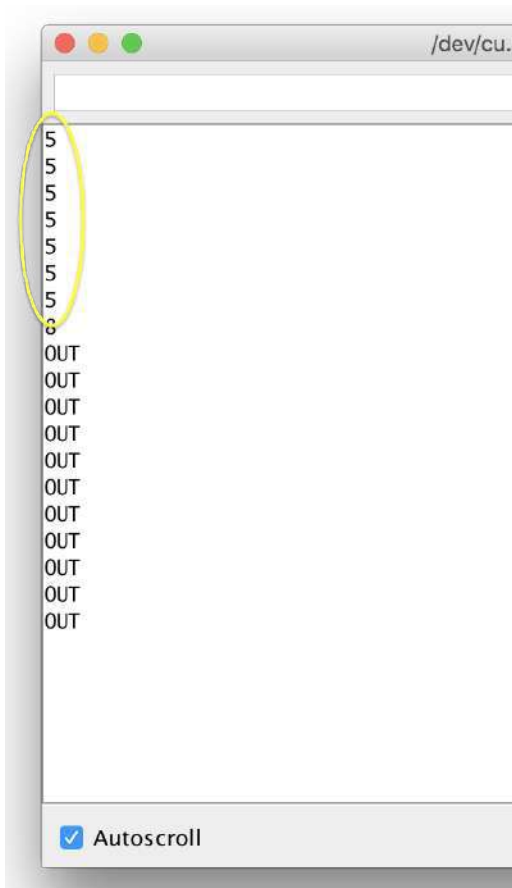
(c) Serial monitor (a) case.

(d) Serial monitor (b) case.

Figure 6.4: Sensor test procedure.

6.2.1   Code of the test.

The Arduino program used for this test is so simple. It is possible to see it in the next lines of text:

```
#define sensor A0 //Sharp IR GP2Y0A51SK0F sensor

void setup() {
Serial.begin(9600); //Start the serial port
}

void loop() {
//value from sensor * (5/1024)
float volts = analogRead(sensor)*0.0048828125;
// worked out from datasheet graph
int distance = 13*pow(volts, -1);
delay(1000); // slow down serial port

if (distance <= 30){
// print the distance
Serial.println(distance);
}
else
{
//If distance is too big:
Serial.println("OUT");
}
}
```

It basically read the voltage of A0 analog input where is connected the output signal wire of the sensor. The value of this voltage is operated accordantly to the data-sheet instructions in order to get the value of the distance. Once this is done, if the distance is bigger smaller than 30mm it is send by the serial communication unless the "OUT" word is sent instead.

6.3   Customized IR sensor for edge detection.

Since the size of the robot must be as small as possible, a customized sensor with the proper shape fits better leveraging the available space inside the robot. This sensor is based in the IR modules for Arduino used previously.

6.3.1   Circuit and design of the PCB.

The circuit of this sensor is quite simple. It uses the integrate LM358 which is a comparator between a reference and the signal measured from the photodiode. This reference is settled by a potentiometer and it can be adjusted. The basic scheme of the circuit is shown in 6.5.
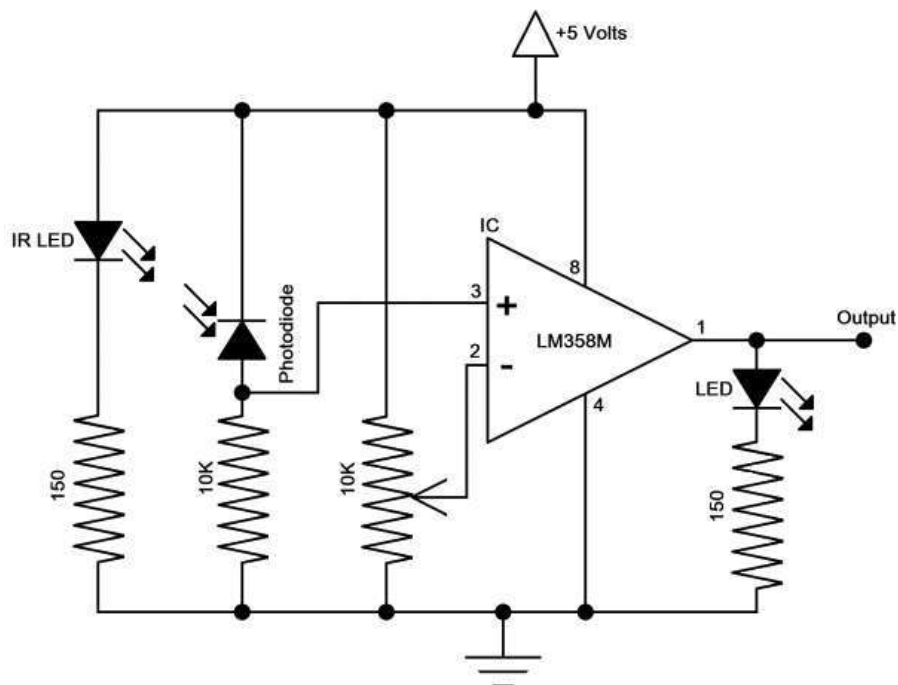

Figure 6.5: Schematic of the IR sensor circuit.

As you can see in the image, the output will be high when the photodiode receive the reflected light from the IR LED and it will be LOW otherwise. The potentiomenter can be used to regulate the detection range of the sensor.

Before the design and manufacturing of the PCB for the presented circuit, it has been tested with the basic components. The comertial integrated circuit LM358

include two comparators that suit perfectly for this application because two sensors are needed.

Both sensors will share the same potentiomenter because they will need to measure from the same distance. The resistances used for this test are the normal ones but for the final PCB SMD resistors will be used because they have a smaller size.

The components for this circuits are the next ones:

- **Resistors:** In order to control the current flow along the circuit. Four resistors of 150Ω and two of 1KΩ are used in this circuit.

- **IR LED:** That is the LED that emits the IR radiation that will be caught by the photodiode. Two of them will be needed.

- **Photodiode:** That is the real sensor of the circuit which capture the radiation emitted by the IR LED. Also, two of them will be needed.

- **Potentiomenter:** As mentioned before, this variable resistor will be used for regulating the range of both sensors.

