Design And Implementation Of A Scale Throwbot Robot For Military Recon And Security

Erick Peñaherrera, Eduardo Villacís, Ricardo Yépez
Escuela de Mecatrónica, *Universidad Internacional del Ecuador*
Av. Simón Bolívar y Av. Jorge Fernández, Quito, Ecuador,
erpenaherrerave@uide.edu.ec, edvillacissa@uide.edu.ec, riyepezzu@uide.edu.ec

***Abstract*—Design and implementation of a Throwbot mobile robot capable of navigating its surroundings by being controlled by the user using a web interface and transmitting video footage through the camera.**

***Index Terms*—Throwbot, Web server, Indoor usage**

I. Introduction

THIS project aims to propose a scale mobile robot commonly called ”Throwbot” [1]. The purpose of this mobile robot is to allow the operator to remotely obtain video for area reconnaissance indoors. The project is proposed as an idea for a security application to recognize, verify and/or analyze the environment and its possible alterations for personnel incursions. In this way, its application establishes a direct relationship with its use for organizations or security institutions such as police or military usage with the concept of “urban combat” or “surveillance team”.

The essential characteristics of the mobile robot in the mechanical area are characterized by the use of 2 wheels with actuators and a free wheel for tracking, while on the other hand for electronics the use of the ESP32 module with built-in camera and remote control is proposed for monitor their mobility and meet the area reconnaissance objective.

A. *Main Objective*

Design and implementation of a scale throwbot robot controlled wirelessly through a smartphone, for military recon and security.

B. *Specific Objectives*

- Research and review the usage of throwbots for military recon and security.
- Design the smallest possible structure capable of housing the two motors and the electronic components.
- Design and implement a throwbot controlled by a phone app that outputs video and can be thrown for deployment.
- Test the performance of the mechanical and electrical components in different indoor scenarios.

II. Theoretical Framework

Nowadays mobile robotics is one of the fastest expanding fields of scientific research. Due to their abilities, mobile robots can substitute humans in many fields. While the industrial use of mobile robots is popular, especially in warehouses and distribution centers, its functions can also be applied to the medicine, personal assistance and security.

One of the main advantages that mobile robots provide in the area of security and surveillance is the reduce the exposure of human capital to hazards that pose a significant risk of injury or death. You move from a traditional method of light curtains or safety controllers to a no-contact environment. [1]

The Throwbot 2.0, which is the main inspiration behind our project, is a throwable micro-robot system developed by ReconRobotics. The robot is used for recording and transmitting video and audio in indoor and outdoor environments. It can locate objects whether they are armed or injured, and reveal the rooms layout.
The robot is equipped with a forward mounted colour camera which allows the operator to view objects in front of the device. During active shooter situation, the operator will have the option to see around corners while clearing a building under danger, locate and identify subjects, confirm presence of hostages, and show layout of the room. [2]

III. Methodology

To explain in a more detailed way the work carried out in the design and implementation of the proposed prototype, it has been divided into 3 stages, mechanical, electronic, and control.

A. *Mechanical Stage*

This first section describes the design and mechanical assembly that was carried out to optimize the CAD model and that the qualities of the throwbot allow it to resist the force necessary for the launches. The design was based primarily on the section on the selection and construction of the specific wheel to withstand shocks in falls, since these wheels must be able to absorb the impact of the fall.

*1) **Model and assembly**:* The original layout is based on the reference ”Throwbot XT” of the company ”Reconrobotics” Fig. 1 [3]. It is structured by two flexible wheels and the main body cylinder. The Fig. 2 and Fig. 4 show the final design.

The development of the Throwbot assembly can be seen in Fig. 5 Where each part is assembled horizontally

Fig. 1: Throwbot XT [1]

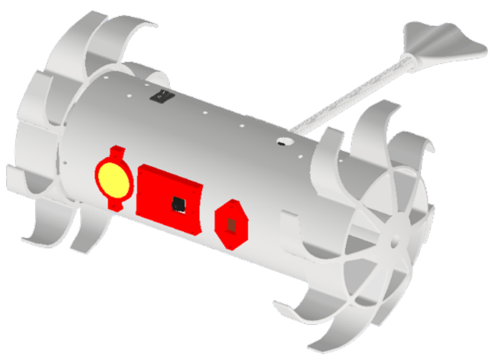

Fig. 2: Final Design

on its side so that the main body of the cylinder is not affected.

The assembly sections are distributed in trow main sections, as following:

- Wheel Section:
  The wheel section is based on a robust 18 cm diameter concentric design with addressable teeth to distribute the impact force over the entire main body, with the wheel tips as the first point of support. Fig. 6

