Interdisciplinary course of

Design and Robotics

9° edition, 2021

Project:
Pluto

Professors:
Andrea Bonarini, DEIB department, Politecnico di Milano
Maximiliano Romero , Design department, IUAV, Venice University

Tutors:
Rohan Vangal

Students:
Francesco Montanaro, school of Industrial and Information Engineering
Francisco Martins Carabetta, school of Design
Mahmoud Badawi, school of Industrial and Information Engineering
Matteo Rubiu, school of Industrial and Information Engineering
Somaiya Afzal, school of Design

Index

Abstract

Pluto, is a robot designed for the space permanent exhibition at the ‘Museo della Scienza e della Tecnologia’. The robot was designed in mind with two different phases, the first one being at a public space and the second one placed at the exhibition. We decided the public place would be a cinema or shopping mall specifically due to our main target audience which is children. The robot was designed with families in mind but children being the main target market. During the first phase, Pluto explores the environment, captivating the attention of people, and allowing them to interact with Pluto. During the second phase, Pluto follows a predetermined path whilst sharing facts about the planets in the solar system.

In this report we will explain all the development processes, starting from the definition of what our robot will do, until the actual robot Pluto. The report is divided mainly in 4 sections: Discover, Define, Development and Deliver, which summarize what we did during these weeks. A particular effort is given to the description of the functionalities, the strategies, the electronics, the coding and the design. Any problems that we encountered are also stated and how we resolved them in order to respect the deadlines we imposed.

Project Management

Team Organization

Our team is composed of:

- Francesco Montanaro, Computer Science Engineer
- Francisco Martins Carabetta, Designer and Engineer
- Mahmoud Badawi, Automation and Control Engineer
- Matteo Rubiu, Computer Science Engineer
- Somaiya Afzal, Industrial Product Designer

The *team leader* is Matteo Rubiu, and our responsibilities are the following:

1. Francesco Montanaro: **Hardware tech manager**
2. Francisco Martins Carabetta: **Art director**
3. Mahmoud Badawi: **Rapporteur**
4. Matteo Rubiu: **Software tech manager**
5. Somaiya Afzal: **Schedule manager**

We consider these only as formal responsibilities, as we worked together overall in order to ensure the work is distributed well and tasks can be accomplished.

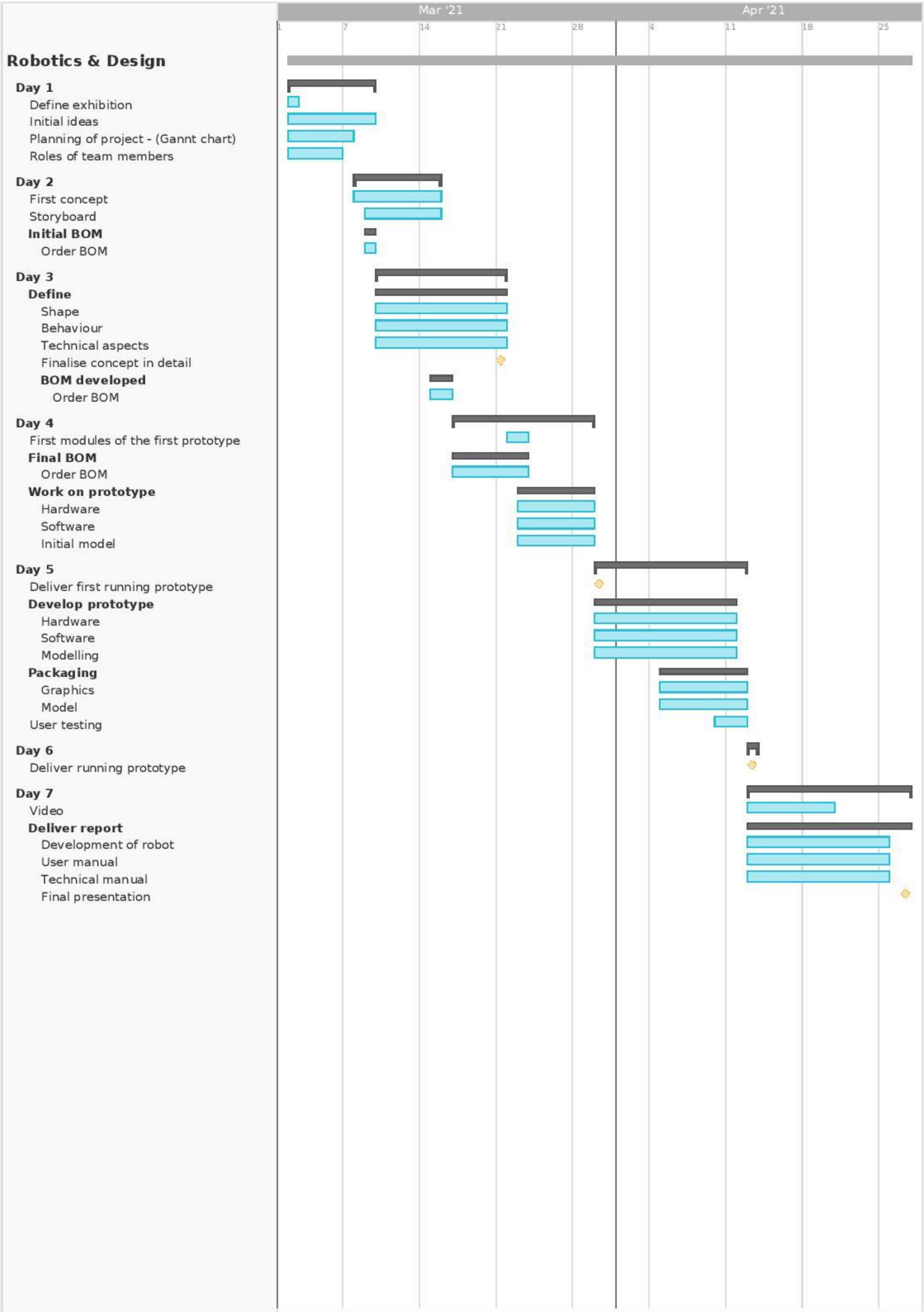
Time Organization

In order to manage our time we made a Gantt chart where we broke down the tasks that need to be accomplished. As you can see it was broken down according to each week and what should be accomplished for each week. The yellow diamonds highlight milestones that must be met by the team and are vital in order to make sure we stay on track.

Each week we made sure to meet outside of lesson time so that we could work on the robot and address what needed to be done for that week.

To see the Gantt chart in detail look at the attachment.

teamgantt
Created with Free Edition



Phase 1: Discover

In this phase we started to organise ourselves, the team management, the tools we will use to communicate and we started to develop a common language. We also ideated and discussed what our robot could potentially look like and what the functionalities of it was. In order to specify what our robot would be, we took different factors into consideration.

Research

Before we were able to identify an exhibition that we wanted to work on, we took to research on 'google arts' exhibitions that were currently going on. We also discussed as a team our interests so that we would be able to identify an exhibition that everyone would be happy to work on. We found that something that would be more science related was of interest to all of us, however we wanted to still be able to play with the creativity of the character of the robot.

Exhibition

The exhibition that we have chosen to develop a robot for is the space permanent exhibition- at the 'Museo della Scienza e della Tecnologia'. Situated in Milan the exhibition tells 'stories, knowledge, and technologies for exploring the cosmos, from antiquity to the present'. Structured according to two main themes which are 'Observing space from the Earth' and 'Going into space', it presents fascinating and original objects such as the only fragment of the moon anywhere in Italy! The part that struck us when researching is when the website stated 'The exhibition opens with the large Merz-Repsold telescope, the same one that Giovanni Schiaparelli used to observe and describe the surface of Mars, contributing to the birth of myths about Martians,' we thought to make our robot inspired by a Martian.
The following shows a Moodboard that we used as inspiration for our 'Martian robot'.

(*Figure 1*)

Concept

The following mood board shows the inspiration used for our robot. As we are targeting children we decided to go with something that would make children curious and therefore decided on an alien sitting in a spaceship.

(*Figure 2*)

Robot strategies

Before we decided the strategies and functionalities of what the robot will do, we defined our target audience so that it was suited to their needs. As many families visit the museum, we decided that we should focus on this, in particular on children. Therefore we defined our target audience as children between the ages of 7-12. As children are curious we are aiming to incite this curiosity whilst giving them an opportunity to learn through images, videos, objects and facts about the cosmos and space exploration.

As phase 1 specified for the robot to be in a public space we contemplated where would be the most suitable place for it, where it would still interact with children. Initially we thought to either put it in a train station or airport but we decided against this as in these places usually people are passing through quickly. We wanted a place where people usually go when they have time and we decided that shopping malls, cinema spaces would be the best place to put our robot, as shown in figure 3.This way it could interact with children and families.

(*Figure 3*)

In phase 2 ,as the robot would be placed in the exhibition, we decided to place the robot at the entrance of the exhibition. This was decided due to a variety of reasons which included the need for space so that visitors were able to view the robot but it would not obstruct them from other exhibits, and so that we could arouse children's curiosity before entering the exhibition.

(*Figure 4*)

In order for the robot to be able to function in both places we identified what we want the robot to do:

1. Attract the child, young people and adults to the virtual exhibition as this was specified in phase 1 of the brief.
2. Entertain them with movements and sound as children like something different.
3. Inform the parents/adults of curiosities of the exhibition so that they are able to learn about space.
4. Interact with the target audience to keep their attention.

Functionalities

As per specified by the brief we started to ideate what the robot would do during the two different phases. The phases are as follows:

Phase 1 - Outdoor:

1. The robot starts singing to attract people.
2. The robot provides a QR code in order to let the people visit a website to input commands to obtain information.
3. The robot can express the "first reaction of a martian with a human" - robot be scared or/and curious in human presence.

Alternative:

1. The robot sings to attract people.
2. When in close proximity it reacts in a surprised way with human presence.
3. Proceeds to tell the audience "Hi there, if you are interested to see my planet, please scan my QR code".
4. Users scan the QR code and can take a virtual tour of the exhibition.

Phase 2 - Indoor:

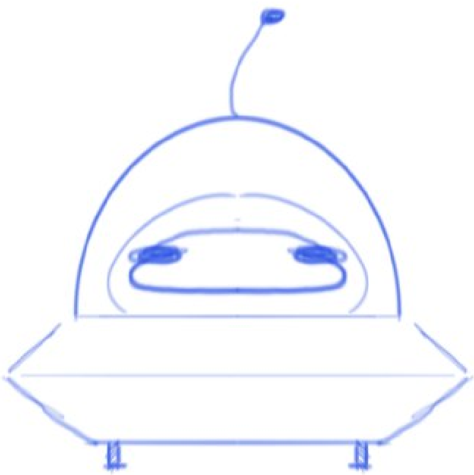
1. The robot can move across different "planets", positioned on planets in a vertical line, and expresses some curiosities about them.
2. The robot lets the children follow it to "explore the solar system".

Phase 2: Define

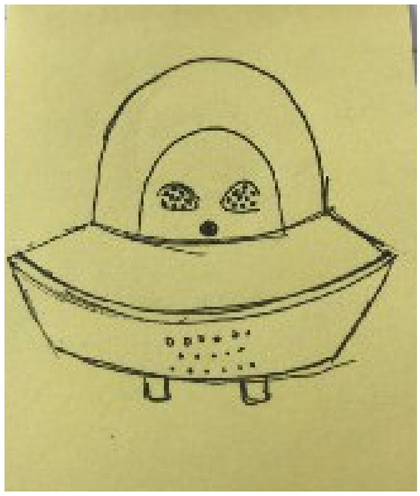
After a broad research we began to define specific goals. Through defining these specific goals we were able to refine our idea and begin to make our initial prototype. The following section will show what we defined for the robot.

Concept

For the concept we defined that there will be a martian sat in a spaceship with only the martian head showing enclosed in a clear dome. The martian head could possibly have an antenna as well. At the bottom of the spaceship there will be wheels that will help the spaceship move around.



(*Figure 5*)



(*Figure 6*)

Functionalities

In order to define how the robot will work we first defined the functions of the robot:

- Interaction with the user by detecting people around and getting scared of them.
- Answer to questions that a person inputs from the website.
- Promote the visit to the virtual exhibition.
- Let the children follow it to explore the solar system by giving curiosities about the planets.

Strategy

In order to explain the strategy of the robot it will be defined in its two phases.