In the next two pictures you can see the results and build of the test:
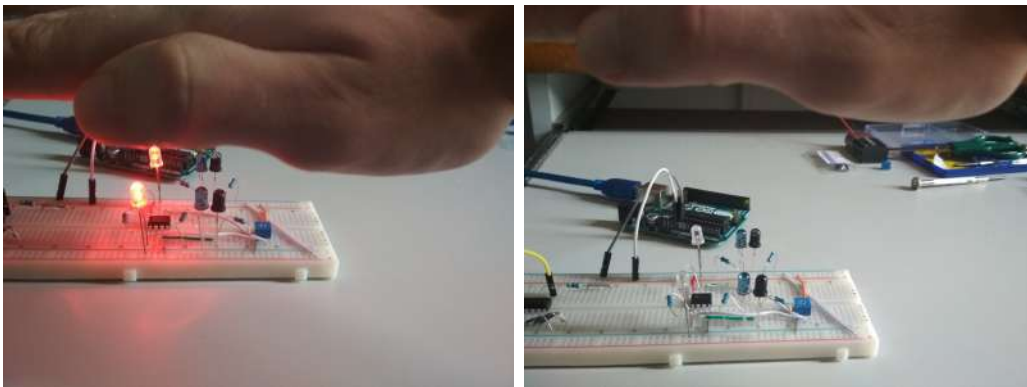
(a) Detection of a proximate object.   (b) Hand is too far to be detected.

Figure 6.6: IR sensor for object detection test.

As you can see in figures 6.6, red LEDs turn on when the sensors detect an object (the hand in this case) and they turn off when the object is too far.

6.3.2   Test of the multiplexor.

A multiplexor has been tested in order to reduce the PWM pin that control the motors from 4 to 2. This is useful if it is required to add new functionality to the robot in the future because the PWM pin are limited. The model is the MAX4053 from MAXIM company. This circuit is based in the guidelines given by the datasheet of the device that you can see in 6.8. The switch is controlled with a digital output from Arduino board thus, this signal is used to make the motor runs in one direction or another but with the same control signal (PWM).

In 6.7 you can see the scheme of the circuit inside the integrated. There are three switches inside (one control signal, one input and two outputs per switch) but only two of them will be used because there are only two motors to be controlled.
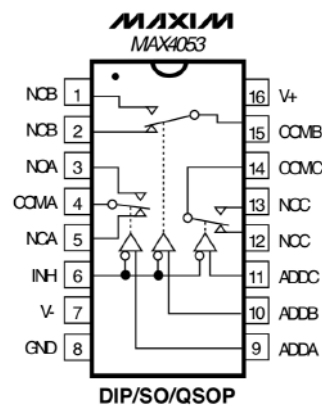

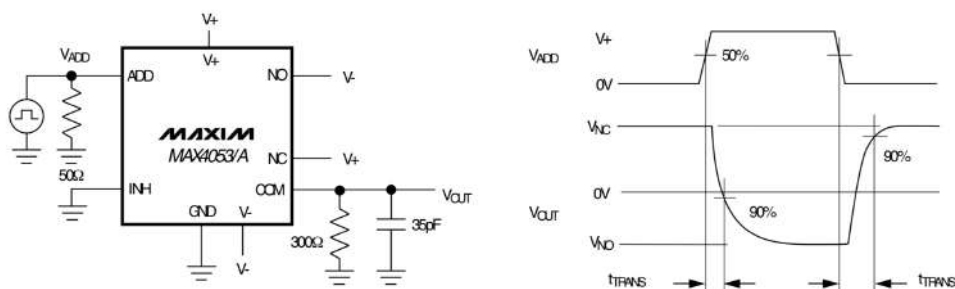Figure 6.7: Scheme of the circuit inside the integrated component.

Figure 6.8: Proposed circuit (left) and example of the signals in a typical operation (right).

Finally, in 6.9 you can see the PWM measured from the output pin of the switch which means that the circuit works correctly. Thus, the digital pin of the microcontroller that select the direction of the spinning is connected to the COM pin of the multiplexor and the PWM pin to the ADD pin. The pins NO (normally open) and NC (normally closed) will be connected to the ADD pin depending of the input of COM pin. While one exit is connected to the PWM signal the other one will provide a low logic signal.
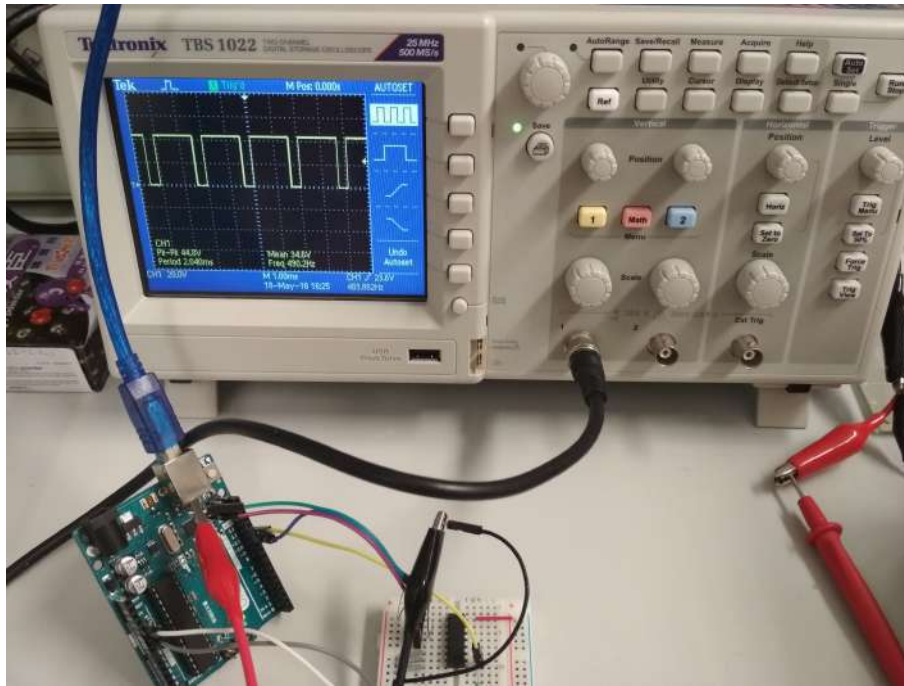

Figure 6.9: Result of the test in the oscilloscope.

6.4 Testing the motors and drivers.

The model of the motor driver (H-bridge) that will be tested is the *DRV8833*. It is capable to control two DC motors or one stepper motor. Its main specifications were explained in previous chapters, however, hereunder you can find the electric characteristics that will be useful for the test.

1 Features

- Dual-H-Bridge Current-Control Motor Driver
  - Can Drive Two DC Motors or One Stepper Motor
  - Low MOSFET ON-Resistance: HS + LS 360 mΩ
- Output Current (at V_M = 5 V, 25°C)
  - 1.5-A RMS, 2-A Peak per H-Bridge in PWP and RTY Package Options
  - 500-mA RMS, 2-A Peak per H-Bridge in PW Package Option
- Outputs can be in Parallel for
  - 3-A RMS, 4-A Peak (PWP and RTY)
  - 1-A RMS, 4-A Peak (PW)
- Wide Power Supply Voltage Range: 2.7 to 10.8 V
- PWM Winding Current Regulation and Current Limiting
- Thermally Enhanced Surface-Mount Packages

Down below, there is a list of the connections of this motor driver matched with a brief explanation of how they work:

- **Output pins OUT1-4:** These signal is the output that control the motors. OUT 1-2 pins will be connected to the first motor and OUT 3-4 pins to the second motor. This signal take the power from the external supply and the signal from the microcontroller.