  This is how the first point of support and cushioning

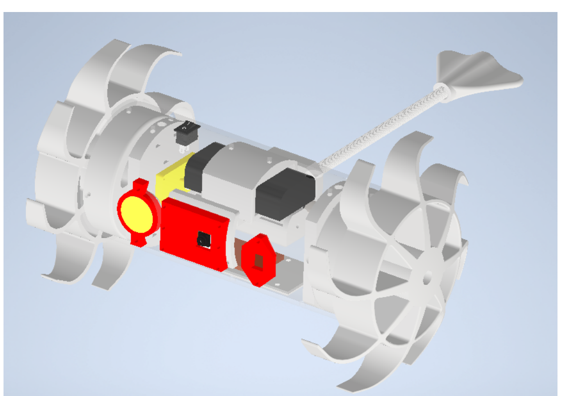

Fig. 3: Assembly: Transparent View

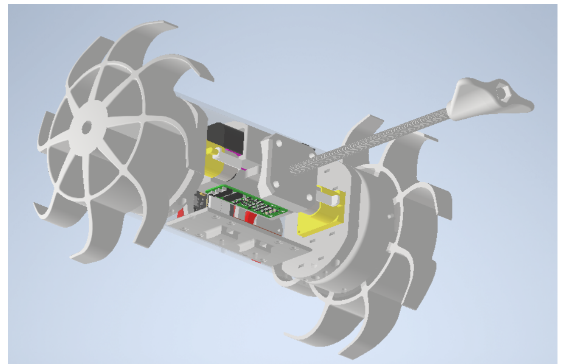

Fig. 4: Assembly: Transparent Back View from Plane

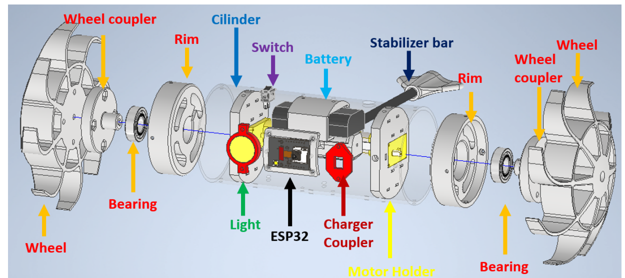

Fig. 5: Assembly: Exploded View

are the wheels with their tips directed, later, the force of impact is directed towards the shaft coupler and the rim made of TPU at 15% infill which allows to absorb the impact much more, to that in this way the remaining impact force is less and is distributed in the rest of the cylinder.

The main feature of the wheel section is the connection of the shaft coupler with the motor coupler through the bearing 6007UU, which is in charge of decreasing the friction coefficient between these parts translating the rotaty motion from the shaft of the motor to the wheel efficiently. Fig. 7 In sense, it means that the key of the throwbot motion is the bearing for the shaft and the shaft coupler made in TPU to hold back the impact.

- Main Body For the section of the main body, the parts are identified by circles that determine the position of the object and its classification.
  - Inner Section:

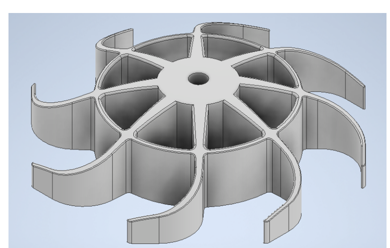

Fig. 6: Flexible Wheel

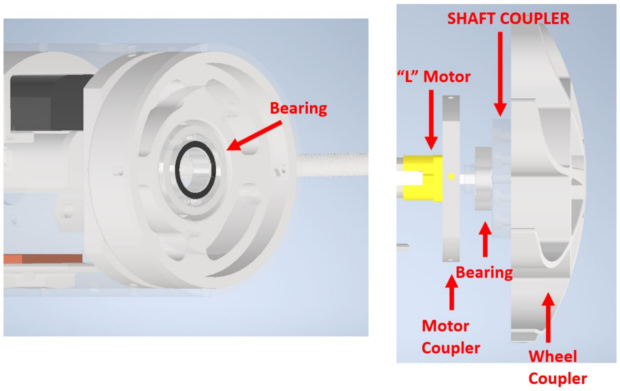

Fig. 7: Wheel Section

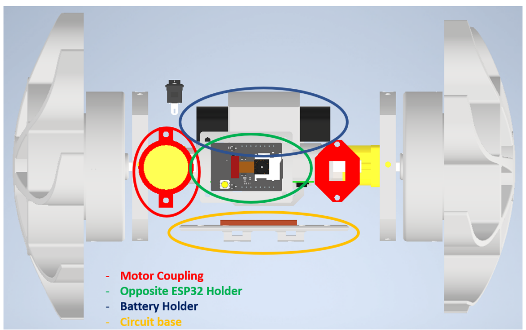

Fig. 8: Inner Body

In Fig.8 the interior body is identified, where the red, blue and green circles describe the position of the yellow gear motor, the battery holder with the load cells and the ESP32 Cam microcontroller, respectively.While the yellow motor is attached to the main cylinder by means of bolts at its ends, the battery pack is held in a battery-holder piece attached to the upper part of the base cylinder. The microcontroller is attached to an internal part of the same dimension to be bolted on both sides. And finally, to highlight the base of the circuits, it is extremely close to the base cylinder, this with the aim of taking advantage of all the internal space and the wiring of the electronic elements.

As the charging module for the batteries has been implemented, the location of the module was precisely coupled to the third battery in order to reduce the extension of the connection of the battery cable to the module and take advantage of the space. Fig. 9

– Outer Section:
The outer section is structured by the light and its respective coupler, as well as the 3.1 jack holder for the battery charging port in conjunction with the ESP32 and its coupling, as seen in Fig. 10
To keep the main cylindrical body stabilized, a stabilizer bar was added to the back with a mobility fin, Fig. 11, which, like the body and wheels, is made of TPU filament. As final addition, a switch is added to turn on and off the robot.

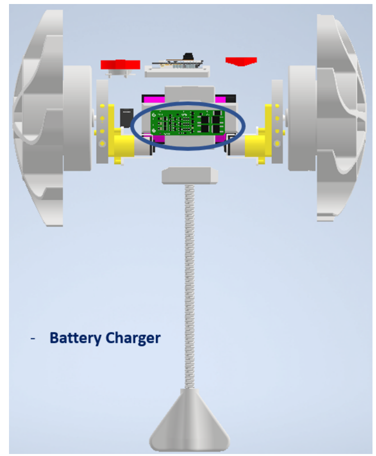

Fig. 9: Inner Body from Up side down

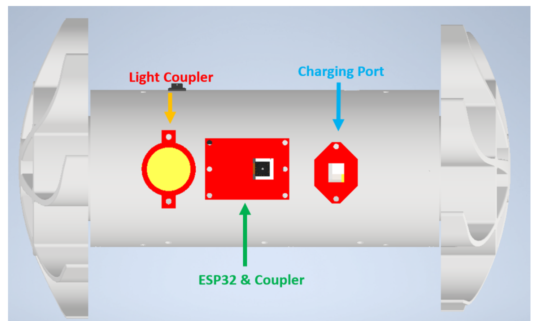

Fig. 10: Outer Frontal Body

2) Actuator Selection: For the selection of the motor, two types of L-shaped motors were taken into account:

- LM62R: This gearmotor has a capacity of 2.4 Kg cm as torque and a speed of 62 revolutions per minute.
- LM85R: The torque of this motor is 4.5 Kg cm with a speed of 85 revolutions per minute.