First phase:

- The robot moves randomly with a constant speed in a specific area, waiting for people.
- The first interaction with a person will be detected with the ultrasonic sensor and then the robot reacts with many movements:
    - It goes backwards with a sudden movement
    - The head rotates and at the same time it hides going down with a motion in the vertical direction through the use of mechanics
    - The eye goes up and down through the mechanics connected with the LED matrix and it shows scared/surprised expressions
    - The robot say to the expectator to scan his QR code
- People can scan the QR code and input 3-4 questions to the robot regarding the exhibition.
- The LED strip around the spaceship will light up when the robot is talking which will be accomplished through the code.

Second phase:

- The main function of the robot in the second phase is to follow a line using Infrared sensors and an RFID sensor, with RFID tags positioned on the various planets. When the robot arrives at a planet it stops and gives some information/curiosities exploiting the speaker and showing through the LED strip the colour of the specific planet.

Electronics

After we defined the strategy and functionalities of the robot we were able to start thinking about the electronics that our robot would use. The following list of electronics shows our initial BOM and for what purpose we will be using the chosen electronics:

Electronic:	**Number of component:**	**Reason for use:**
Arduino uno board	1	Used to program the robot and connect all the components together
RFID module	1	To detect the NFC tags in the second phase
Servo Motor SG90	1	To move the eye
Stepper Motor	1	Used to rotate the head
UN2003 stepper motor driver module	1	Used to control the stepper motor through Arduino
Ultrasonic sensor	1	To detect people and make the head react
MAX7219 LED matrix module	1	Used for the eye
DC motor	1	It was tried for the vertical movement of the head
Breadboard	1	To create the circuits for the connections

Structure

The base of the robot, which is the space ship, will be 3D printed due to the shape that we want to achieve with a LED strip running across the edge. The head of the martian poking out of the base will be also made by 3D printing and will have a ‘LED matrix’ as an eye, which will be used to show expressions. The top of the robot will be made out of an acrylic clear dome as a ‘helmet’ of the spaceship and finally at the bottom of the spaceship there will be three wheels, two actuated wheels and one caster wheel that is free to move only to guarantee stability so that there are three points of contact.
The internal structure with the mechanics and electronics of the robot will mostly be hidden either in the base of the robot (spaceship) or on the inside of the martian head so that it is not visible.

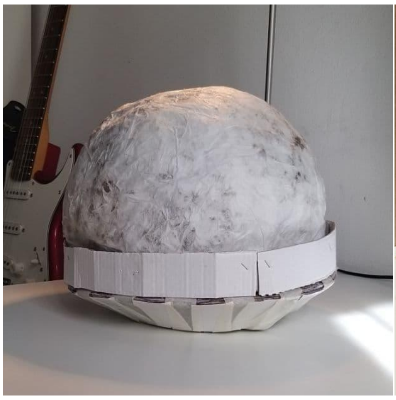
Whilst designing the robot we are also emphasising on making sure that the robot will be able to be taken apart ,if needed, so that if any of the electronics need to be changed it can be accessed without a problem.

(*Figure 7*)

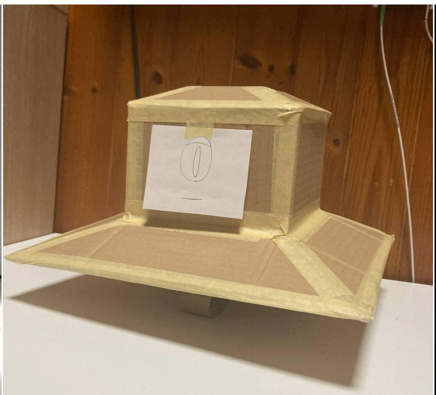
(*Figure 8*)

Shape

Each member of the team made an initial prototype made out of cardboard to test working with different dimensions, shapes and sizes as well as the aesthetics. Even though the overall form of the robot was the same as decided through our ideation, we decided to see how changing size and structures would change the overall form. This can be seen in figures 9-13 below. We had to also take into account that the robot would need to enclose all of the hardware/electronics in order for the robot to work.

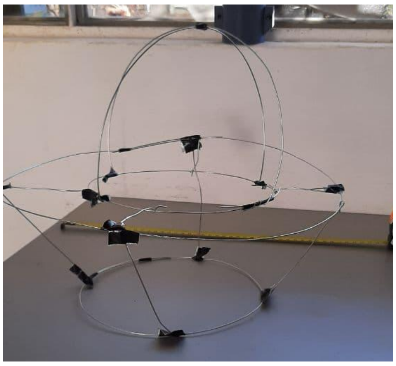


(*Figure 9*)



(*Figure 10*)

(*Figure 11*)



(*Figure 12*)

(*Figure 13*)

As you can see from our models just changing the shape can make such a big difference to the overall aesthetics of the robot. However this is not the only thing to consider when making the robot, most importantly we should consider the internal structure and how the electronics and mechanics will fit within this comfortably.

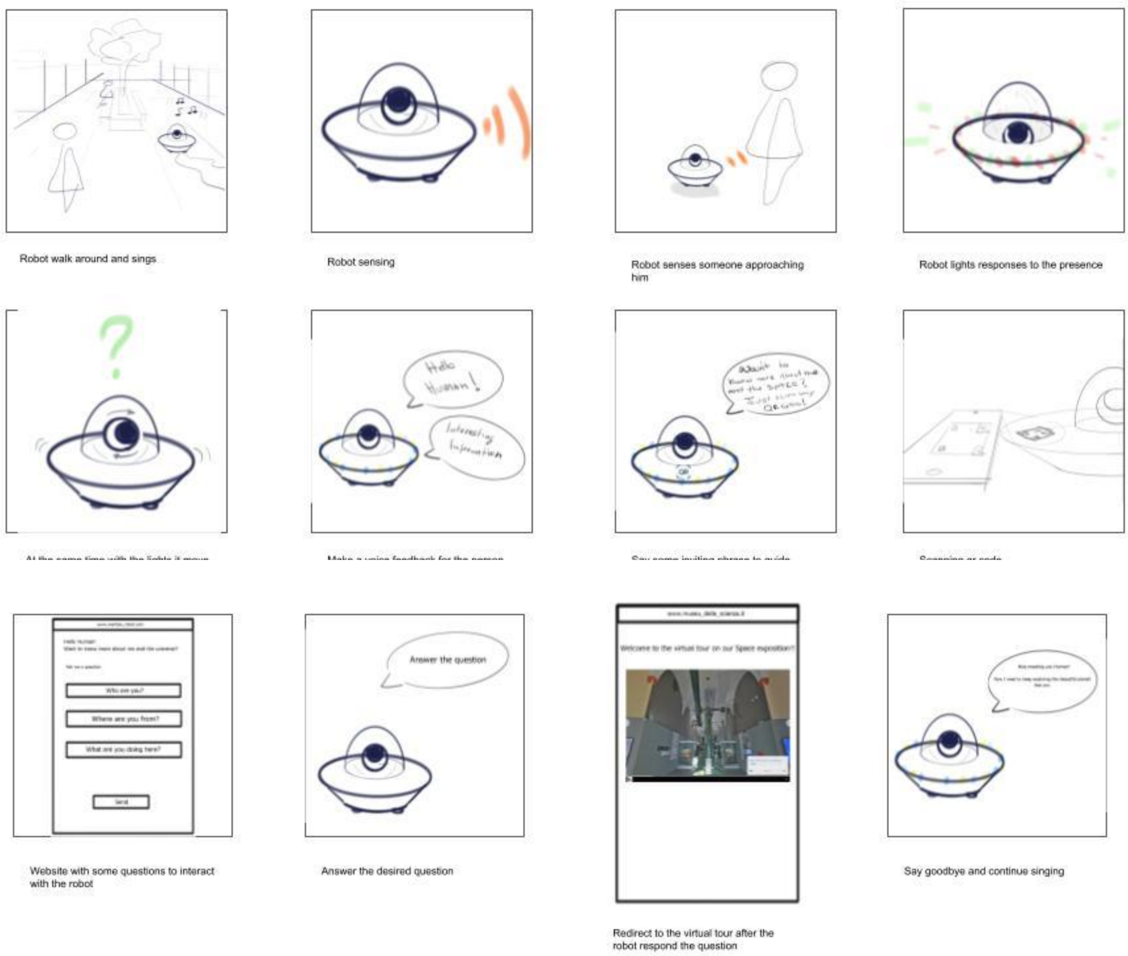
Phase 3: Development

In this phase we describe the development process, departing from the first prototype to the final improvements.

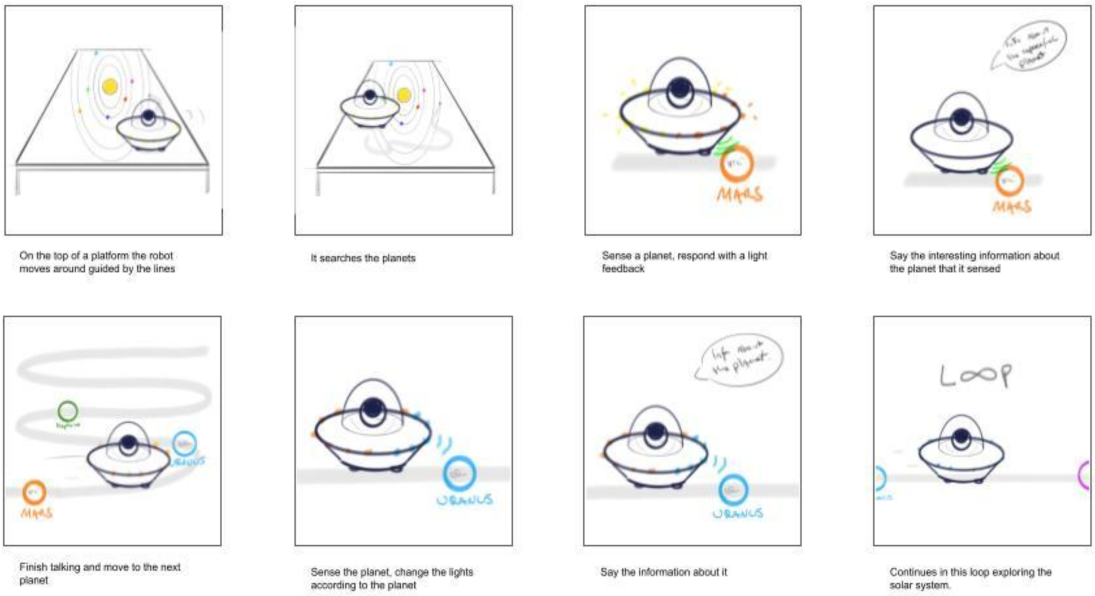
Strategy

We made a storyboard to define what the robot would do and how it would interact with the users at different stages.

Storyboard - Phase 1



Storyboard - Phase 2



Electronics

In this part we describe our first connections among the electronic components that we used at the beginning, considering also some problems that we faced and how we solved them. In the development phase still we didn't consider the power supply and the connections at the beginning were done using a breadboard.

Sensors

The main sensors that we used to make the robot behave in an autonomous way are:

- 4 ultrasonic sensors HC-SR04 , used to detect people and so to trigger the head movements and to activate the motors when the robot goes backwards and scares.
- 2 IR sensors, used to follow the line in the second phase.
- RFID module, used to detect RFID tags in the second phase to state curiosities about the planets.

Actuators

To make the robot be able to move and react we decided to use the following actuators:

- 2 DC motors, with L298N driver in order to control them, to move the robot.
- 2 Micro Servo 9g SG90, used for the eye rotation and the head rotation around the vertical axis.
- Servo Motor MG996R for the motion of the head along the vertical axis.

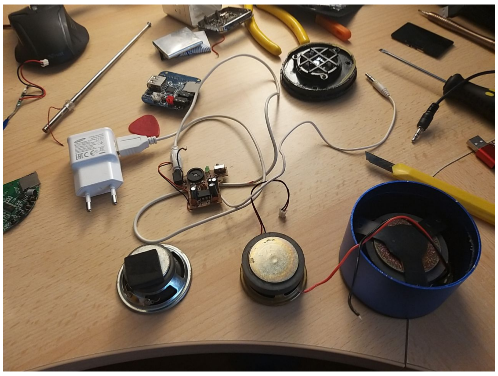
First we tried to obtain the head rotation and the up-down motion with a stepper motor and a DC motor without a gearbox, but this was not suited very well for our purpose since the stepper motor requires a dedicated driver and was also too slow whilst the DC motor had a too high speed.