- **Input pins IN1-4:** These pins are connected to digital outputs of the microcontroller. The MCU generate a PWM signal with the desired power that want to be applied to the motors. IN 1-2 pins control the first motor and IN 3-4 pins control the second motor. One pin is to turn the motor in one direction and the other pin in the opposite direction.

- **Power input VCC and GND:** The purpose of these pins is to connect the external power supply. The VCC pin will be connected to the positive terminal of the battery and must have a range between 2.7-10.8 V. On the other hand, the GND pin is connected to the ground terminal of the battery and also to the ground terminal of the microcontroller.

- **Enable pin EEP:** If this pin has a HIGH value, the motor driver will work in its nominal mode. Otherwise, if this pin has a LOW value, the motor driver will go into the sleep mode to save energy. Then, this pin will be connected to a digital output of the microcontroller.

- **Failure status pin ULT:** This is an output pin that is set to HIGH when there is any problem with the motors, like a short-circuit or a overheating. Therefore, it will be connected to a digital input of the microcontroller in order to read the status of the motor driver.

6.4.1   Test procedure.

In order to test all the features of this motor driver, a simple test bed has been designed. The components of this are listed and explained below:
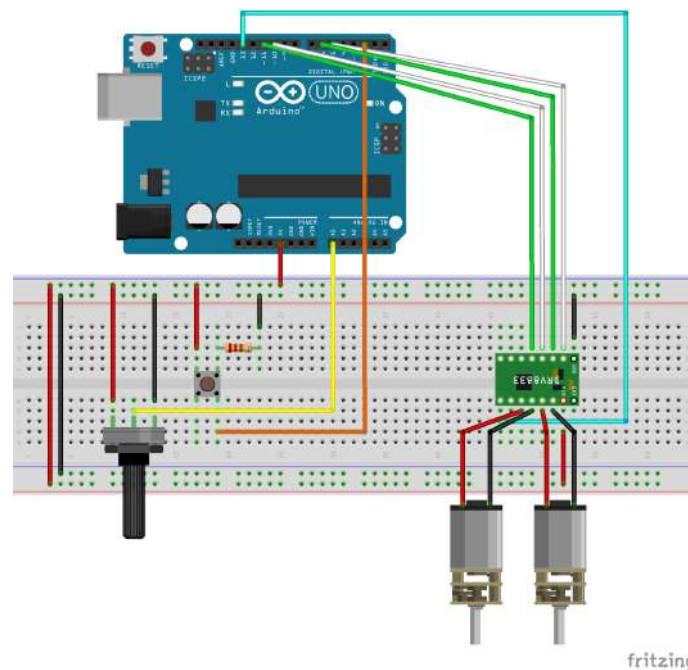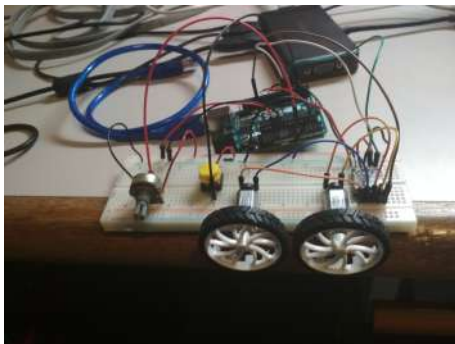

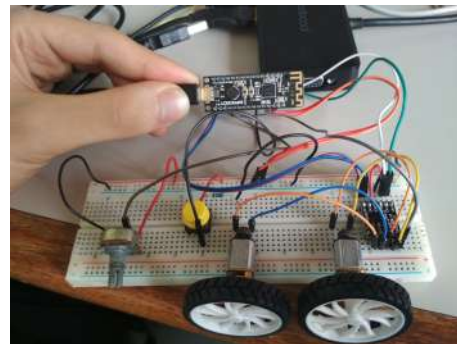Figure 6.10: Connections scheme of the test bed used for this experiment.

- **Motors:** They are the Pololu motors extracted from Vortex robot with the gears and the wheel. It was explained in previous chapters.

- **Motor driver:** It is the *DRV8833* H-bridge mentioned before.

- **Arduino UNO board:** That is the board used for this test that has exactly the same connections and functionalities than the Bluno nano one.

- **Potentiometer:** It will be used to change the power given to the motors. The output will be read by the MCU and it will generate the corresponding PWM signal.

- **Button:** The purpose of this button is just to change the rotation direction of the motors. When it is push, the motors will turn in one direction and when it is not, they will turn in the opposite one.

In this experiment, an external power supply won't be used. Instead, the circuit will be powered with the Arduino board. This is not advisable because a problem with the motors, such as a short-circuit or a overheat can damage the board, besides, the motors need more power to work properly. For these reasons, it is a good practice to isolate the MCU power supply from the motors one. This will be implement on the final design. In 6.10 is shown a scheme of the test bed connections.

<table>
<tr><td>(a) Front view.</td><td>(b) Top view.</td></tr>
</table>

Figure 6.11: Real connections of the test bed.

Red and black wires matches with VCD and GND signals respectively. If you pay attention to the scheme, there is a little resistor in order to adjust the current that will be send to the digital input of Arduino when the button is pushed. Yellow and orange wires carry the potentiometer and button signals respectively. The light blue wire is the enable signal and the green and white wires carry the PWM signals generated by the MCU in order to control the power delivered to the motors.

The test procedure is quite simple, the Arduino UNO board is connected by USB to the computer from where it takes the power. Then, the program is charged to the board from the computer. Once that is achieved, the motors start rotating with the power gives by the potentiometer reference in clockwise direction. Subsequently,

the position of the potentiometer is changed to check that the speed of the motors changed. Furthermore, when the button is pushed, the motors stop and then resume rotating in anti-clockwise direction. Finally, in 6.11 you can see two pictures of the real connections.