The difference of the motors and scale factors can be seen in Fig. 12. And finally, as a decision, it was decided to choose the engine with greater torque, this was due to ensure the mobility of the tires in case there is too much friction.

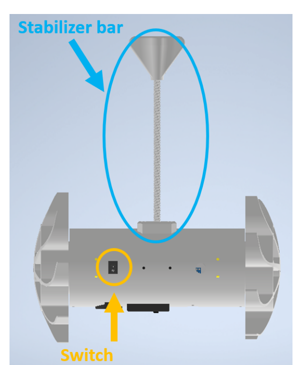

Fig. 11: Outer Upper Body

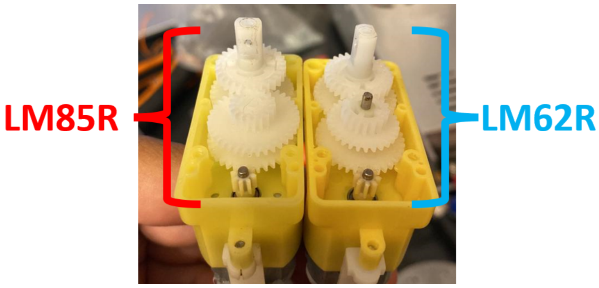

Fig. 12: "L" Motors

Fig. 13: Calibration Cube

*3) **Parts Manufacturing and selection**:*

- TPU printing settings and tests
  The printing tests of the TPU filament and its elastic properties dependent on the extrusion temperature were discussed here. The printing tests were X,Y,Z calibration cubes, an "Octopod" figure to observe the adhesion of the layers with irregular surfaces. And finally the first two tests of the flexible wheels of the CAD design.

  As shown in Table I, all the prints were made with a layer height of 0.35 mm to reduce the printing time of each piece, this is due to the volumetric extrusion of the filament, its extrusion is twice as slow. than other filaments such as PLA, so for example the v2 wheel, being the largest print but with less infill, took 16 hours.

Parts	Shield	Layer	Infill	Temp [°C]	Time	Weight
Cube 1	3	0.35	5%	240 - 230	21 min	13.4 g
Cube 2	2	0.35	5%	230 - 222	12 min	10.3 g
Cube 3	2	0.35	5%	225 - 222	12 min	10.36 g
Octopod	3	0.35	10%	222	119 min	15.8 g
Wheel V1	2	0.35	10%	222	719 min	83.45 g
Wheel V2	2	0.35	5%	222	973 min	101.93 g

TABLE I: TPU Test

  The selection of flexible wheel was fundamentally characterized by the dynamics that it presented at the time of receiving the impact in each design and if the dimension of the diameter completely covered the main cylinder.
  It is for this reason that there are two versions of wheels,

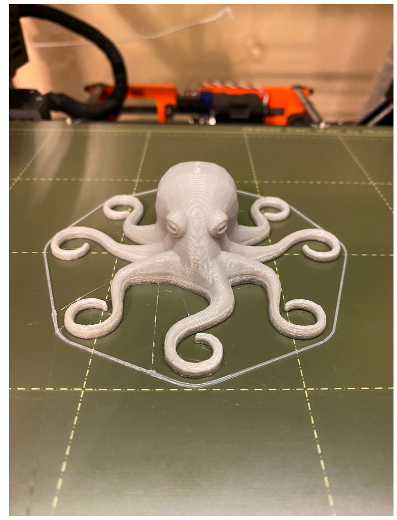

Fig. 14: Octopod

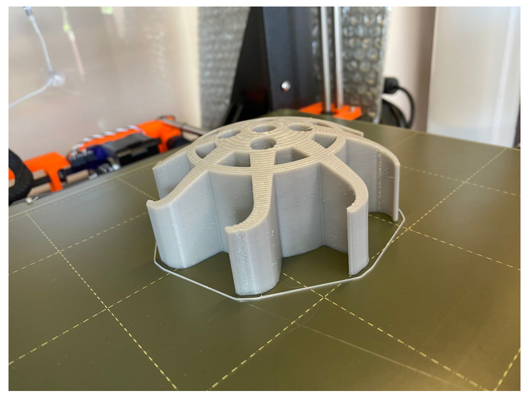

Fig. 15: Wheel V1

  the first Fig. 15 was basically a basic design with a diameter of 12 cm, the qualities of this design were insufficient when its impact on the ground was tested, due to this it was presented the second design Fig.16

  The printing tests determined that a layer height of 0.35, an infill of 15% and an extrusion temperature of 222°C are the ideal conditions that the TPU reaches to have good layer adhesion and good flexibility. As summary of the setting is:
  - Extrusion temperature: 220°C
  - Bed temperature: 60°C
  - Layer height: 0.2 mm
- Wheel
  The choosen wheel was the the one shown in Fig. 16 with the printing test, which got as final result shown in Fig. 17. This is due to its size that covers the dimensions of the main cylinder and, as will be seen in the test section, due to its resistance to falls.