Lights

Regarding the lights we have basically 2 components: the LED matrix MAX7219 to simulate the eye and give the expressions and an RGB LED strip to enforce the robot's reaction and to make the robot more attractive.

Sound

In order to express sounds and make the robot be able to speak we introduced a speaker that we found at home and we did some hacking to make it suitable for our purpose, as you can see from figure 14.
By the way in the end, we found out this speaker was not loud enough, so we opted for using another JBL bluetooth speaker, connected directly through the AUX output, and powered by USB, for providing power continuously, even with a dead battery.



(*Figure 14*)

Logic Board

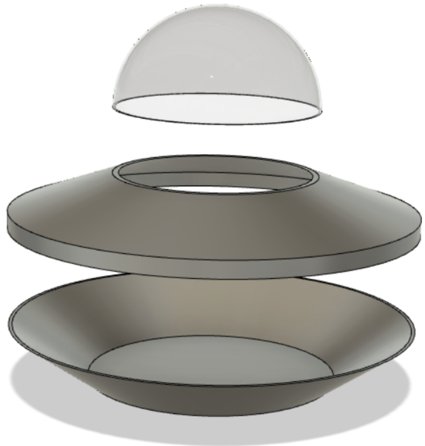
At the beginning our main microcontroller was Arduino UNO, but by adding more and more elements in our robot we discovered that this board was not enough in terms of number of pins. We solved this problem by adding a Raspberry pi zero, and we chose this one for mainly two reasons:

1. As already said the number of pins was not enough.
2. With the Raspberry Pi zero we could easily implement the internet connection over wi-fi and the speaker simply could be connected through a simple USB sound card.

Shape

The shape of the robot was developed to make the base wider, more like an UFO. By having a wider base also meant that it would be able to mount electronics on the base of the robot.

(*Figure 15*)

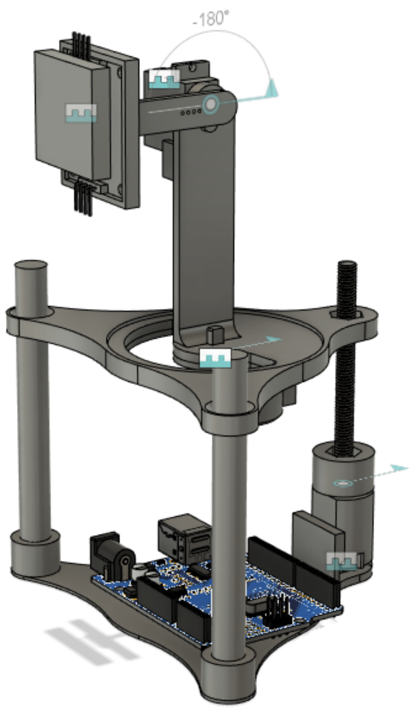


(*Figure 16*)

(*Figure 17*)

We changed the shape to encompass the electronics as well as the mechanics. As you can see due to the positioning of certain components such as the sensors and the LED strip that will go around the spaceship, this also affected the change. For the dome head, that is clear, we used a standard size of 20 cm of diameter. Thus this also determined the size of the martian's head that is inside of the dome.

Mechanics



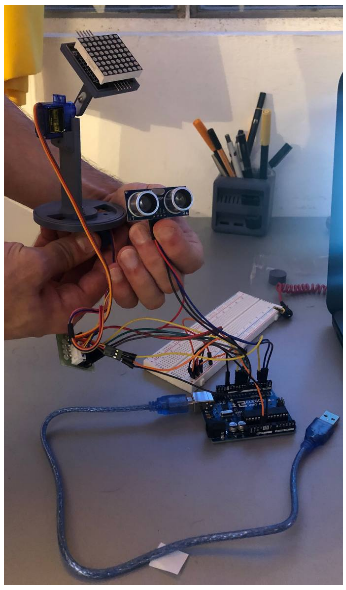
(*Figure 18*)

As we want the robot's head to go up and down imitating a turtle that hides when shy or scared, we created a mechanism that would imitate this. The following figures from 18 to 21 show how this was implemented. As well as the head going up and down the eye would move slightly up and down. The LED matrix is the eye and the arm extended moves this up and down on a rotation from a Servo Motor.

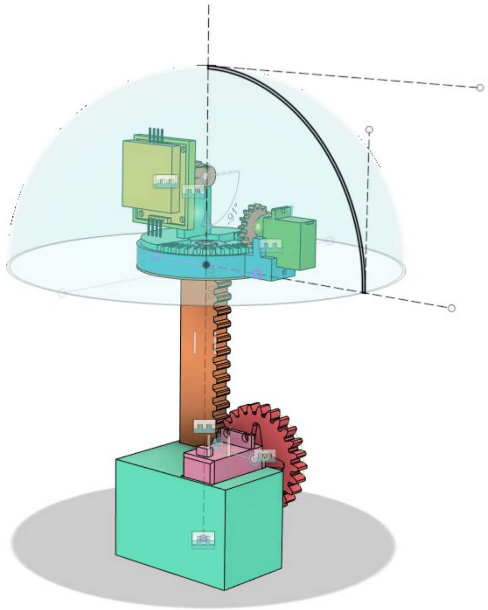
However the main problem with this mechanism was that it was not smooth enough moving up and down and there was a problem of it coming loose.
The matrix eye extended by an arm however worked well and we tested this with a sensor as shown in figure 21.

(*Figure 19*)

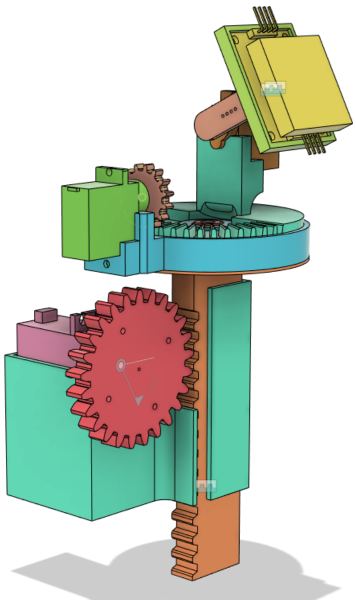
(*Figure 20*)



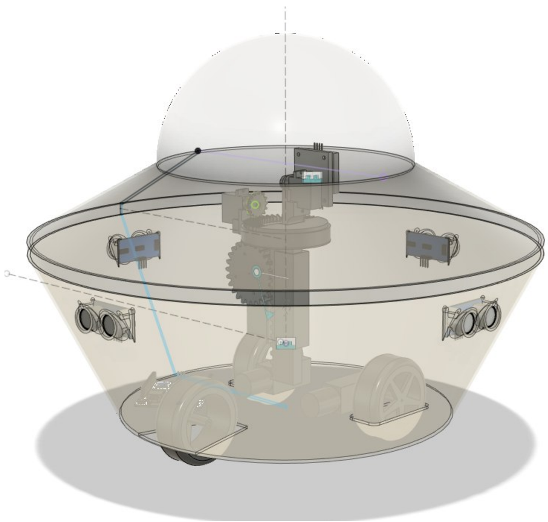
(*Figure 21*)



(*Figure22*)

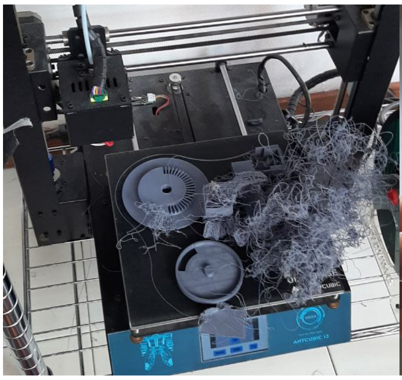


(*Figure 23*)



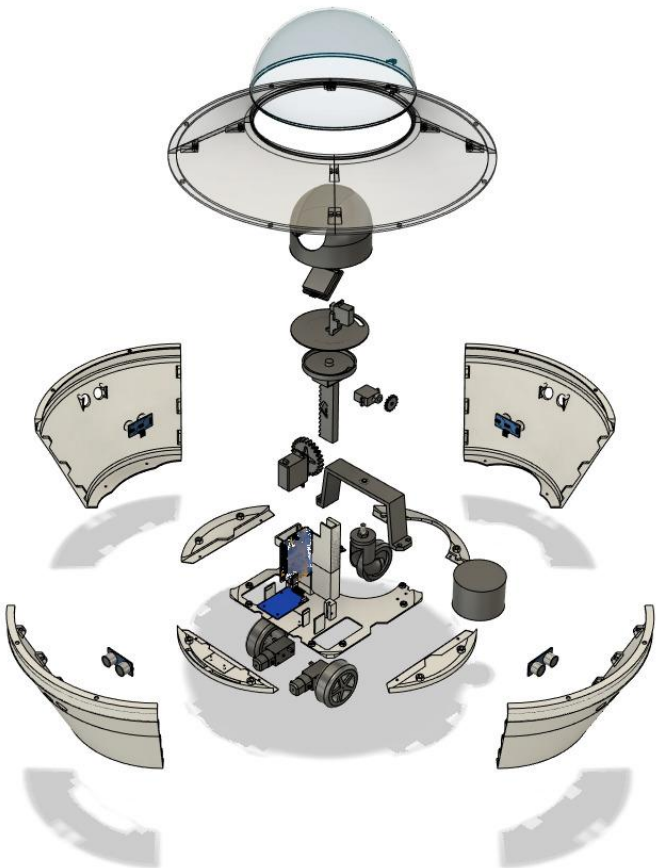
We then changed the mechanism to a rack and pinion with gears. When initially designed and 3D printed there was a problem as a support for the rack was not in place and therefore it moved around. Once the small support was put into place this stopped the rack from moving around. In terms of executing the up and down action of the head, the rotation of the head and moving the eye slightly up and down, the mechanism worked well. Below, figure 26 shows the printed mechanism and how the dome would look over it.

(*Figure 24*)



(*Figure 25*) - on left
(*Figure 26*) - on right

We also had a problem with 3D printing as shown in figure 25 which was most likely due to the PLA not sticking to the bed of the 3D printer.



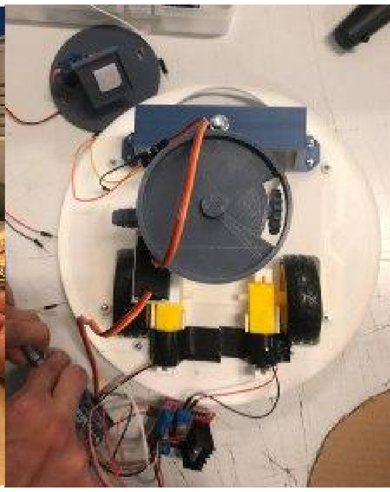
(*Figure 27*)

The exploded drawing on the left shows the arrangement of the mechanisms as well as other pieces within the robot.

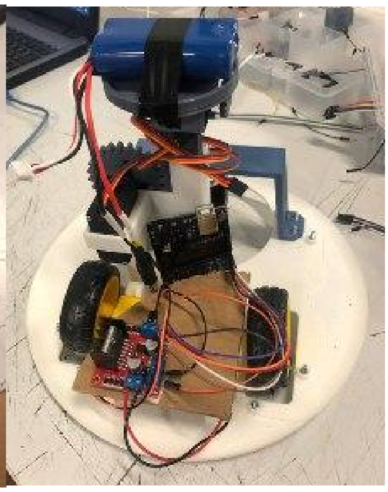
We also developed the mechanism further as it was flipped around. This was due to space management and so that we could attach the head of the martian to the mechanism directly.

It is also present a small change in the position of the Micro Servo to rotate the head, since before was not placed in the center and in this way the components were not balanced in terms of gravity force. Now the motor is under the plate of the head positioned horizontally and no more vertically.