6.4.2   Code of the test.

The Arduino program used for this test is so simple. It is possible to see it in the next lines of text:

```
const int switchPin = 2;      // switch input
const int motor1PinA = 11;
const int motor1PinB = 10; // H-bridge leg 1 (pin 2, 1A)
const int motor2PinA = 6;
const int motor2PinB = 5;// H-bridge leg 2 (pin 7, 2A)
const int enablePin = 13;      // H-bridge enable pin

const int sensorPin = A0; //Read potentiometer
int power = 0;      // store the value given to the PWM
bool direct = false;

void setup() {

// set the switch as an input:
pinMode(switchPin, INPUT);

// set all the other pins you're using as outputs:
pinMode(motor1PinA, OUTPUT);
pinMode(motor1PinB, OUTPUT);
pinMode(motor2PinA, OUTPUT);
pinMode(motor2PinB, OUTPUT);

pinMode(enablePin, OUTPUT);

// set enablePin high so that motor can turn on:
digitalWrite(enablePin, HIGH);

}

void loop() {

power = analogRead(sensorPin); // Read the potentiomenter.
direct = digitalRead(switchPin); //Read the switch.

//It is necesary to adecuate the potentiomenter signal
```

```
36  // to the PWM otuput value:
    power = (power * 255) / 1023;
38
    if (direct)
40  {
    // if the switch is high, motor will turn on one direction:
42  analogWrite(motor1PinB, 0);
    analogWrite(motor2PinB, 0);
44  analogWrite(motor1PinA, power);
    analogWrite(motor2PinA, power);
46  }
    else if (!direct)
48  {
    // if the switch is low, motor will turn in the other
50  //direction:
    analogWrite(motor1PinA, 0);
52  analogWrite(motor2PinA, 0);
    analogWrite(motor1PinB, power);
54  analogWrite(motor2PinB, power);
    }
56  else
    {
58  //if others, the motors will stop:
    analogWrite(motor1PinA, 0);
60  analogWrite(motor2PinA, 0);
    analogWrite(motor1PinB, 0);
62  analogWrite(motor2PinB, 0);
    }
64  }
```

The code is explained with the comments. It reads the inputs from the potentiometer and the button and generate the PWM signal according to that.

6.5 Final Test

The final test checks out that the robot works properly. For this test, it has been used the first prototype of the robot using the algorithm explained in chapter 5.
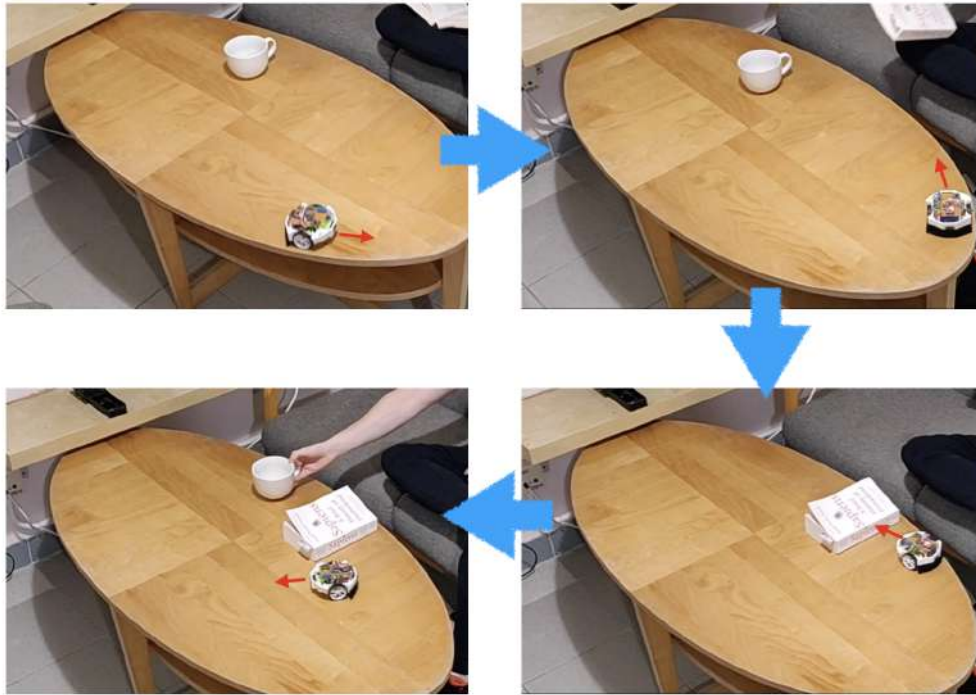

Figure 6.12: Scheme that shows the sequence of the final test.

Figure 6.12 shows how the robot behaves when it faces different problems on the table. There is also a video that shows this test and it can be found in the next link: `https://www.youtube.com/watch?v=jJccSLd0YT8`

Part III

Conclusions.

Conclusions and future work

6.6   Conclusions

After all the work developed in this project, in this section the final concepts and conclusions are exposed.

As you can see along the document, most of the aims proposed at the beginning have been achieved. However, some of them have stayed behind and they will be proposed for future work. Next are listed the goals achieved during the project:

- Design of different test beds in order to analyse the diverse subsystems of the robot.

- Design and make both the electronic system and the body of the robot, integrating everything together.

- Design and implementation of a simple algorithm that allow the robot navigate over the table safely.

- Addition of the disinfection lights to the bottom part of the robot and program the cycle of the lights.

The most challenging feature has been the reduced size that the robot must have. It includes several sensors and electronic components what makes difficult to assemble everything together in a diminished space. Although the final prototype of this project is quite small, it can be made even smaller using other motors with custom gear box and using a proper designed PCB for the whole electronic system.

Hence, the main achievement of this project has been the fulfilment of the mentioned challenge getting a prototype that, in fact, is able to carry out the main task proposed for this work.

This robot has been designed to make the Hi-NW technology portable and usable either for hospitals applications or domestics environments. Its small dimensions and

interactivity make it easy to use and manageable. Since the UV light sources has a low penetration, this application must be used as a complement of other disinfection systems.

6.7 Future work

As mentioned in the conclusions, not all the goals have been achieved. The prototype developed in this final thesis can be improved in different ways:

- As mentioned before, the size of the robot can be smaller changing some components and the body design.

- Body design can be improved giving it a more friendly appearance because it has to be sold in the market.

- For now, the robot is able to navigate the table surface avoiding the potentials hazards on it. Nevertheless, it is required to design a better algorithm that allows the robot charts a more efficient path in order to travel to the whole surface of the table.

- The hardware of the wireless connection is implemented in the robot. However, it lasts to develop the software to communicate it with a smart-phone or tablet.