- Main Body
  On the other hand, the printing time of the main body was 33 hours and 21 minutes, with the detail of having

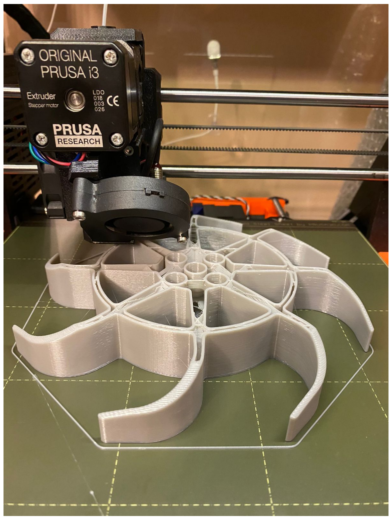

Fig. 16: Wheel V2

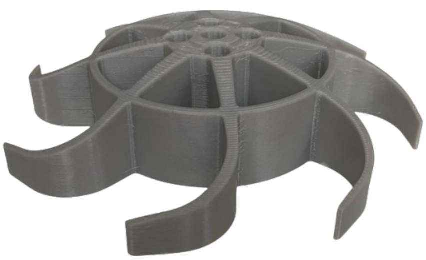

Fig. 17: Printed Wheel V3

been printed with supports configured with a distance of 0.4 mm between support and part Fig. 19, because the normal configuration of 0.2 mm, with TPU solidifies the supports and they are attached directly to the part.

- Shaft Coupler
  Once the shaft coupler manufactured, the wheel section is completed. In consequence, the TPU printing show good results as a perfect deflection material to avoid any outer damage and prevent to mess the inner pieces up.

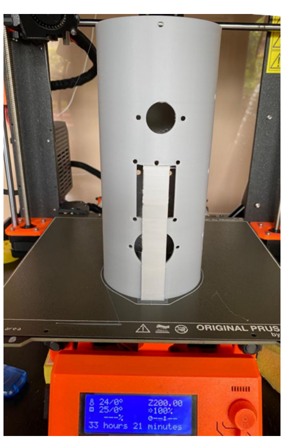

Fig. 18: Printed Main Body

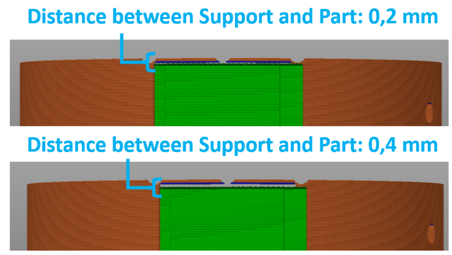

Fig. 19: Supports configuration in PrusaSlicer

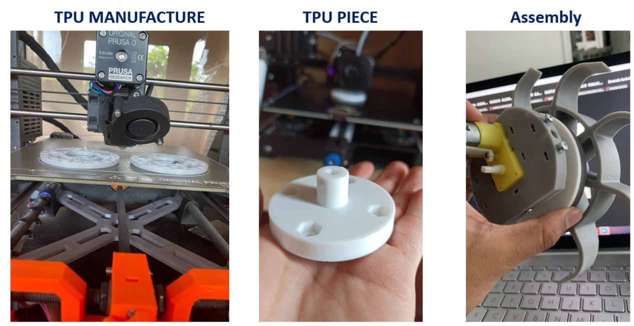

Fig. 20: Shaft Coupler

The manufacturing of the shaft part was carried out with the previous parameters purchased for a correct 3D printing of TPU.

*4) **Assembly Features**:* The assembly characteristics within this project are emphasized by the coupling of its parts from long cables with terminal connectors, in this way it is ensured that all the electronic elements such as the mechanics and their communication are inserted, without first bolting everything. In Fig.21 you can see the section of the wheel-motor with its connection cable attached to its respective terminal on the board.

On the other hand, the coupling of the light is simple and since it goes directly to the main body, it can be connected directly. However, another detail is the coupling of the ESP32, which is designed to have the ability to be unbolted and tightened at ease to be able to upload programs if needed.

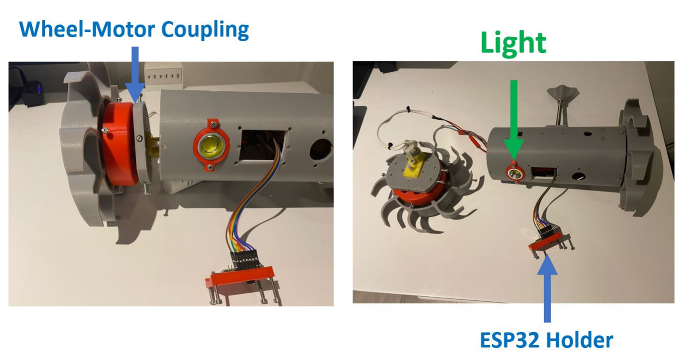

Fig. 21: Assembly Features

B. *Electronic Part*

For the electronic part the following components were selected:

Actuators: Geared motors will be used as actuators, these will be in charge of moving the robot. In this case, the selected motors have a speed of 170 RPM without load, operating voltage of 3 to 12V and a maximum torque of 800g/cm [6].

Microcontroller: As a microcontroller, the ESP32-CAM will be used. In this case the selected microcontroller is a low-cost ESP32-based development board with onboard camera, small in size. It is an ideal solution for IoT application, prototypes constructions and DIY projects. The board integrates WiFi, traditional Bluetooth and 9 IO ports [8].

Motor Driver: In this case, the L293D module was used since, the microcontroller needs 5V and the actuators 3V-12V to work. It is necessary to use a driver that helps the microcontroller to regulate the speed and direction of rotation. This module features a wide 4.5V to 36V supply voltage range, 600mA output current, and high noise immunity [7].

Power supply: In order to power the electronic circuit, 18650 batteries were used, since they provide 8800mA, 3.7V and their size is ideal for our application [5].

Voltage Regulator: By having a source that provides a higher voltage than the microcontroller needs, a voltage regulator is needed to lower the source voltage and thus feed the microcontroller. In this case the LM7805 regulator was used as it provides a voltage of 5V and a current of 1A as output [4].

After selecting these components, Table II was generated to see the current consumption that the project will have (the maximum current consumption of each component was used).