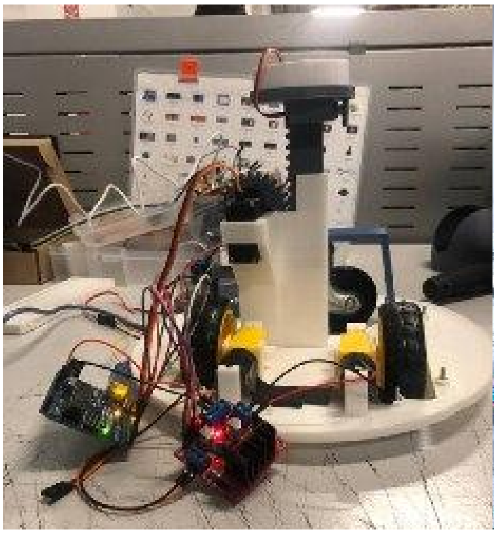
(*Figure 28*)

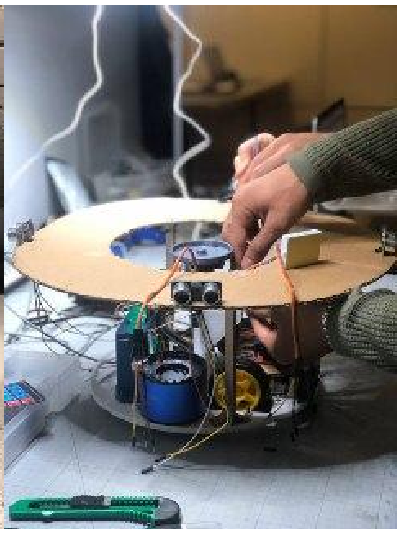


(*Figure 29*)



(*Figure 30*)





We mounted the mechanisms and electronics and used the cardboard model which is explained in the following section.

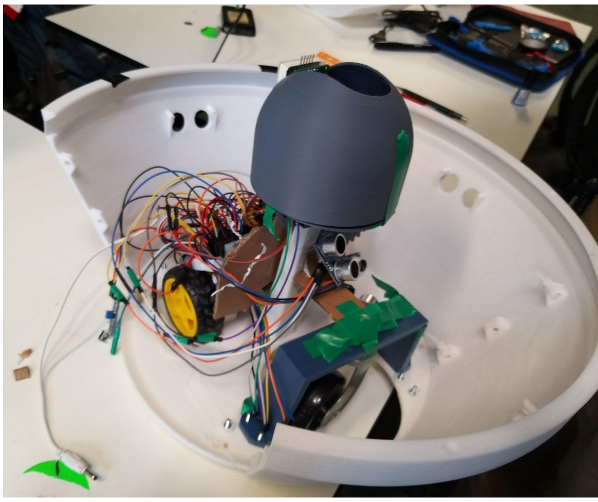
(*Figure 31*) (*Figure 32*)

Structure

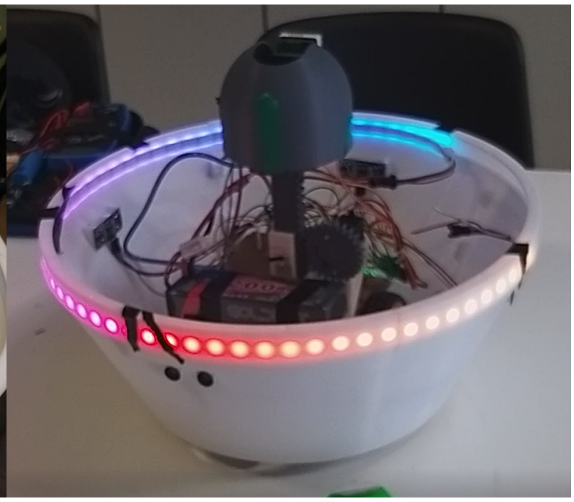
Before 3D printing we made the main structure out of cardboard. This was so that we could finalise whether the size we chose was correct and how it would arrange together. As we were happy with the structure we then moved onto 3D printing starting with the base which is shown in figures 28-32.

(*Figure 33*) (*Figure 34*)

After printing the base we then printed the casing of the bottom section of the robot. This section is the main part that withholds the components so it was very important that the dimensions were accurate. Due to the overall dimension of the robot it has been printed in sections which were joined together. In figure 36 it demonstrates how the LED strip sits flush in the side of the robot. The wall at this section has been made thin enough so that the colours from the LED strip can be seen, as colours will change depending on what the robot is doing and it's expressions/mood. A problem that we encountered with the base is that it was too thin and wobbled so the thickness needed to be adjusted.

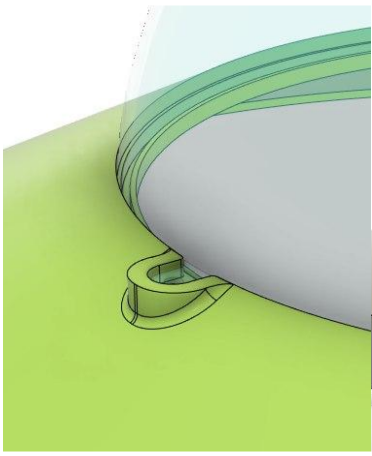


(*Figure 35*)

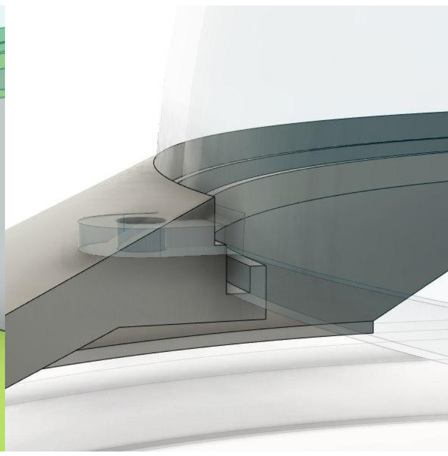


(*Figure 36*)

In order to join the dome of the robot to the top structure we contemplated on two different structures. Idea one (figure 37) where the dome would be screwed in as it has an attachment already to do so, or idea two (figure 38), where the dome would sit in edges without the need of a screw. We decided on idea one as the screw would ensure that the dome was secured and we did not see the need to get rid of this part. Figure 39 shows a sample of how this would look like and as you can see it is very secure.



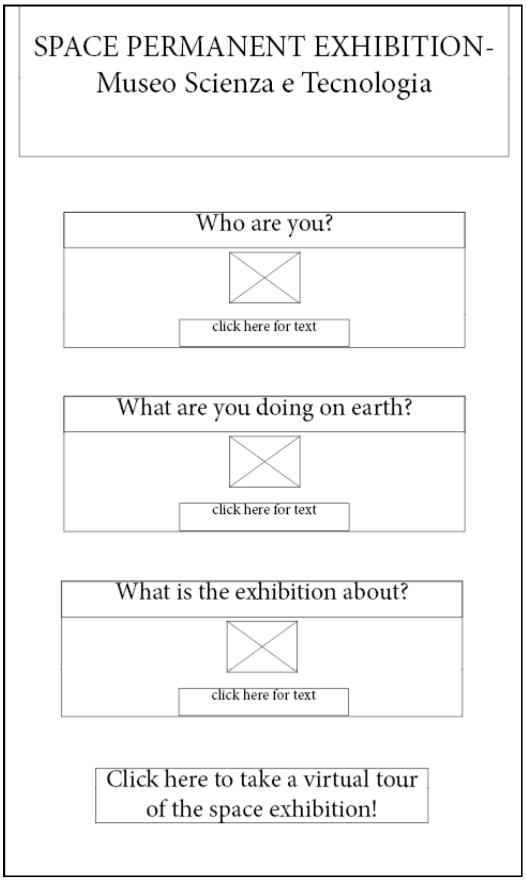
(*Figure 37*)



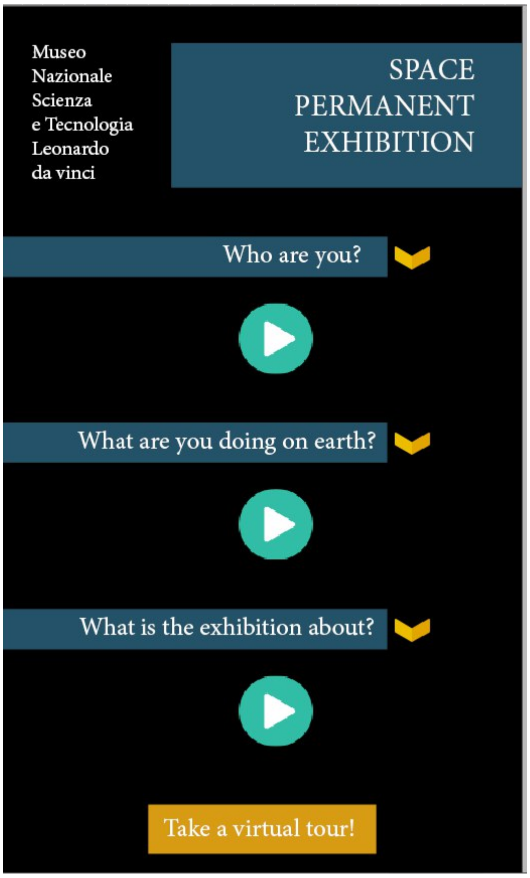
(*Figure 38*)

(*Figure 39*)

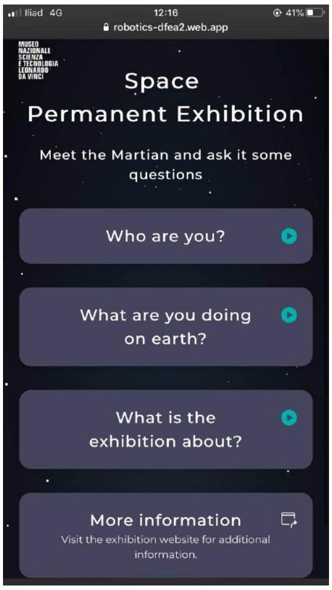
Website design



(*Figure 40*)



(*Figure 41*)



(*Figure 42*)

As we discussed initially when defining the robot, the user would be directed to a website once they scanned the QR code in phase 1. Before creating the website a wireframe was made and then an initial idea was created. We also took into account that if there was a possibility of a deaf user using the robot, they would not be able to hear the robot and therefore we made sure that text would also drop down once a question was clicked on. Figure 42 shows the final design which will further be shown in 'Phase 4: Deliver'.

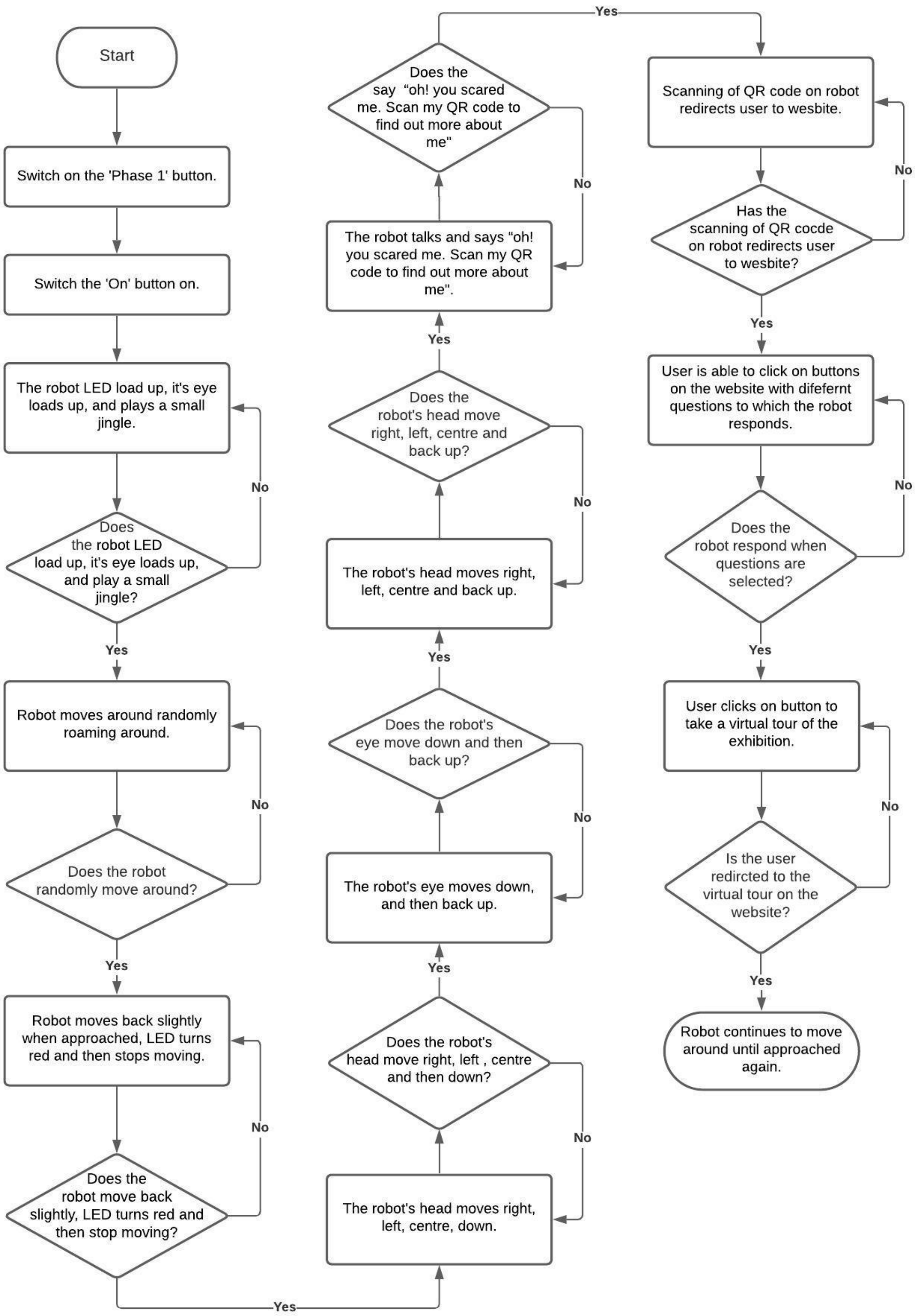
To simply explain, the user is directed to this website which has 3 questions and the last button directs them to the virtual tour of the exhibition. Once the user selects a button the robot responds and talks.