- Finally, other characteristics can be included to make the robot more interactive such as a microphone for voice commands recognitions, illumination sensor that detects the light in the room or an IR sensor that detect the dirtier areas of the table.
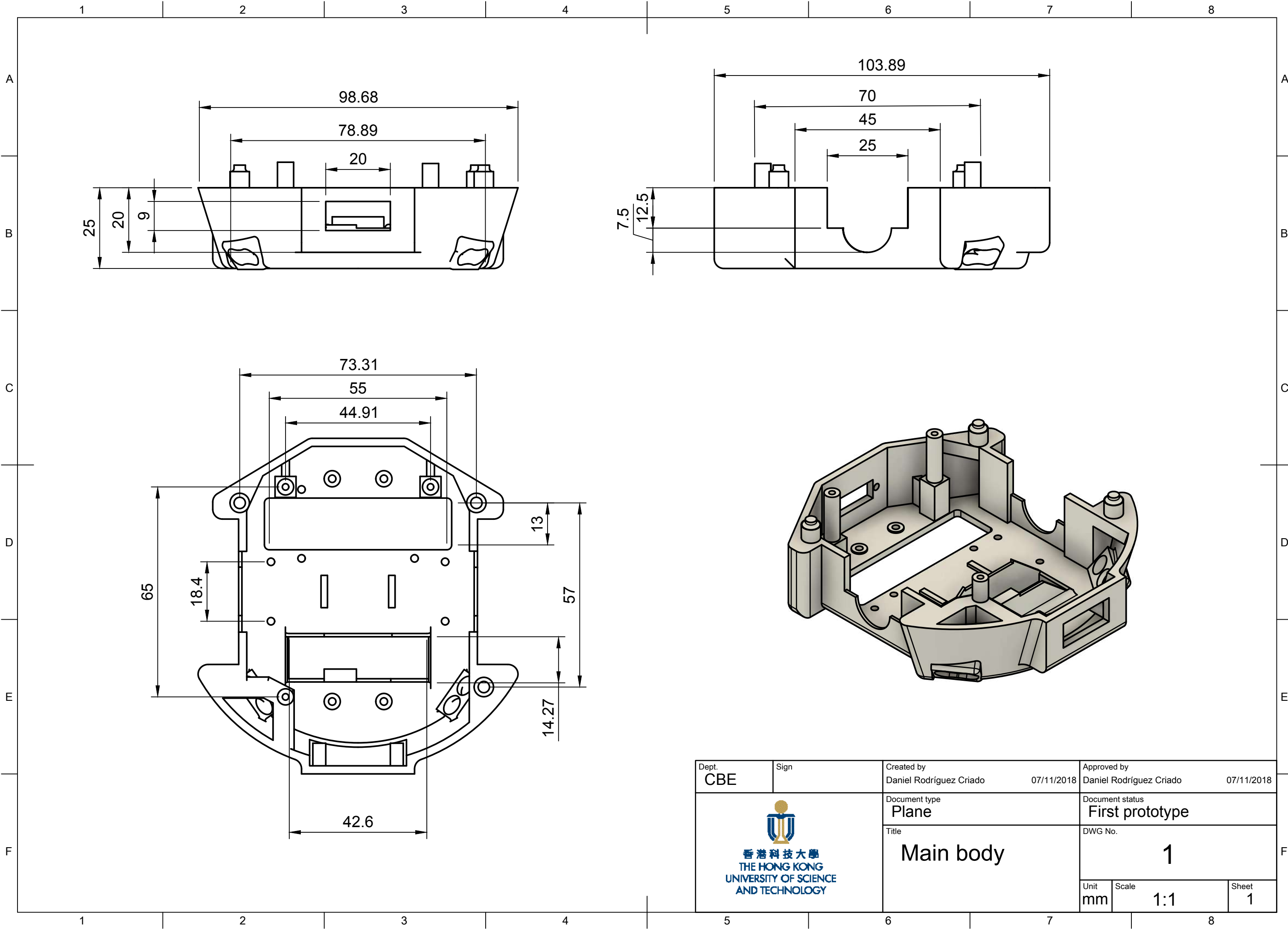
All this characteristics ar proposed as future work in order to create a proper robot for commercialization.
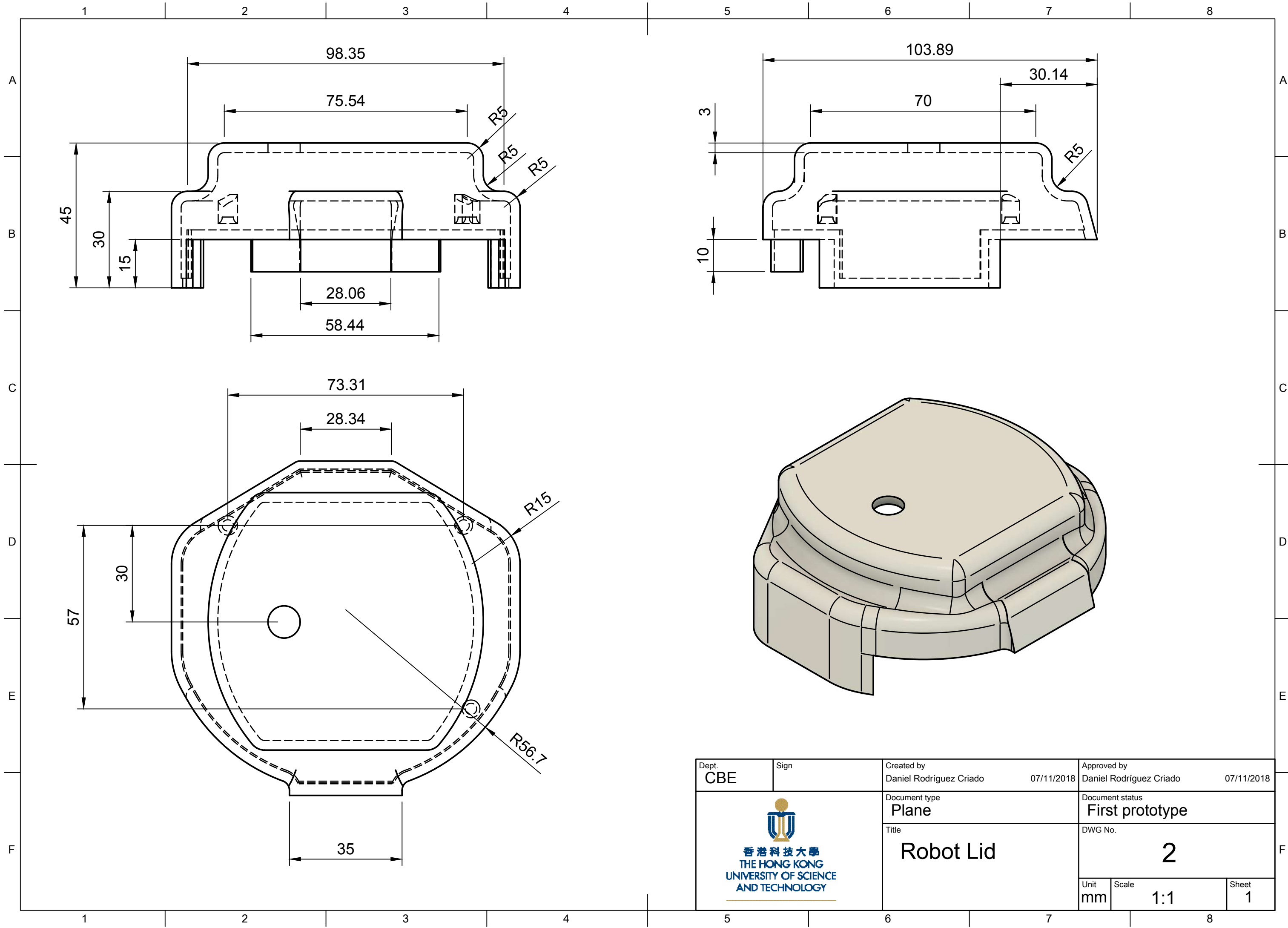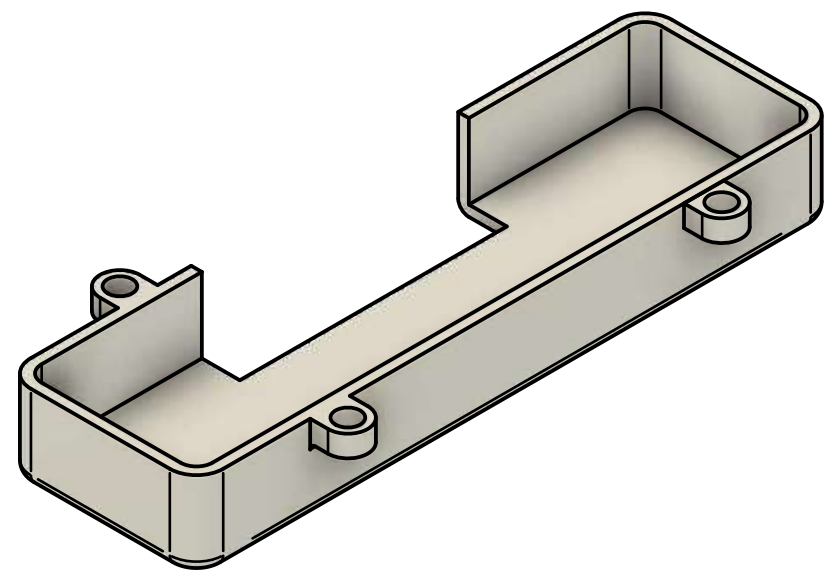
Part IV