TABLE II: Component current Consumption

	Component	Quantity	Current Consumption []
1	ESP32 Cam Module	1	500mA
2	Motors	2	1000mA
3	LED	1	100mA
Total			1.6A

Knowing the current/hour provided by the batteries and the current consumption that the project has, it is possible to calculate the autonomy that the batteries will have. Equation 1 shows how to obtain the autonomy of the batteries.

$$\begin{aligned} Autonomy &= \frac{BatteryCurrent}{ChargingCurrent} \\ &= \frac{8.8A/hour}{1.6A} \\ &= 5.5hours \end{aligned} \tag{1}$$

Figure 22 represents a block diagram, which helps to visualize the logic of the project.

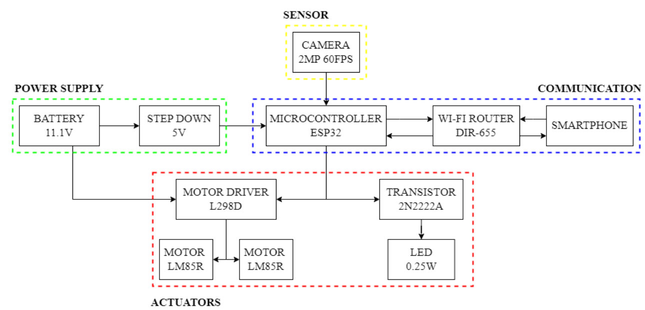

Fig. 22: Block diagram of the project

As the ESP32 CAM module was selected, the pinout has to be considered. The pinouts are very useful since they mention the characteristics of each pin as shown in Fig. 23.

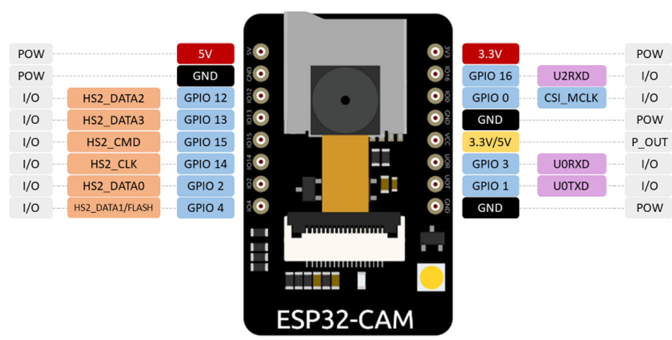

Fig. 23: ESP32 CAM Module Pinout [8]

As the robot is focused on recognition, it needed to have a light that illuminates the camera and at the same time facilitates the work of the operator. In this case, a 2V and 100mA LED was used, its luminance and model is unknown since the seller did not know it. In order to use the mentioned LED, a digital output of the ESP32CAM module had to be used. Connected to the base of a transistor in order to use it as a switch, as can be seen in FIG. 24. The sizing of the circuit is as follows:
From the 2n2222a transistor we know the following:
$I_c Max = 800mA$
$\beta = 100$
The Current of the collector divided by the current in the base of the transistor will be equal to β, as Eq. 2 shows.

$$\frac{I_c}{I_b} = \beta \tag{2}$$

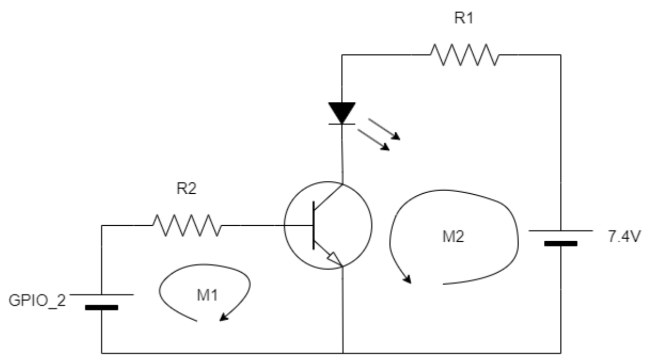

Fig. 24: LED schematic circuit

Since the LED need 80mA, that will be the current assumed for the collector of the transistor.

$$I_b = \frac{80mA}{100} = 0.8mA$$

Applying summation of voltages equal to zero in M1 we got the value of the voltage in R2 as Eq. 3 shows.

$$5V - VR2 - VBE = 0 \tag{3}$$

$$VR2 = 4.3V$$

Applying Ohm's law we can obtain the value of the R2 as shown in Eq. 4.

$$R2 = \frac{VR2}{I_b} \tag{4}$$

$$R2 = \frac{4.3V}{0.8mA} = 5.37k\Omega$$

Applying summation of voltages equal to zero in M2 we got the value of the voltage in R1 as Eq. 5 shows.

$$7.4V - 2V - VR1 = 0 \tag{5}$$

$$VR1 = 5.4V$$

Applying Ohm's law we can obtain the value of the R1 as shown in Eq. 6.

$$R1 = \frac{VR1}{I_c} \tag{6}$$

$$R1 = \frac{5.4V}{80mA} = 67.5\Omega$$

After analyzing the pinout and taking into account each chosen component, the electronic schematic diagram of the project was developed in Proteus as shown in Fig. 25.

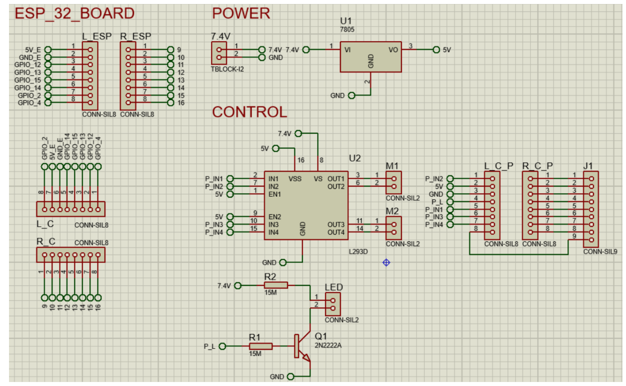

Fig. 25: Electronic schematic diagram

These PCBs were also designed using the proteus software as can be seen in Fig. 26, and after manufacturing they were as shown in Fig. 27.

