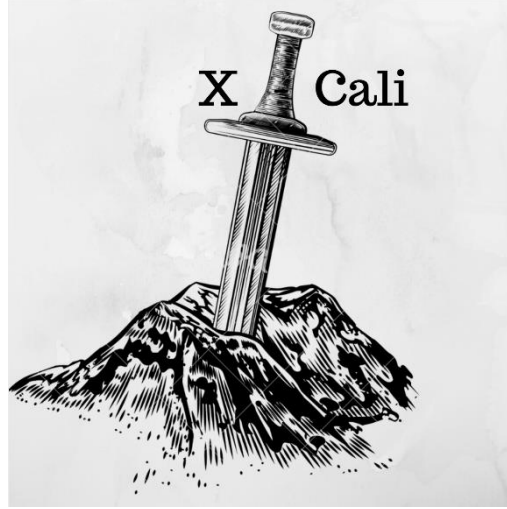# X-CALI

Final Report

"Design of Robots Collaboratively Carrying a Long Object through an Open-Top Maze"

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Executive Summary

The X-Cali company was founded by five shareholders at September 2017. All of the shareholders are qualified senior Electrical & Electronics Engineering students. The main interests of the X-Cali are research, development and producing useful products for the customers. Customer satisfaction is the most important concern of the X-Cali.

For the shareholders of the X-Cali, the 'Maze Solving Robots' project has been a great experience. We learnt a lot about electrical and electronics engineering applications. We tried to go beyond our limits and do our best for this project. Different solution approaches were discussed and after all the work we performed, we came up with a final innovative solution.

In today's world, efficiency is everything and we are aware of this fact. We believe that we did our best and created the most efficient robot that is possible in every aspect.

For all of us, this teamwork was the first one we experience and it will be very useful in our professional career since probably we will work as team members in the future.

To sum up, we think that we did our best and produced a robot that is useful and easy to use. We are happy with our product and sure, that customers will be happy too. We hope that we will continue to research and development processes and to produce innovative products.

Introduction

At the beginning of our last year, we formed a project group as five senior Electrical & Electronics Engineering students and this was where our adventure started. Choosing a project was the first step of the project process. At September, we started to think about which project to choose. We had to consider all the important parameters and make a choice accordingly. Detailed researches were done. After long discussions, we chose the 'Maze Solving Robot' project. In this project, two robots are supposed collaboratively to carry a plank through an open-top maze.

After the choice was made, we began to research process. Firstly, we conducted a research about which components to use at the construction of the project. There were many options and we had to be cautious. Once the component decisions were made, our second concern were the algorithms those will determine the movement of the robots. Again a research was conducted and we started to work on the several solutions. Until the end of the first semester, we continued to work on algorithms theoretically and implemented a robot that would be used temporarily for the first demo.

At the spring semester, we worked on both software and hardware parts of the project. A prototype of the robot was constructed and test procedure was started. After several tests, we evaluated the results and made some changes on the robot. Towards the end of the semester, we had two demonstrations to our Design Studio Coordinator. After those demonstrations, we were ready for the final demonstration.

In conclusion, the whole project process had been a good experience for us. We tried to explain our design and implementation of the project in this report. We hope that it will be useful for our customers.