Phase 4: Deliver

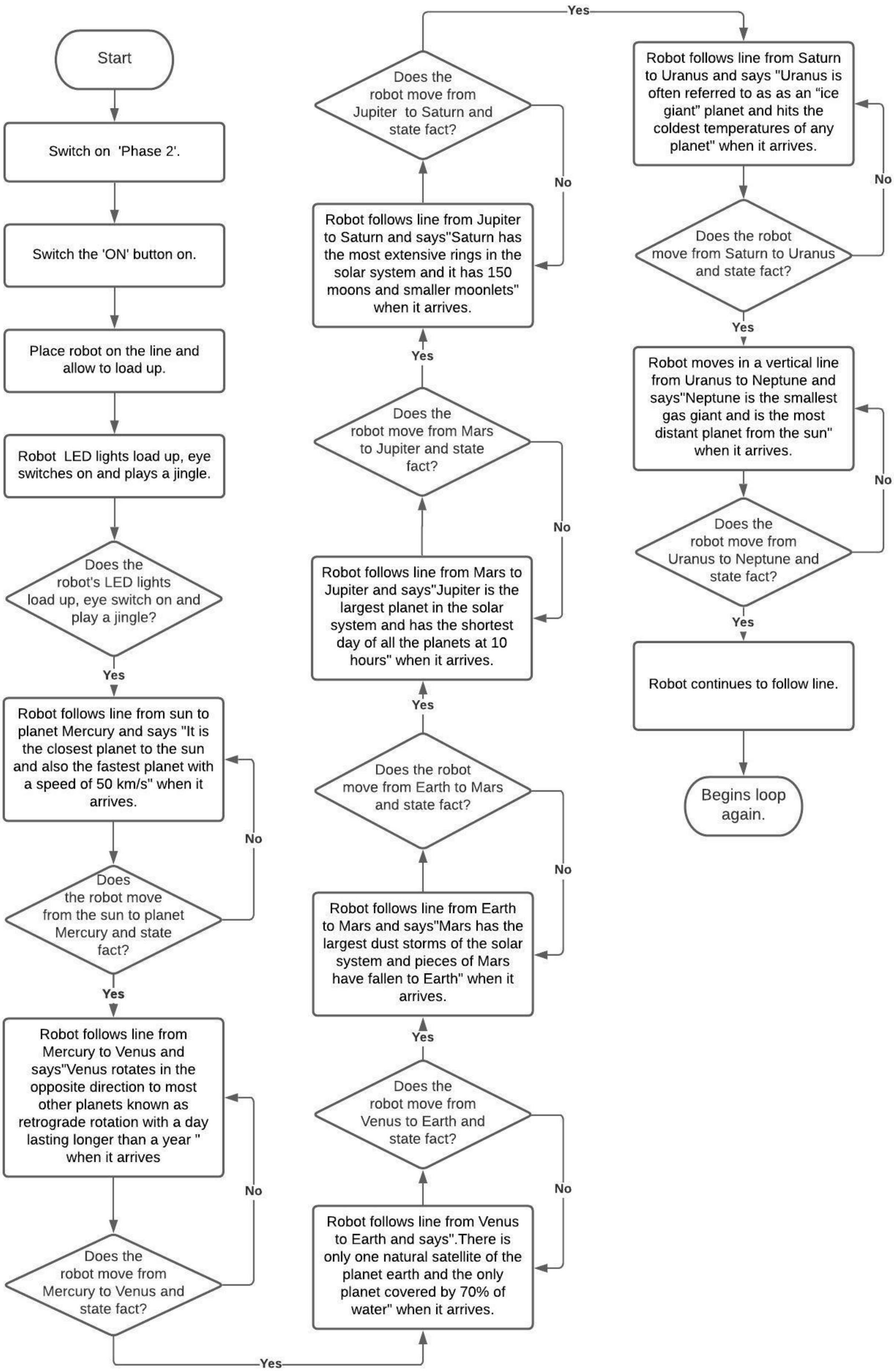
In this phase we describe the final robot and we show how it looks like at the end of the process.

Strategy

The following flowcharts show how the robot behaves during the two different phases.

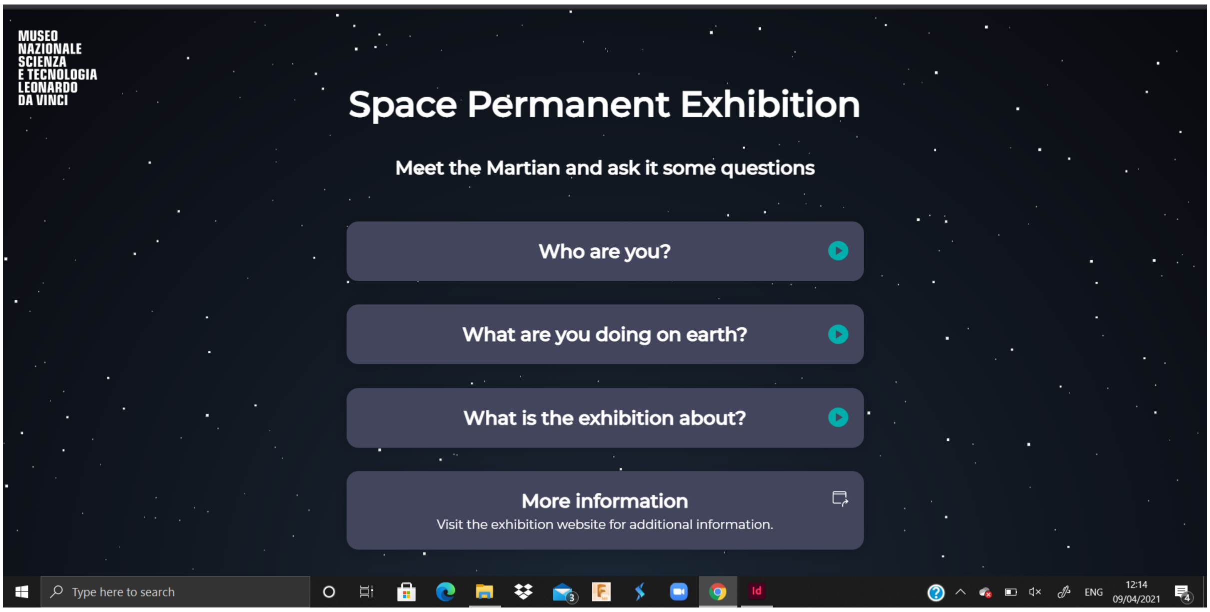


(*Figure 43*)

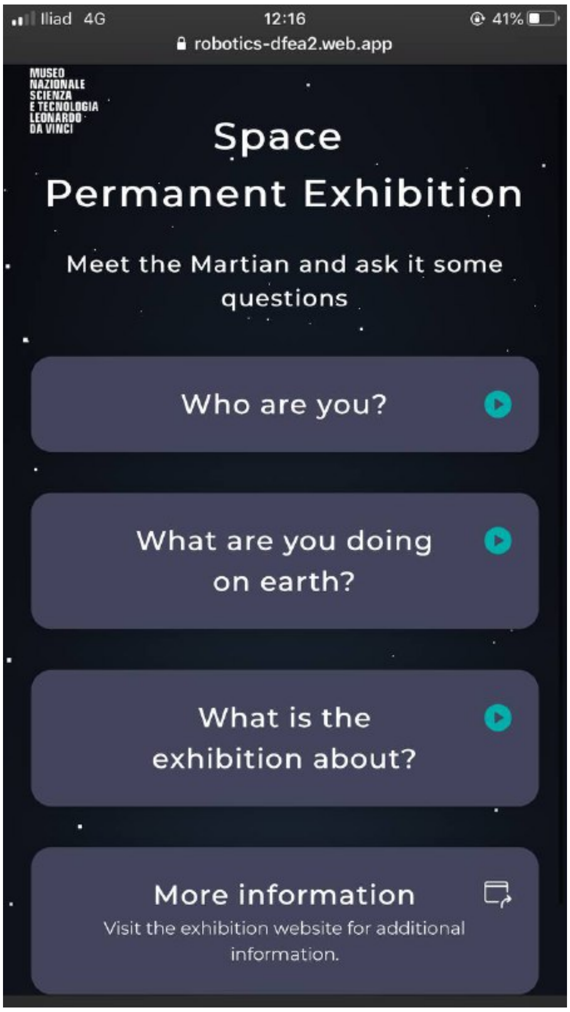

Start
Switch on 'Phase 2'.
Switch the 'ON' button on.
Place robot on the line and allow to load up.
Robot LED lights load up, eye switches on and plays a jingle.
Does the robot's LED lights load up, eye switch on and play a jingle?
Yes
Robot follows line from sun to planet Mercury and says "It is the closest planet to the sun and also the fastest planet with a speed of 50 km/s" when it arrives.
Does the robot move from the sun to planet Mercury and state fact?
No
Yes
Robot follows line from Mercury to Venus and says"Venus rotates in the opposite direction to most other planets known as retrograde rotation with a day lasting longer than a year " when it arrives
Does the robot move from Mercury to Venus and state fact?
No
Yes
Robot follows line from Venus to Earth and says".There is only one natural satellite of the planet earth and the only planet covered by 70% of water" when it arrives.
Does the robot move from Venus to Earth and state fact?
No
Yes
Robot follows line from Earth to Mars and says"Mars has the largest dust storms of the solar system and pieces of Mars have fallen to Earth" when it arrives.
Does the robot move from Earth to Mars and state fact?
No
Yes
Robot follows line from Mars to Jupiter and says"Jupiter is the largest planet in the solar system and has the shortest day of all the planets at 10 hours" when it arrives.
Does the robot move from Mars to Jupiter and state fact?
No
Yes
Robot follows line from Jupiter to Saturn and says"Saturn has the most extensive rings in the solar system and it has 150 moons and smaller moonlets" when it arrives.
Does the robot move from Jupiter to Saturn and state fact?
No
Yes
Robot follows line from Saturn to Uranus and says "Uranus is often referred to as as an "ice giant" planet and hits the coldest temperatures of any planet" when it arrives.
Does the robot move from Saturn to Uranus and state fact?
No
Yes
Robot moves in a vertical line from Uranus to Neptune and says"Neptune is the smallest gas giant and is the most distant planet from the sun" when it arrives.
Does the robot move from Uranus to Neptune and state fact?
No
Yes
Robot continues to follow line.
Begins loop again.