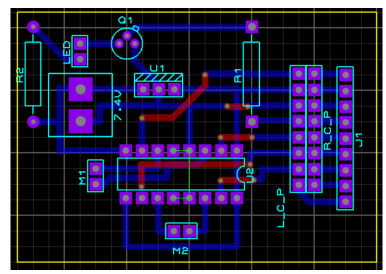

Fig. 26: PCBs Designed in Proteus

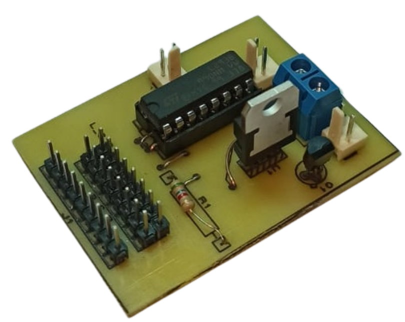

Fig. 27: PCB of Control

When using the robot for long time, the batteries discharged and in order to charge the batteries the entire robot has to be disassembled, taking valuable time and becoming annoying for the user. To avoid the previously mentioned, the BMS 3s module was added to the electronic circuit. This module helps to charge 3 18650 batteries in series providing 12V and a current of up to 20A. The connection of the module is simple and need to be connected as in Fig. 28.

C. Software Development

The ESP32 CAM was selected for this project due to its versatility, even though it is very small it has a lot of features that are really useful for the robot, such as

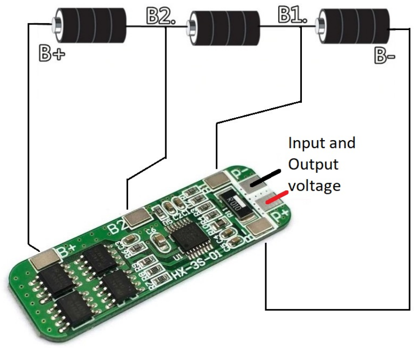

Fig. 28: BMS 3s Module

the 2-megapixel camera, along with integrated Wi-Fi and Bluetooth connectivity, and 10 GPIOs. However, because of its small size, there's no built-in USB programmer, and the reset switch is on the bottom, which isn't easily accessible. [8]

Since there is no direct USB connection, an FTDI TTL USB to serial adapter is needed. In order to program the ESP32 CAM the Arduino IDE was used, since it is compatible with the board and the language is fairly simple and easy to learn. Once the respective libraries were installed, a simple code was implemented to get the ESP32 CAM to connect to a Wi-Fi network, as seen on Fig. 29, the code is very straightforward, first enter the SSID and the password of the network you want to connect to, and call the "WiFi.h" function, which initializes the actual connection and allows us to get live feed from the camera and send signals to control the motors. [9] [10]

Fig. 29: Connection Set Up for the ESP32CAM in Arduino IDE

Once the Wi-Fi connection is stablished an IP address is set to connect to the ESP32 CAM through a web page which is accessed through said IP, as shown in Fig. 30.

Fig. 30: Serial output of the IDE with the IP

After setting up the initial connections a web app was developed in HTML, as seen on Fig. 31, in order to have a user interface for controlling the robot, with the user interface we are able to create buttons and assign functions that allows us to control the robot. Each button controls a different direction or rotation for the robot to move by sending a determined string of characters, which is read by the micro controller. [11]

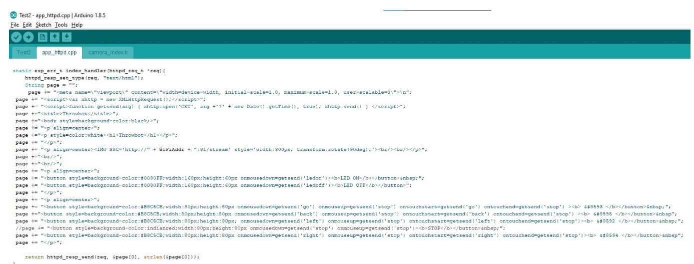

Fig. 31: HTML code for the user interface

Once the user interface was successfully implemented we were able to test both the camera connection and the button functions. Since the app was developed using HTML it can be accessed through any device like a PC or mobile phone, as shown in Fig. 32 and 33 respectively, connected to the same network using a web browser.

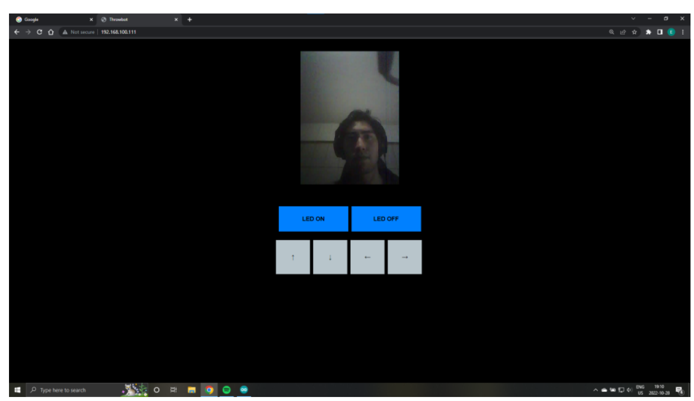

Fig. 32: Web App in a PC browser

In order for the app to work as intended a stable Wi-Fi connection was needed, in order to achieve this the first option was to use the University's network since it would allow us to use the robot and perform test anywhere on campus, however, due to the traffic on the network the available bandwidth was not enough to get a stable camera feed and the input tended to lag. The second option was to use a smartphone as a portable