Appendix

Appendix A

Project planes

60

38.72

8

25.05

3.53

R.5

18

1

25

Ø2.3

R2.5

35

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AND TECHNOLOGY

Document type
Plane

Document status
First prototype

Title
Battery Lid

DWG No.
3

Unit
mm

Scale
2:1

Sheet
1
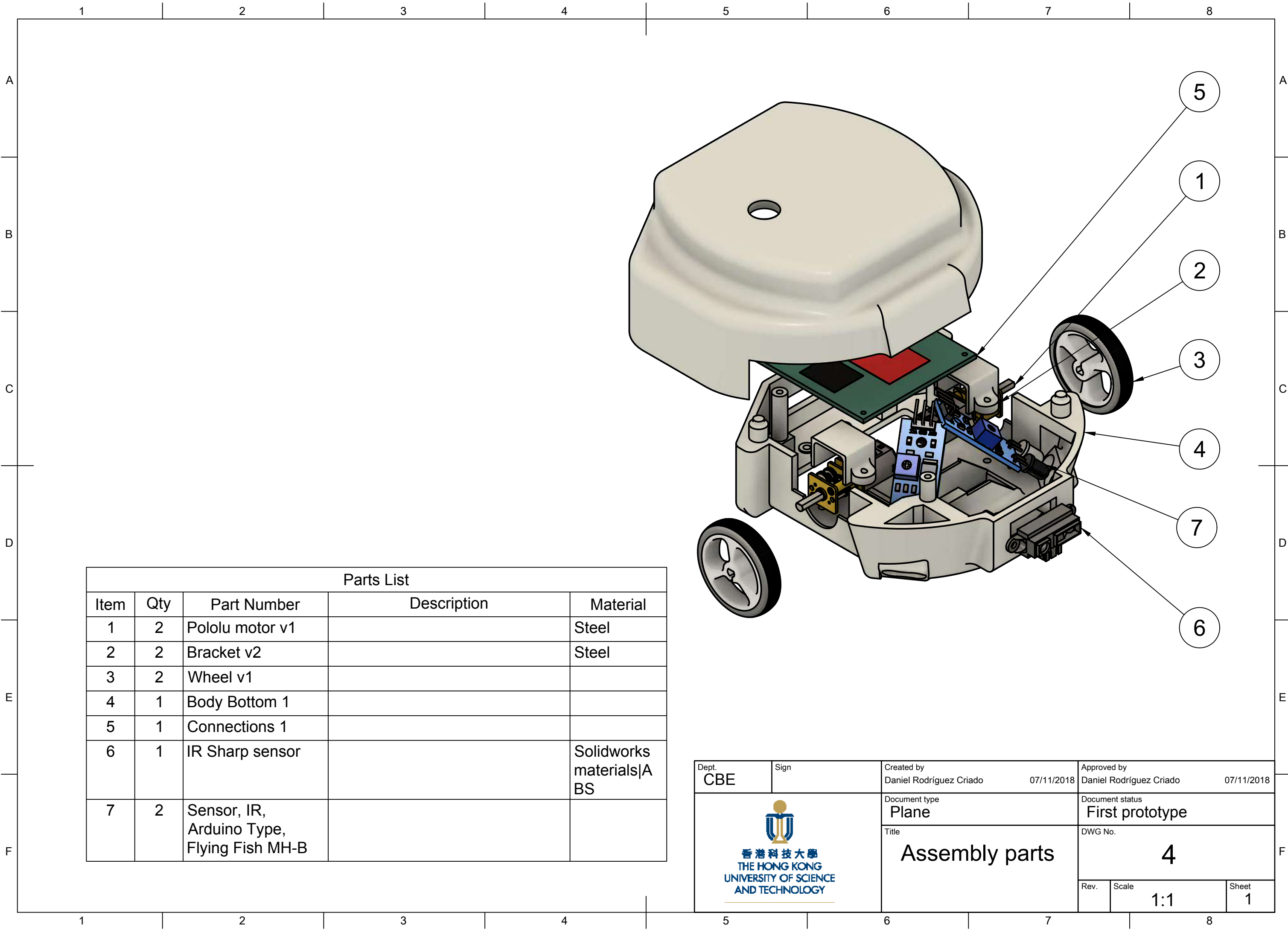
Parts List

Item	Qty	Part Number	Description	Material
1	2	Pololu motor v1		Steel
2	2	Bracket v2		Steel
3	2	Wheel v1		
4	1	Body Bottom 1		
5	1	Connections 1		
6	1	IR Sharp sensor		Solidworks materials|ABS
7	2	Sensor, IR, Arduino Type, Flying Fish MH-B		