(*Figure 44*)

Website design



(*Figure 45*)

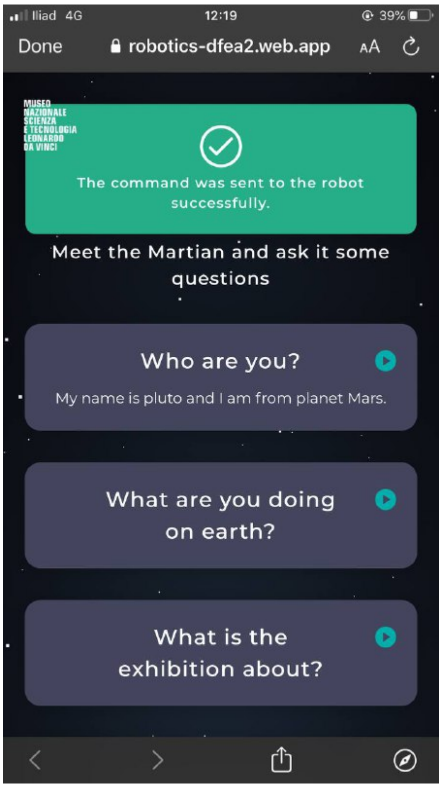


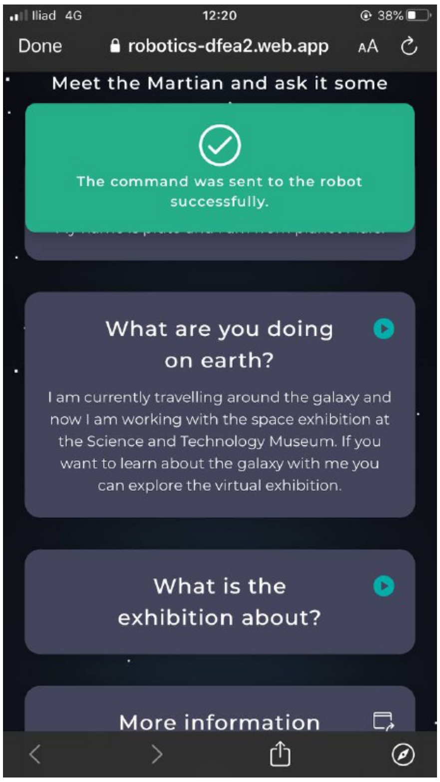
(*Figure 46*)

The following print screens show our final design and website for our robot. This is used in phase 1 to allow the user to interact with the robot Pluto so that they can find out more information about the robot.

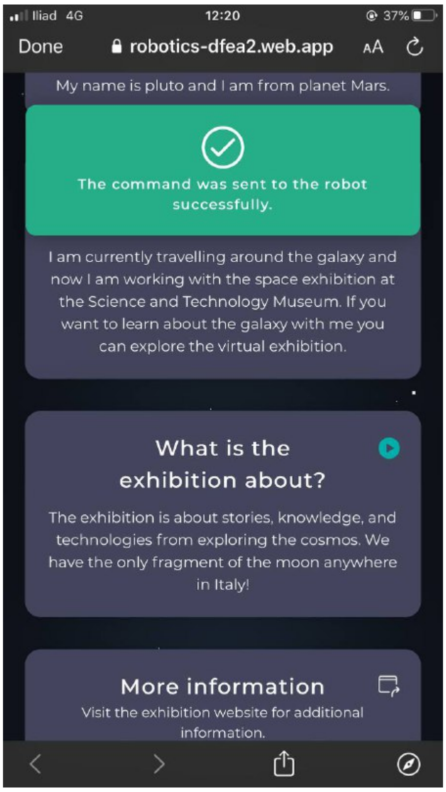
Once the user clicks on a question the robot will speak and say the answer. A drop down will also allow text to be shown so that the answer can be read as well. The reason as to why text is also shown is to make the user interaction inclusive and user friendly as we took into consideration that if someone deaf was interacting with the robot they would still be able to read what the robot was saying.

A QR code is self explanatory therefore we do not have any worries that if the user was deaf they would not use it.





(*Figure 47*) - top left
(*Figure 48*) - top right



(*Figure 49*) - bottom left
(*Figure 50*) - bottom right

(*Figure 51*)

The following answers are shown below for each question and what the robot will say.

Question 1: Who are you?

My name is Pluto and I am from planet Mars.

Question 2:What are you doing on earth?

I am currently travelling around the galaxy and now I am working with the space exhibition at the Science and Technology Museum. If you want to learn about the galaxy with me you can explore the virtual exhibition.

Question 3: What is the exhibition about?

The exhibition is about stories, knowledge, and technologies for exploring the cosmos. We have the only fragment of the moon anywhere in Italy!

As shown in the print screen, if you click on a different question without the robot finishing it's answer it will show up an error message stating 'sorry, the robot is still executing an action. Please try again later.' This means that the robot must finish what it is saying before the user is able to select a different question.

Packaging design

We also considered the design of the packaging that will hold the robot and decided to keep the packaging with minimal aesthetics as the museum would be the target market buying and using the robot.

This would be a simple box that internally would have a support so that the robot would flushly sit in the box and not move around. The handles of the packaging would be fabric making it easy to hold to box if the user wishes to hold it by the handles.

The following design shows the front of the box and as you can see a logo was made which would encompass the spaceship and one eye that our martian has.

(*Figure 52*)

Shape

The final shape of our robot "Pluto" is the one defined at the beginning, so an alien inside its spaceship coming from Mars. The head is green, to better give the idea of an alien and the eye at the end was covered with a specific structure in order to make the LED matrix more rounded and to cover pins and wires. The spaceship is white because we wanted to be minimal in the design and also in this way we have a big contrast between the base and the head. We just covered the upper part of the spaceship with an adhesive vinyl because the 3D printer generated some imperfections on this part.

To enforce the design of the robot and also make it more aesthetic we placed an antenna behind the head, which can also be lowered.
Finally we inserted small shelves ,with a lot of holes, inside the spaceship, with the role of supporting the electronic components and the cable management in an ordered manner.

Almost everything is 3D printed, from the base and the walls of the spaceship until the head and the mechanics, because we needed specific holes and configurations to place the components.

(Figure 53)

(Figure 54)

(Figure 55) - left image
(Figure 56) - right image

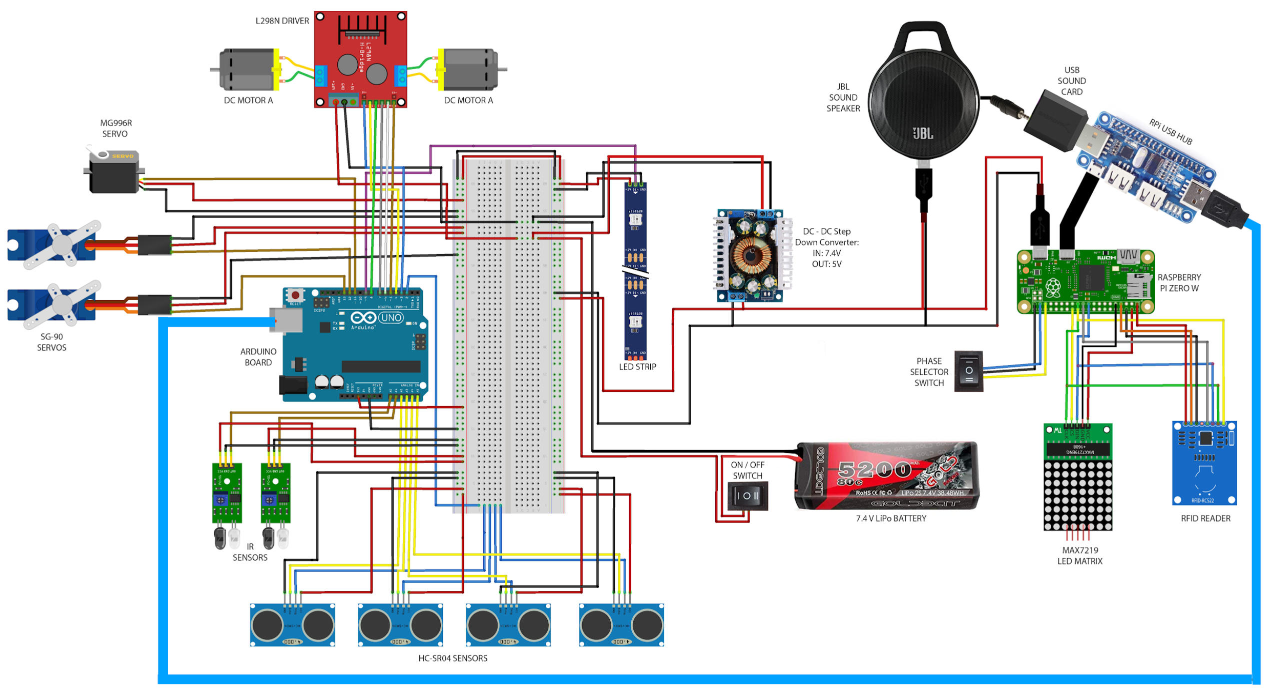
In figure 53 you can see our final result, where we also attached the QR code on the spaceship.

Mechanics

As said in the development phase, at the end we adopted the mechanism of the rack and pinion to move the head with a wider base to support it, with the three servo well positioned and fixed taking into account also the inertia of the components so that the weight is distributed in the center.

To make the robot easy to disassemble we placed some magnets all around the spaceship in order to easily open it and see the electronics and the mechanics inside. This approach was used also for the head so that it is fixed but can be also removed in a very simple way.

Electronics



(Figure 57)

Figure 57 shows our final circuit with the Arduino and the Raspberry pi zero connected through the USB port. The components are more or less the one already presented in the development phase, but at this final stage we added also the power supply and everything is soldered on a PCB (for convenience in the circuit it is represented as a breadboard, but the real connections are soldered). Specifically:

- The components connected to the Raspberry are the LED matrix and the RFID sensor as shown, and the speaker is connected through a jack (in the figure this is not presented for the sake of simplicity). The speaker that we modified in order to be suitable for us was at the end changed due to the really low volume once the spaceship was closed.

- The power supply is given by a LiPo battery of 7.4 V with a capacity of 5200 mAh, that directly gives power to the motor's driver and the rest is powered through a DC-DC converter (step-down). At the beginning we tried to use directly the converter inside the motor's driver, but the current delivered was not enough to supply all the components, this is why we used an external one.
- In order to ease the user's experience, we implemented two switches: one simply to turn on/off the robot and the other to pass from phase 1 to phase 2 whenever he/she wants.

As already said, the final connections were soldered on a prototype board shield that we put on the Arduino and also we made sure to have the connections the most stable possible by welding the wires also on the components' pins.

Coding

The coding part of the project was carried out by adopting a bottom-up strategy. All the components were developed individually and then merged and tested.Each one of them has been developed by using specific technologies and efforts have been made to optimize the use of available resources in the best possible way.
The components and the main development choices that have been carried out will be listed and described below:

Web Platform

The web platform has been developed in order to allow people to interact with the robot by sending commands to it. It is composed of an interface by a frontend (a website) and a backend (a web server) which manages and stores the platform's main logic.

- **Frontend:** It represents a reactive interface to the web server to allow users to send commands to the robot through a set of API calls to the backend. It has been developed by using html, css and javascript technologies and then hosted on the Firebase platform.
- **Backend:** It is devoted to handling all the main logic features of the web platform and to allow both the users and the robot to retrieve and update the commands to be respectively sent and received. It has been developed by using the Node.js and Express technologies and then it has been hosted on the Heroku platform. More in detail, the web server is composed of a set of endpoints each of them devoted to carry out different tasks.
  To host the commands sent by the users was decided as a first attempt, to store them into a Database hosted on MongoDB Atlas, however, in order to decrease the response time and optimize the expenditure of the available resources it was decided to move it to a local file on the Server instance. To avoid possible conflicts coming from simultaneous requests of the frontend a concurrency control mechanism has been implemented.