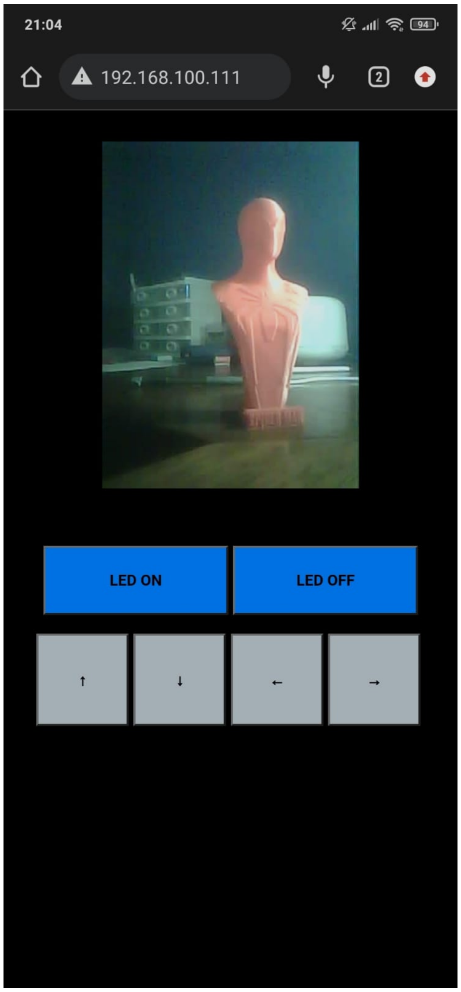

Fig. 33: Web App in a mobile phone

network, this provided a good connection and allowed for a stable communication, but each time it was turned off the IP address changed and the robot would not be able to connect. Finally it was decided to use a router to provide a private network as can be seen in Fig.34 , albeit without internet connection, this allowed the robot to have a good and stable connection to the app and since the only devices connected would be the robot and the whichever device is used to control it, the whole bandwidth would be available to have the video feed without any lag.

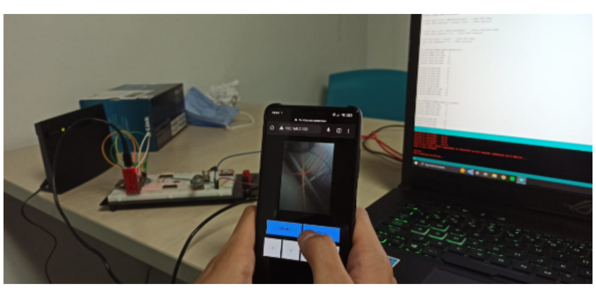

Fig. 34: App Connection

To ensure that nobody but the user of the robot would connect to the Wi-Fi network, a password was added and the SSID of the router was changed in order to more easily identify it. This was done using D-Link's configuration page as seen in Fig. 35 and 36.

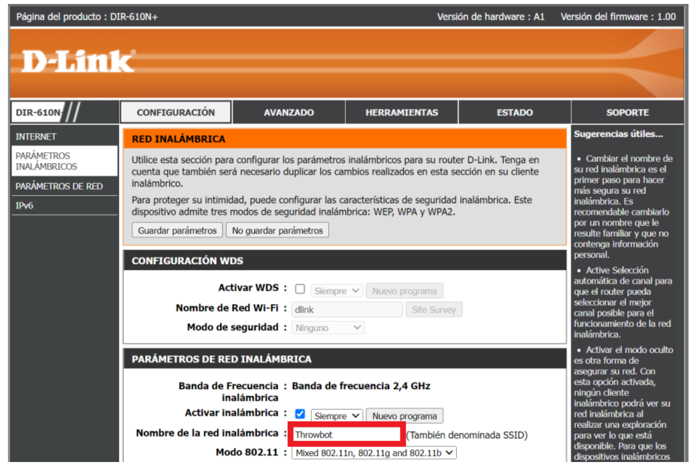

Fig. 35: SSID change

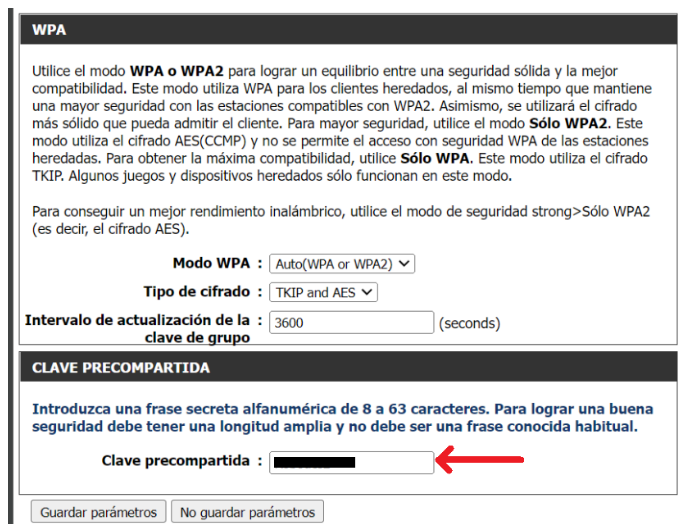

Fig. 36: Password change

To have a better way to know when the robot is connected to the network a blinking light was added, the integrated LED light of the ESP32 CAM will blink until the robot is successfully connected to the Wi-Fi network, as seen on Fig. 37 and perform a routine highlighting the movements the robot can make.

IV. Tests & Results

A. Falling Test

Within the drop tests to verify the resistance of the TPU, 3 tests were carried out at different average launch heights.

1) Test Height 60 cm: For the first drop test, the backslash hit caused the Throwbot to rise an average of 20 cm.
2) Test Height 100 cm: For the second test, it was performed with a height of 100 cm, which in Fig. 39 can be seen that the backslash hit causes an average height

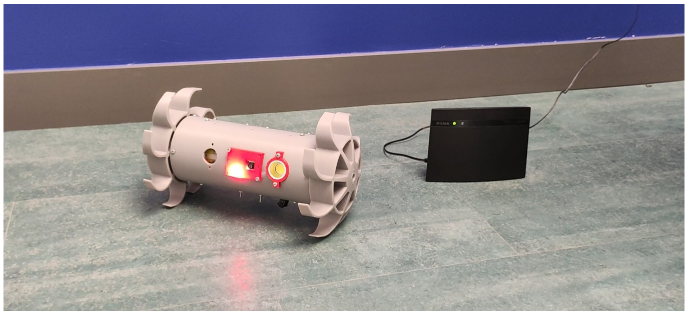

Fig. 37: ESP32 CAM LED light turned on

Fig. 38: Test Height 60 cm

equal to the first test but adding a somersault in the air.