Appendix B

Electronic schematics
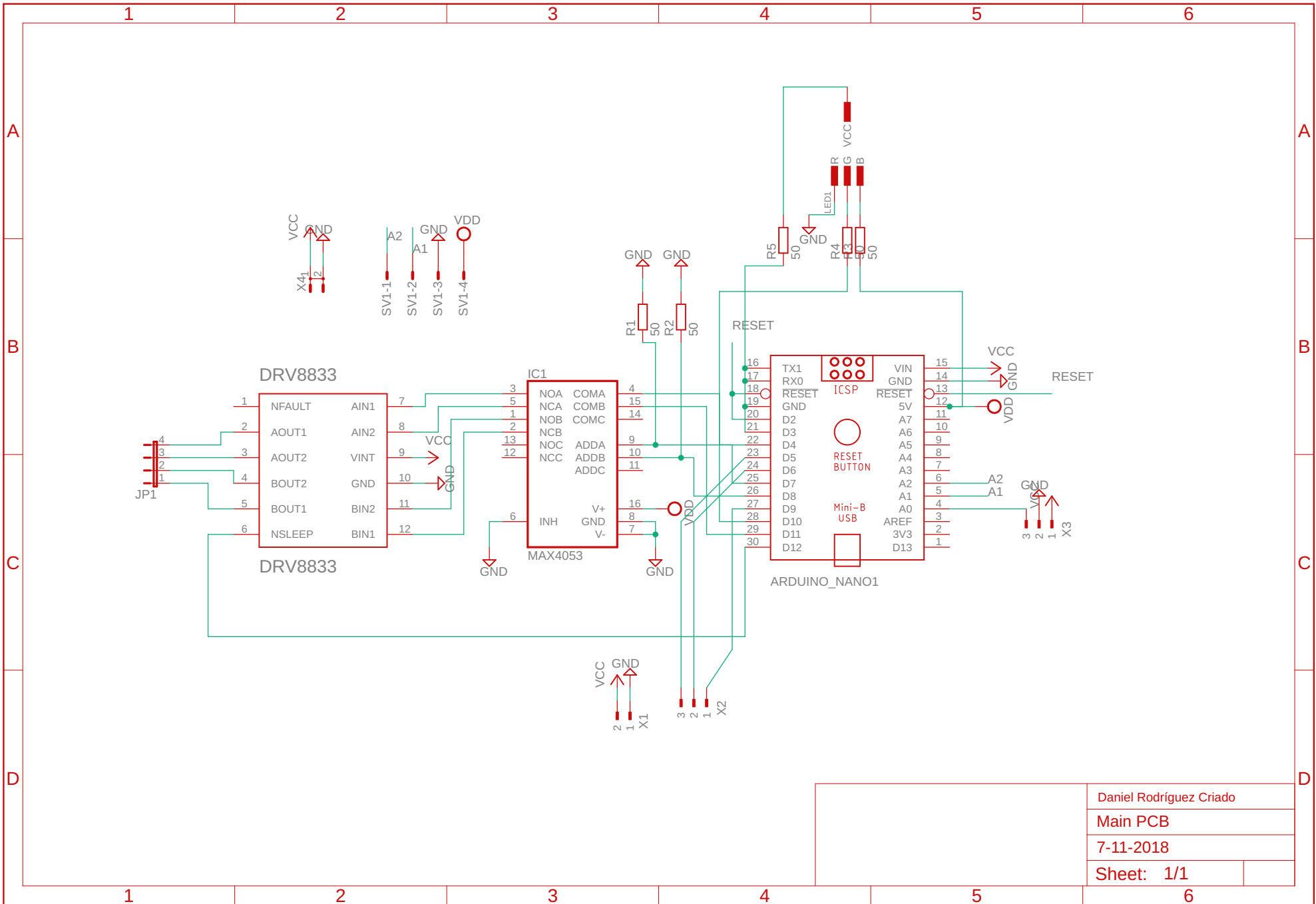
Appendix C

Arduino code of the last prototype

Contents

Hereunder you can find the full Arduino code that is implemented in the last prototype of that project. Many improvements can be applied in future work, this is only the basic frame to make it work.

C.1   main.ino

This is the main program that implements the main algorithm of the robot. It follows the scheme indicated in chapter 5.

```
1  #include "motors.h"
   #include "sensors.h"
3
   //Objects creations
5
```

```
   motor tmotor(50);
 7 sensor tsensor;
   ledRGB tledRGB;

 9
   //Other variables
11
   void setup() {
13
   tmotor.ini();
15 tmotor.stopm();
   tledRGB.ini();
17
   Serial.begin(9600); // start the serial port
19
   }
21
   void loop() {
23
   tsensor.readSensors();
25
 //     Serial.print(analogRead(edgeL));
27 //     Serial.print(" | ");
 //     Serial.print(analogRead(edgeR));
29 //     Serial.print(" | ");
 //     Serial.println(tsensor.distance);
31 //     delay(500);

33 tmotor.goStraight();

35 if (tsensor.dr > edgeThreshold || tsensor.dl > edgeThreshold || ((
       tsensor.distance <= 25) && (tsensor.distance > 10))) {
   if (tsensor.dr > edgeThreshold) {
37 tmotor.turnLeft();
   }
39 if (tsensor.dl > edgeThreshold) {
   tmotor.turnRight();
41 }
   if ((tsensor.distance <= 25) && (tsensor.distance > 10)) {
43 tmotor.turnLeft();
   delay(1300);
45 }
   }
47 else {
   tmotor.goStraight();
49
   }
51 }
```

C.2   motors.h and motors.cpp

Library with all the definitions and functions that are used to control the motors.