Robot's Logic

The logic part is divided into two subsystems, each one managing different physical components of the final robot:

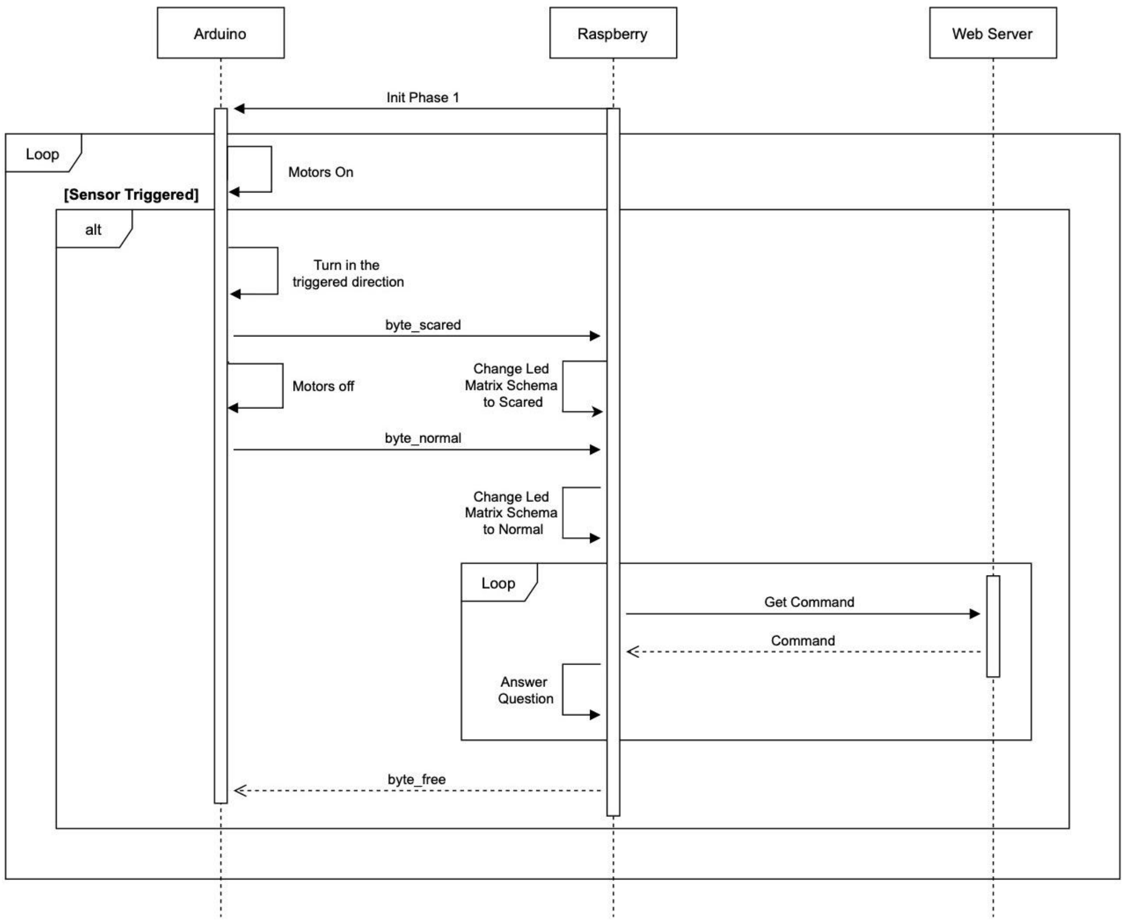
- **Arduino:** it accounts for the main logic of all the robot's sensors and actuators, except for the RFID reader and the eye's LED Matrix, that are handled by the Raspberry Pi zero.
  The code makes use of libraries such as *NewPing.h, Servo.h*, *FastLED.h*, used for controlling respectively the readings from the sonar sensors, the actuation of the servo motors and the blinking of the LED strip.
- **Raspberry Pi:** It's used to handle the selection of the chosen phase, according to the position of a button and the animation of the robot's eye (LED matrix); during the first phase it handles the communication with the web server, receiving the commands of the corresponding questions; in the second phase it handles the reading of the content inside the RFID cards. It accounts also for the reproduction of the robot's voice.

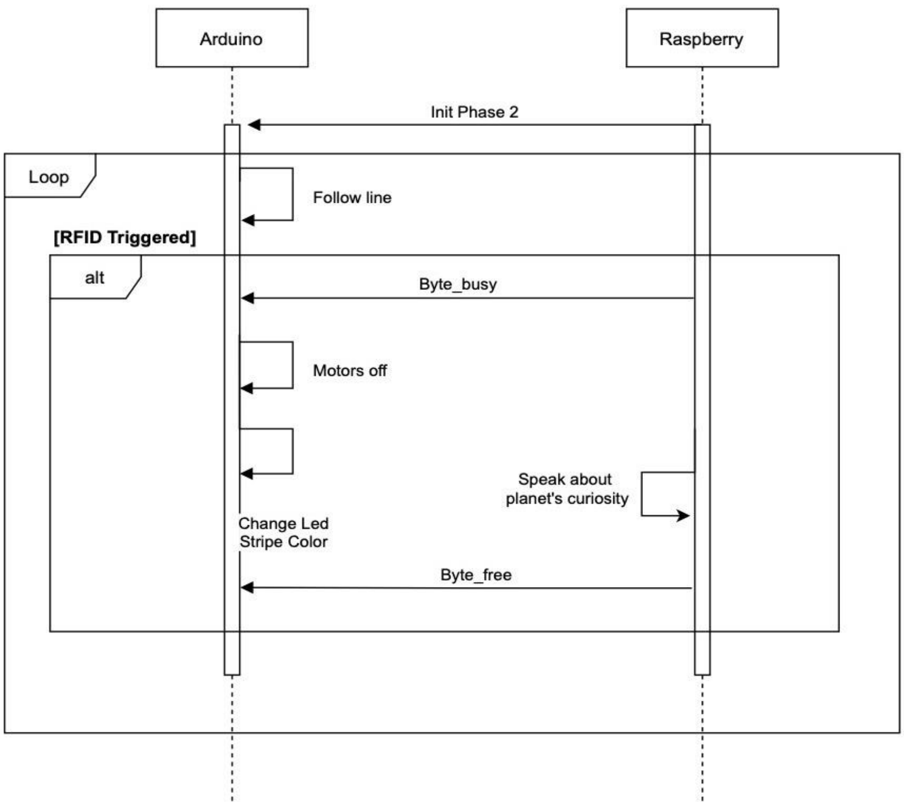
The synchronization in between these two components is crucial, and it’s carried out by a serial connection through a USB cable that permits the exchange of byte signals from one to the other, to permit a perfect coordination.

In particular, the following diagrams explains how the coordination is carried out between all the components into the two different phases:

- **Phase 1:** From the Arduino side, the robot starts going around the space, until one of the sonar sensors relevates an obstacle (a person) below a certain distance threshold: when this occurs the robot stops and turns in the direction in which the obstacle is sensed and retreats.
  Now the robots enters in a status in which it’s scared, so the Arduino sends a first signal to the Raspberry, then it performs an animation of the head and blinks the LED strip with some red colors; from the Raspberry side it makes a scared animation of the eye on the LED matrix.
  After the head movement, the robot recognises the obstacle as a human, so the arduino blinks the strip with a green color and then sends a signal to the Raspberry telling that the “scaring state” is ended, and to enter into the “normal state”.
  Now the arduino enters in a “busy state” in which it waits for a “free signal”: from the Raspberry side now it starts a timer of 1 minute and waits for commands received from the Web Server (notes that for this functionality is required the raspberry to be connected to the internet through a hotspot, see manual for more information), that corresponds to questions that, once received, the robot plays, by using its voice.
  When the timer hits zero, the Raspberry exits this state of “waiting for questions” and sends a “free signal” to the Arduino, which starts again the procedure of going around from the beginning.

- **Phase 2:** this phase is more straightforward w.r.t. the previous one; in this case the Arduino starts by performing a line-following strategy, using two infrared sensors to relevate when a black line is crossed by the robot from left or right and reacting accordingly, to maintain a correct trajectory when moving.
  On the Raspberry side, there’s a loop in which it performs a read from the RFID sensor: when it reads a card, containing a string with the name of a planet, it sends a signal to the Arduino, containing the information about that planet.
  On the Arduino, when the signal is received, it stops the line-following, entering a state in which the robot is still and blinks the LED strip with the colors of the corresponding planet.
  On the Raspberry it uses the voice to tell a curiosity about that planet, and after that it sends the free signal to the Arduino, to resume following the line.





(*Figure 58*): Phase 1 (top) and Phase 2 (bottom) Diagrams

Some Additions:

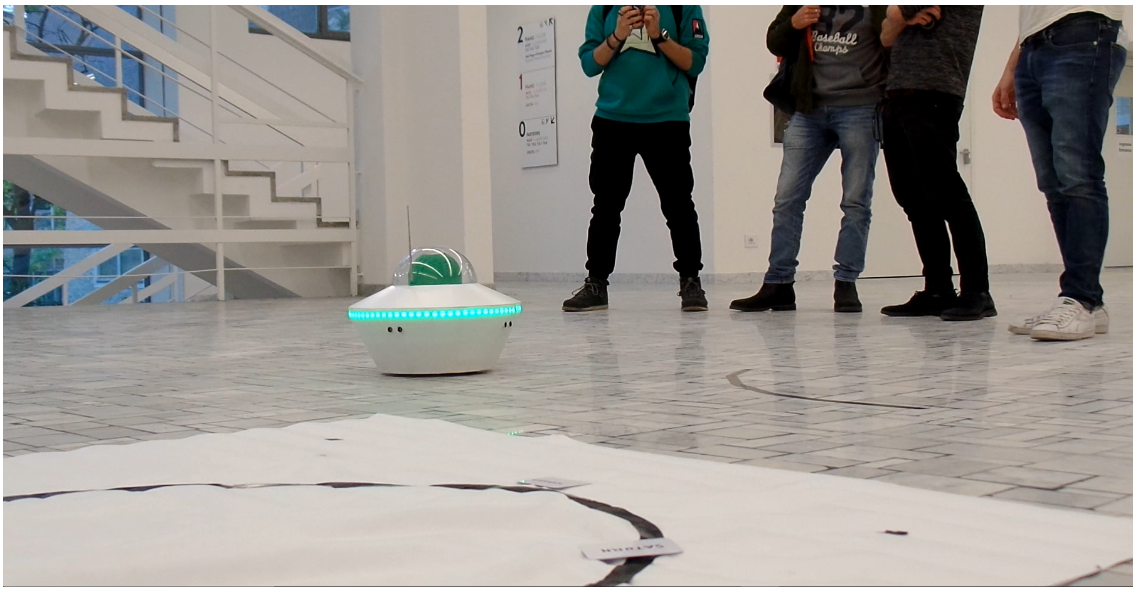
- **Sound:** The voice of the robot it's obtained by using a Google API in python (gTTS library) inside the Raspberry Pi, which permits to obtain the corresponding voice audio file, by inputting the phrase string, we want to say; then this file is processed using the "sox" software, that permits to obtain a "robotic voice" by processing the audio with some effects such as reverb, pitch shifting, chorus, etc.
  Finally the audio is played through the 3.5mm audio output, on the speaker.
  As a first attempt the voice of the robot was generated on the go, every time the robots needed to say any phrase, for permitting also some kind of personalization of the phrases. After some time we denoted that the Google API was not so reliable, failing from time to time, so we decided to pre-generate some fixed phrases, in order to increase the reliability and the response time of the whole system.
- **LED Strip:** the animations for the led strip, programmed on the Arduino firmware, caused some problems, due to the sequential nature of the execution in the Arduino board, so we had to get some software workarounds for permitting the concurrent execution of animations and other procedures simultaneously, by breaking the animation function into steps, being performed, each time a method is called, and synchronized making also use of timers inside the Arduino (millis() function), instead of use just simple delay() functions.
- **Web Server:** from time to time the concurrency control mechanism on the web server, could turn into a deadlock for the Raspberry, being not able to receive any new question, so we implemented an additional timer from the web server side, in order to avoid this problem: after a fixed time interval from when the request is sent from the web server, whether the raspberry receives or not the command, the webserver unlocks the lock.