3) Test Height 130 cm: For the test of height of 130 cm, at the moment of the blow there is a deep flexion that can be seen in Fig. 40 and like the previous test, the recoil blow presents a somersault in the air.

   It is worth mentioning that this project does not focus on a deep analysis of dynamic resistance against blows of the main parts, nevertheless it has been proof, the project can hold back the relative falling force. In the following link you can see the tests done in an audiovisual way.

   ThrowBot - Prototype Version 1.2 Tests: https://www.youtube.com/watch?v=i9h-vVrpSWI

B. Light Test

The project also includes the addition of a light that serves to illuminate the Throwbot's path at night. In Fig. 41 the operation can be seen.

C. Motion Test

For the mobility test, the programmed pins were interacted with to move the robot forward, backward, left and right. This can be seen in the following link.
ThrowBot - Prototype Version 1.2 Motion Test: https://www.youtube.com/shorts/0UCtxqn8BnQ

D. Night Indoor Test

In the operation test indoors in the dark, the robot worked correctly, showing that there is no interference when performing remote control from the web application.
ThrowBot - Prototype Version 1.2 Night Indoor Test: https://www.youtube.com/shorts/mWE-JJHGFOE

Fig. 39: Test Height 100 cm

Fig. 40: Test Height 130 cm

V. Conclusions

- The sizing of the throwbot was adequate for the cylindrical measurements of the main body and the flexible wheels capable of housing the electronic and mechanical components structuring system with the ability to withstand average launch impact forces with an average distance of 300 cm and a maximum height of 180 cm
- While on the other hand, the maximum connection distance in line of sight between the router and the throwbot is 36 meters, and 29 meters without line of sight.
- The connection time of the robot for its operation is 1.4 seconds assuming that the router is already active and ready to establish a connection between the devices.
- The robot is capable of being controlled by a web interface, using any device with access to a browser, while transmitting live video through the 2.4GHz Wi-Fi network, allowing for indoor surveillance.
- The test gave as result a throwbot´s average speed of 20 meters in one minute or in oder words a maximum reachable speed of 1.2km/h.
- A possible suggestion for the testing section is to perform indoor connection tests but in an environment where there are no walls, so that in this way the signal between the router, the throwbot and the smartphone is as clear as possible and verify the distance of maximum connection.
- Above all, it can be concluded that the process carried out within this investigation determines the fulfillment of the main objective of designing and implementation of a scale throwbot robot controlled wirelessly through a smartphone for surveillance and revognition applications.

Acknowledgments

We would like to express our special thanks to our Professor, as well as our parents who gave us the opportunity and support to carry out this project, in which a lot of work and learning was done. We are very grateful to them.

Appendix A
Total Costs

To implement the robot, the components and materials of Table III need to be purchase. The 3d printing prices were

Fig. 41: Light Test

Fig. 42: Motion Test

not taking in count since the group have its own 3d printers. With "others" we refer to materials related to soldering like soldering paste, tubing, solder, etc.

TABLE III: Total Costs

	Quantity	Component	Price [$]
1	3	18650 Li-Ion Battery	10.5
2	1	Battery Charger	7.60
3	1	Battery Holder	5
4	1	ESP32 CAM	16.90
5	2	6V Motor	7
6	1	PLA Filament (1kg)	20
7	1	TPU Filament (1kg)	25
8	1	LED Light	3
9	1	PCB	13
10	1	ESP32 Programmer	5
11	1	Battery Charger Module	3.8
12	1	Jack Connector	0.8
13	1	Nuts and Bolts	1
14	1	Cable	3.4
Total			122

Appendix B
Mechanical Diagrams

To be able to visualize the diagrams you have to enter the following link: ThrowBot - Mechanical Diagrams

Appendix C
Electrical Diagrams

To be able to visualize the diagrams you have to enter the following link: ThrowBot - Electrical Diagram

Appendix D
User Manual

To be able to visualize the User Manual you have to enter the following link: ThrowBot - User Manual

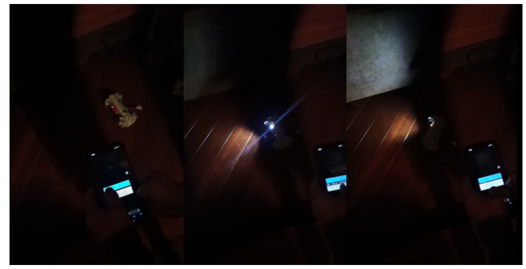

Fig. 43: Night Indoor Test

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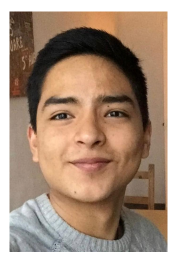
Biography Section



Ricardo Yepez: Student of Mechatronics Engineering in Universidad Internacional del Ecuador. Has made previous studies in physics in Germany for 2 years before enrolling in mechatronics engineering. In the actual time he is coursing the eighth semester of the career in Universidad Internacional del Ecuador.

Erick Peñaherrera Vega was born in Quito, Ecuador in 1999. He coursed highschool in Centro Educativo Isaac Newton and graduated in 2017 and was accepted in Universidad Internacional del Ecuador the same year, he is currently in his final year of Mechatronics Engineering.

Eduardo Villacís Santamaría was born and raised in the heart of Quito and grew up a very outgoing and active child. Right now he is currently a last year Mechatronic Engineering Student, at UIDE University. He will graduate in December 2022 with a Bachelor degree on Mechatronic Engineering.