C.2.1   motros.h

```cpp
#ifndef MOTORS_H
#define MOTORS_H

#include <Arduino.h>

/////////////////////CONSTANT VARIABLES//////////////////////

//Motors pins

const int motor1PinA = 10;
const int motor1PinB = 11;
const int motor2PinA = 6;
const int motor2PinB = 5;
const int enablePin = 12;

//Maximum and minimum values

#define throtMAX 110    //Maximum throttle
#define throtMIN 20     //Minimum throttle
#define throtNOM 35     //Nominal throttle

////////////////CLASS DEFINITION////////////////////////

class motor {

int power, powerB;

public:

motor(int p=throtNOM) : power(p) {}  //Constructor of the class

//Other methods
void turnRight(); //turn right
void turnLeft();  //turn left
void ini();              //Initialite motors
void stopm();             //stop motors
void goStraight();       //Resume motors
void goBack();        //Go backwards
```

```
40 };

42 #endif
```

C.2.2 motros.cpp

```cpp
1 #include "motors.h"

3
  /////////////MOTOR CLASS DEFINITIONS///////////////////
5
  void motor::ini(){
7
  // set all the other pins you're using as outputs:
9 pinMode(motor1PinA, OUTPUT);
  pinMode(motor1PinB, OUTPUT);
11 pinMode(motor2PinA, OUTPUT);
  pinMode(motor2PinB, OUTPUT);
13
  pinMode(enablePin, OUTPUT);
15
  powerB = 1.21 * power;    //Motor compensation
17 }

19 void motor::stopm(){

21 //Reset motors:
  analogWrite(motor1PinA, 0);
23 analogWrite(motor2PinA, 0);
  analogWrite(motor1PinB, 0);
25 analogWrite(motor2PinB, 0);

27 // set up the enable pin to LOW (not enable):
  digitalWrite(enablePin, LOW);
29 }

31 void motor::goStraight(){
  // set up the enable pin to HIGH(enable):
33 digitalWrite(enablePin, HIGH);

35 //Go straight:
  analogWrite(motor1PinA, power);
37 analogWrite(motor2PinA, powerB);
```

```cpp
   digitalWrite(motor1PinB, 0);
39 digitalWrite(motor2PinB, 0);
   }

41
   void motor::goBack(){
43 // set up the enable pin to HIGH(enable):
   digitalWrite(enablePin, HIGH);

45
   //Go Backwards:
47 analogWrite(motor1PinA, 0);
   analogWrite(motor2PinA, 0);
49 digitalWrite(motor1PinB, power);
   digitalWrite(motor2PinB, powerB);
51 }

53 void motor::turnRight(){
   // set up the enable pin to HIGH(enable):
55 digitalWrite(enablePin, HIGH);

57 //Go right:
   analogWrite(motor1PinA, 0);
59 analogWrite(motor2PinA, power);
   analogWrite(motor1PinB, power);
61 analogWrite(motor2PinB, 0);
   }

63
   void motor::turnLeft(){
65 // set up the enable pin to HIGH(enable):
   digitalWrite(enablePin, HIGH);

67
   //Go left:
69 analogWrite(motor1PinA, power);
   analogWrite(motor2PinA, 0);
71 analogWrite(motor1PinB, 0);
   analogWrite(motor2PinB, power);
73 }
```

C.3   sensors.h and sensors.cpp

Library with all the definitions and functions that control the status LED and the sensors of the robot.

C.3.1   sensors.h

```cpp
#ifndef SENSORS_H
#define SENSORS_H

#include <Arduino.h>

///////////////////CONSTANT VARIABLES//////////////////

//LED RGB
const int LEDB = 2;
const int LEDR = 3;
const int LEDG = 4;

//Sensors
const int sensorFront = A1; //Read SHARP IR sensor
const int edgeR = A5;      //Read Right edge IR sensor
const int edgeL = A4;      //Read Left edge IR sensor

#define edgeThreshold 900

////////////////CLASS DEFINITION///////////////////

class sensor {
float volts = 0.0; //Volts measured by the sensor

public:
int distance, dl, dr; //Distance measured by the sensor
void readSensors();


};

class ledRGB {

public:
void allOff();
void ini();
void blue();
void green();
```

```cpp
   void red();
40 void mixColor(char r, char g, char b);
   };

42
   #endif
```

C.3.2   sensors.cpp

```cpp
   #include "sensors.h"
2
   //////////////SENSOR CLASS DEFINITIONS//////////////////
4
   void sensor::readSensors() {
6
   //Read edge sensors
8  dr = analogRead(edgeR);
   dl = analogRead(edgeL);
10
   //Read the IR sensor:
12 volts = analogRead(sensorFront) * 0.0048828125; // value from sensor *
      (5/1024)
   distance = 13 * pow(volts, -1); // worked out from datasheet graph
14 delay(1); // slow down
   }
16

18 //////////////LEDRGB CLASS DEFINITIONS//////////////////

20 void ledRGB::ini() {
   pinMode(LEDR, OUTPUT);
22 pinMode(LEDR, OUTPUT);
   pinMode(LEDR, OUTPUT);
24 this->allOff();
   }
26
   void ledRGB::allOff() {
28 digitalWrite(LEDR, LOW);
   digitalWrite(LEDG, LOW);
30 digitalWrite(LEDB, LOW);
   }
32
   void ledRGB::blue() {
34 digitalWrite(LEDR, LOW);
```

```cpp
digitalWrite(LEDG, LOW);
digitalWrite(LEDB, HIGH);
}

void ledRGB::green() {
digitalWrite(LEDR, LOW);
digitalWrite(LEDG, HIGH);
digitalWrite(LEDB, LOW);
}

void ledRGB::red() {
digitalWrite(LEDR, HIGH);
digitalWrite(LEDG, LOW);
digitalWrite(LEDB, LOW);
}
```

Appendix D

Project budget Estimate

Table D.1: Estimate budget of the project.

Price for one robot unit					
Expenses	**Price HKD**	**Unit**	**Amount**	**Total HKD**	**EUR estimation**
Main components					
Motor	60	Component	2	120	13,2
LiPo battery 1000mAh, 20C and 7.4 volts	55	Component	1	55	6,05
Bluno Nano board	240	Component	1	240	26,4
SHARP IR senosr GP2Y0A51SK0F	105	Component	1	105	11,55
Digital IR sensor	35	Component	2	70	7,7
Prototyping or custom PCB	15	Component	1	15	1,65
Expendable Material					
Connector for 9V battery	5	Component	1	5	0,55
Charger for LiPo batteries	55	Component	1	55	6,05
RGB LED	5	Component	1	5	0,55
Wires and connectors	50	Box	1	50	5,5
Wires Jumpers	5	Component	6	30	3,3
Heat shrinkable sleeve	0,1	cm	50	5	0,55
Disinfection LEDs					
UV-C LED LG LEUVA66B0 0HF00	475	Component	1	475	52,25
Wavelength 405 LED NCSU275T	105	Component	1	105	11,55
Wavelength 470 LED LB G6SP- V2BB-35-1	7	Component	1	7	0,77
			Total in:	**HKD**	**EUR**
				1342	147,62

Final approximation of the budget for one prototype is ONE THOUSAND AND THREE HUNDRED FORTY TWO Hong Kong Dollars or ONE HUNDRED FORTY SEVEN WITH SIXTY TWO Euros.

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