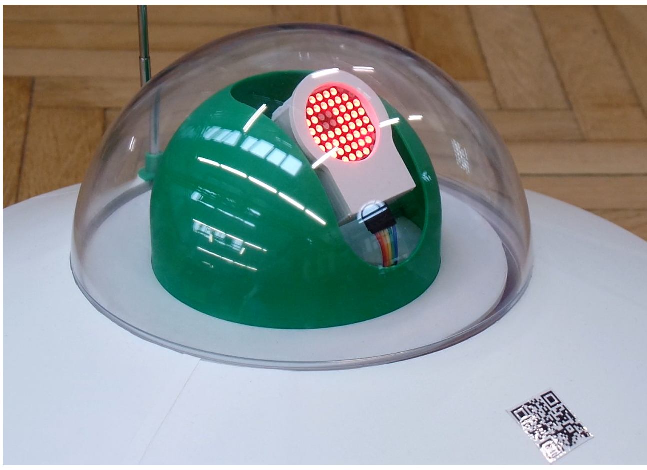
Conclusion

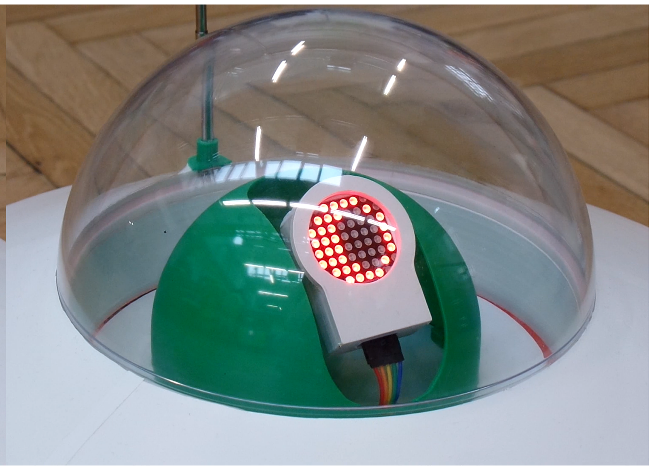
In this group the work was organized in a way where most of the time we were all together in order to be able to have a fast comparison of the ideas, but for specific objectives we worked in parallel, for example building the website, writing the code in a subgroup and testing the electronic components, thinking on the design of the robot with 3D models, filling the report in due time, in the other subgroup.

This experience was very interesting for many reasons: it was the first time for us where we merged our capabilities to build a real working robot, where we had the chance to test us on new fields, and also attending an interdisciplinary course that makes one be aware on how to work in a team, even with people with different knowledge. We learnt how to organise our time better in order to complete specific goals every week, how to relate with our teammates and understand their thoughts, how to use a device such as an Arduino, since for most of us it was the first time, and in general how to solve problems that a project like this can present.

The time management was a very crucial point since at the end we had only one month for prototyping and building the final robot, and we faced a lot of problems that we needed to solve in time, but we think that this challenge is a really keypoint to be able to deliver a requested project by respecting the deadlines.







APPENDIX

Minutes of the Meetings

Meeting 02/03/2020

Time: 9:30
Venue: Microsoft Teams
Attendees: Francesco Montanaro,Francisco Martins Carabetta, Mahmoud Badawi, Matteo Rubiu, Somaiya Afzal.

- In this initial meeting we discussed what exhibition we wanted to work on and eventually defined this to be the space exhibition at Museo Scienza e Tecnologia.
- Made a moodboard as inspiration for our ideas.
- Started to explore both of the phases that the robot would be placed in.
- Defined who the visitors were to the exhibition and our target market that we would focus on.

Meeting 06/03/2020

Time: 11:00
Venue: Microsoft Teams
Attendees: Francesco Montanaro,Francisco Martins Carabetta, Mahmoud Badawi, Matteo Rubiu, Somaiya Afzal.

- We assigned the roles to all of the team members.

Meeting 09/03/2020

Time: 9:30
Venue: Microsoft Teams
Attendees: Francesco Montanaro,Francisco Martins Carabetta, Mahmoud Badawi, Matteo Rubiu, Somaiya Afzal.

- We continued to think about the shape and design of our robot.
- We decided where to place the robot in both the phases, in particular we chose a mall in phase 1 and the entrance of the exhibition inside the museum for phase 2.

Meeting 13/03/2020

Time: 15:30
Venue: Microsoft Teams
Attendees: Francesco Montanaro,Francisco Martins Carabetta, Mahmoud Badawi, Matteo Rubiu, Somaiya Afzal.

- We discussed how to do the cardboards and we said that everyone could build its own representation of the robot with different dimensions, so that we could compare at the end.

Meeting 16/03/2020

Time: 9:30
Venue: Microsoft Teams
Attendees: All the members

- We begin the day with the presentation of the dimensional models that the groups made, as well as a presentation from the professors about a previous dancing robot showing us important aspects of the construction and features.
- After the presentations we worked on the Gantt chart,Bill of Materials (BOM), deciding the initial components that we need to use. Also we took some decisions about the usability of the robot regarding the movement that we were previously thinking about doing on top of a table for phase 2, changing for the movement in the floor such as in phase 1.
- After the construction of the dimensional models we are not completely close with a measurement but the idea is to have 400 mm diameter and between 300 to 400 mm height.
- We are initializing the 3D model to better understand how we will attach the components inside and also the construction.
- Since now we are still not sure if we use an Arduino or Raspberry pi to computate it all. We know that Arduino can do it but we are afraid that in the future we can be limited by its features while with the Raspberry we can be free to implement further features.

Meeting 20/03/2020

Time: 15:30
Venue: Microsoft Teams
Attendees: Francesco Montanaro,Francisco Martins Carabetta, Mahmoud Badawi, Matteo Rubiu, Somaiya Afzal.

- We continued to work on the Bill of Materials in order to start the testing phase.
- We started to think about robot expressions.

Meeting 23/03/2020

Time: 09:30
Venue: Microsoft Teams & in person
Attendees: Francesco Montanaro,Francisco Martins Carabetta, Mahmoud Badawi, Matteo Rubiu, Somaiya Afzal.

- After receiving the first electronic components from an “Arduino Kit”, we tested them out each one of them singularly: the Led Matrix, the Stepper Motor, the Servo Motor, Ultrasonic Sensor.
  We achieved this by prototyping some circuits and performing some coding.

- We designed some possible “faces” for the robot’s eyes on the 8x8 Led Matrix.
- We designed the first prototype of a moving head mechanism.
- Software development of the website.
- Some improvements to the BOM, i.e. decisions about components to buy.

Meeting 28/03/2020

Time: 15:00
Venue: Microsoft Teams & in person
Attendees: Francesco Montanaro,Francisco Martins Carabetta, Mahmoud Badawi, Matteo Rubiu, Somaiya Afzal.

- We continued to test software and hardware together.
- We evaluated whether it was worth implementing the audio functionality using the arduino we already have, or if adding another Raspberry pi zero, in order to also manage the audio processing.
  In the end we decided for the second option, because this permits us better flexibility with audio processing (allowing also the generation of some personalized audio). Furthermore adding the Raspberry, let us avoid to buy an additional wifi module for the arduino.
- Tested the head movement - we need to change the structure due to weight and power.
- Designed the page for the website - wireframe.
- To do before next meeting:

1) Finalise website design
2) Buy final BOM
3) 1st draft of flowchart

Meeting 30/03/2020

Time: 09:00
Venue: Microsoft Teams & in person
Attendees: Francesco Montanaro,Francisco Martins Carabetta, Mahmoud Badawi, Matteo Rubiu, Somaiya Afzal.

- Continued to work on the report.
- Updated the internal design of the robot.
- Audio speaker assembly: hacking some old speakers, we managed to get a working one, connected to a small audio amplifier circuit that we’ll be connected directly to the Raspberry pi.

Meeting 02/04/2020

Time: 10:00
Venue: Microsoft Teams & in person
Attendees: Francesco Montanaro,Francisco Martins Carabetta, Mahmoud Badawi,

Matteo Rubiu, Somaiya Afzal.

Aims for today:

1. Develop prototype - hardware, software - test everything except all sensors movement and tracking line.
2. Finish website design - (finalise what the robot will say).
3. Finish 1st draft of both phases flowchart.
4. Continue to work on CAD models.
5. Make a 1st draft for design of packaging & graphics.
6. Record small videos.
7. Update report - if not done on day update before next meeting.

To do before next lesson:

- Finalise what the robot will say in the second phase.
- Work on martian's head and expressions.

Aims accomplished:

- Tested the sensors together.
- The website design was finalised as well as what the robot would say when the buttons on the website were clicked. The sound was also tested and by the end of the day the robot was able to speak.
- The 1st draft of the flowchart was made.
- Changes were made to the CAD model.
- The packaging design for the front and the logo of Pluto was made.

Meeting 06/04/2020

Time: 11:00
Venue: Microsoft Teams & in person
Attendees: Francesco Montanaro,Francisco Martins Carabetta, Mahmoud Badawi, Matteo Rubiu, Somaiya Afzal.

Aims for today:

1. Develop prototype - hardware, software and put things together.
2. Make a cardboard model with correct dimensions to test if everything works well.
3. Finalise how the robot will be assembled and disassembled.
4. Finalise robot expressions.
5. Finalise aesthetics.
6. Finalise flowcharts.
7. Continue to work on CAD model.
8. Record small videos.
9. Update report - if not done on day update before next meeting.

Note: Maybe between the 6th and 9th we can 3D print anything that we need after we see how the model works.

Aims accomplished:

- Continued to work with hardware and software this time making sure that the wheels work and testing out the sensors together with the motion of the robot.
- A cardboard model with the correct dimensions that we will use for our final prototype was made. However due to tools available it is off by a few mm. Overall the dimension of the model seems to work and we are happy that there is enough space to hold the components as well as the dimensions looking aesthetically pleasing.
- We finalised that the robot sections will be assembled and disassembled by using magnets. By using magnets we can detach and attach the robot.
- We decided in order for the electronics to not be seen in the head we can use a stretchy material such as lycra that will stretch and go back to its original form depending on where the arm of the eye is.
- Recorded a few small videos.

Meeting 09/04/2020

Time: 10:00
Venue: In person
Attendees: Francesco Montanaro,Francisco Martins Carabetta, Mahmoud Badawi, Matteo Rubiu, Somaiya Afzal.
Aims for today:

1. Make the final robot prototype.
2. Record video.
3. Update report - if not done on day update before next meeting.

- User testing before the 13th so we can record this and make notes of it in the report.
- Possibly we may need to meet another day as well if we don’t manage to finish the robot.

Aims accomplished:

- Began to make the final robot and join different components together, also testing out if it works, however problems were encountered. Changes to the design will have to be made, the main change being the base of the robot holding the electronics and mechanics and it may possibly be buckling underneath the weight. By adding ribs and making other changes this can be resolved. The code was also worked on. To find out more refer to ‘Phase 3: Development’.

Meeting 10/04/2020

Time: 12:00
Venue: In person
Attendees: Francesco Montanaro,Francisco Martins Carabetta, Mahmoud Badawi, Matteo Rubiu, Somaiya Afzal.

Aims for today:

1. Make the final robot.
2. Record videos.
3. Update report - if not done on day update before the 13th.
4. Print out planets.

Meeting 13/04/2020

Prototype presentation day

Aims for today:

1. Present prototype.
2. Make the video.

Meeting 17/04/2020

Aims for today:

1. Make any developments to prototype if needed.
2. Make packaging.
3. Work on report.
4. Edit video.
5. User manual.

Meeting 20/04/2020

Aims for today:

1. Work on report.
2. Finish editing video.
3. User manual.
4. Circuit.

Meeting 27/04/2020

Final presentation day!

Bibliography

https://www.museoscienza.org/en/offer/permanent-exhibitions/space

Attachments

GANTT Chart:
https://drive.google.com/file/d/1kyHkhPNGX9WRvFYUpHM4g55VVeKWTqxb/view?usp=sharing

Instruction Manual:
https://drive.google.com/file/d/1BC7V2coGRIhP2jUBi1P1cBfNcbw5N58I/view?usp=sharing

Flowcharts (Phase 1 & 2):
https://drive.google.com/file/d/1AOrFsIRXVX_tKtXbV43rxb1bhYHbIzWr/view?usp=sharing

https://drive.google.com/file/d/1xe9gROs2vc_z6H4LI4DeG8gmv2VAzWD6/view?usp=sharing

Final Circuit:
https://drive.google.com/file/d/1zcs_Bv8sIuR6w6IqwoqqIhyj03C5zGRs/view?usp=sharing

Final Code:
https://drive.google.com/file/d/1UKWIOriiDer5t-FSqCentO7DUoMVf-cT/view?usp=sharing

Final Bill Of Materials:
https://docs.google.com/spreadsheets/d/1O4iTk4L1cc4B1bvT3YErFWo25P7a1eCMBEEJeuqKAm4/edit?usp=sharing

Technical Drawings:
https://drive.google.com/file/d/1ZRbnef_k-4_kPqX5xeEPZZH0PV-_5mD1/view?usp=sharing

3D Model:
https://drive.google.com/file/d/1mBmz4RPmiuX91Iq72AfJDhmIVcXKyI4j/view?usp=sharing