Design Descriptions

This project aims to build a robot that can collaboratively carry an object with another robot in an open-top maze. This duty's main requirements are designing a robot which is aware of its surrounding and which can freely, predictably and precisely move. To achieve this purpose, we have designed and built the robot in three main subsystems according to their functions. The robot includes a body part, which is the main chassis and passive components on it, a detection part that is composed of a camera, proximity sensors and algorithms that provides surrounding awareness, and finally movement part with motor drive system, tires and movement control algorithms. Detailed block diagrams and flowcharts of these subsystems of the robot are provided on Figures 1 and 2 below.
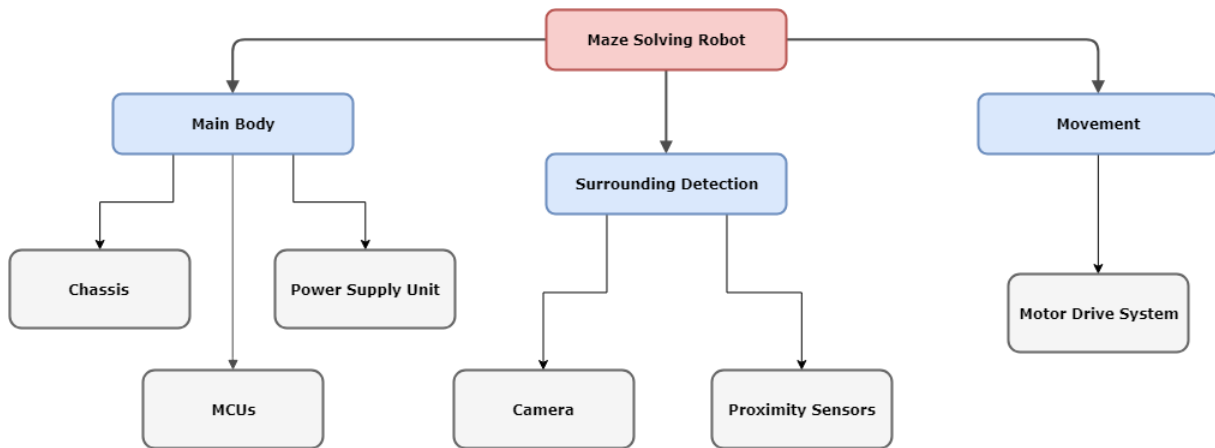

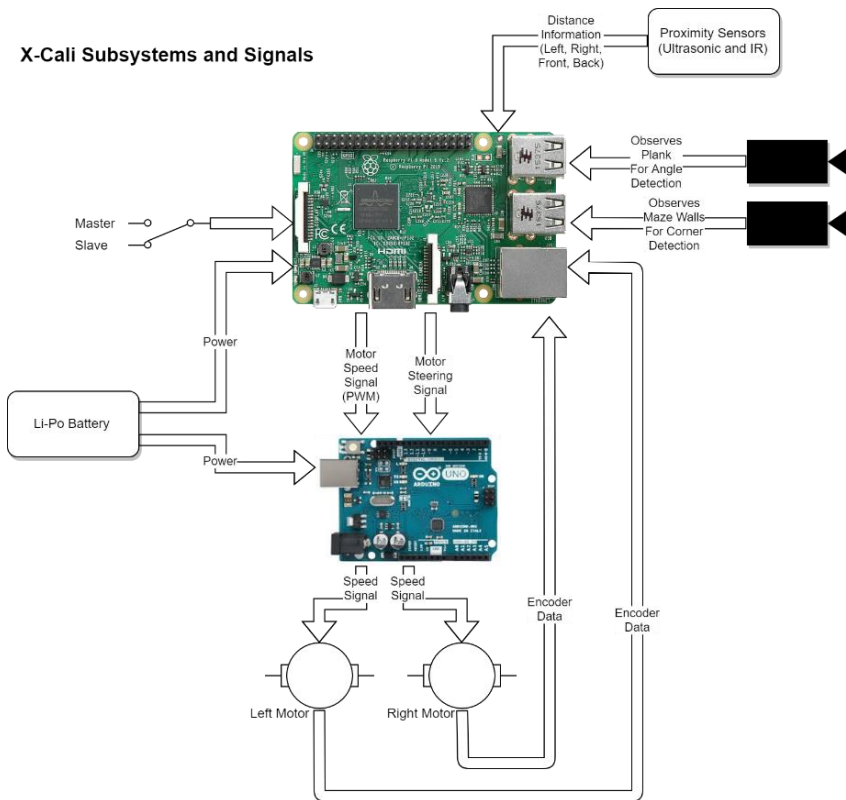Figure 1: Block Diagram of the Overall System

Figure 2: Flowchart of the System Functioning

Technical Details

Mechanic Design

Robot is design in a circular shape. This is the most applicable geometry in the maze in order to prevent obstruction. Circular shape provides flexibility to robot for continuing its path after contact with the wall. Although RaspberryPi does not fit perfectly to the robot, it is still the best solution for chassis design. The robot has a diameter of 100mm. By making the robot that small, it can travel in the maze easily by polling the distances between the two walls. The procedure is given under Movement. There are three layers. In the first layer, the motor driver and side wall sensors are located. In the second layer, RaspberryPi and front wall sensor are placed. On the top layer, battery and power bank is located. Using the advantage of connections of layers, we build the camera holders on top of them. The produced robot can be seen in the Figure 3 below.
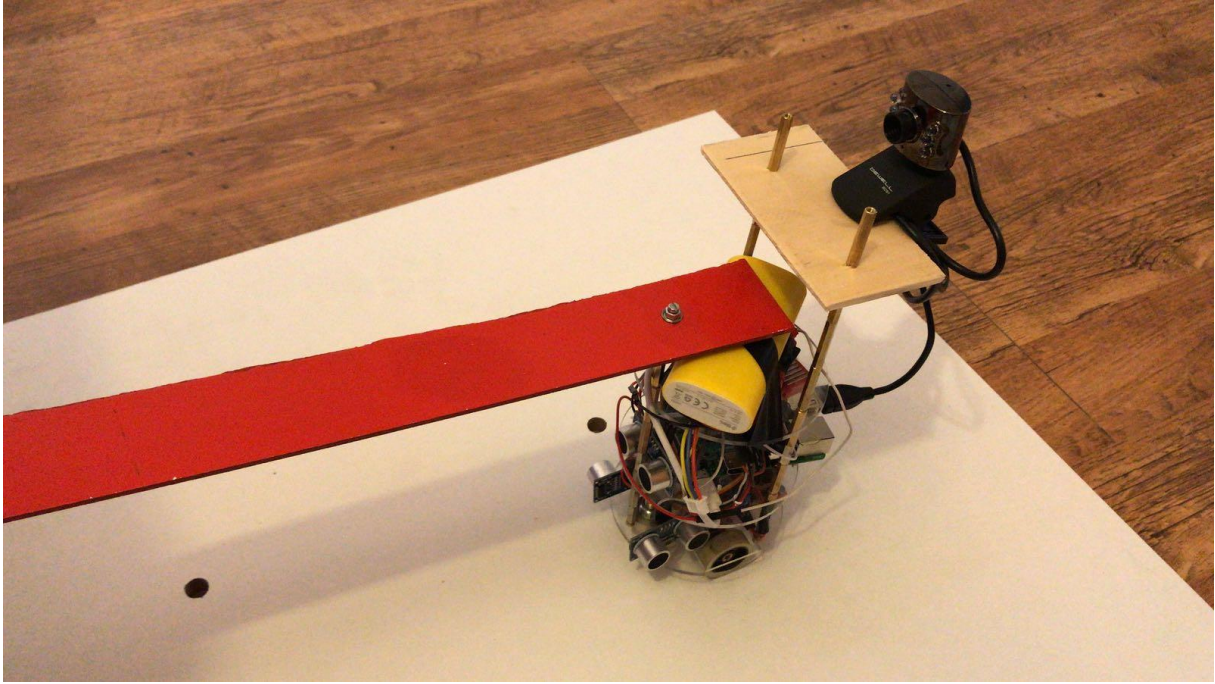
Figure 3: Photos of our robot

Movement

The robot proceeds through maze using Bang-Bang algorithm. Bang-Bang algorithm is simply proportional feedback system. It takes the distances from the sides as inputs. The width of the road is given initially. Using these data, it tries to stay at the middle of the street. The proportional constant is tuned by experimenting the robot behavior in the maze. Since the robot is small – actually, we made it smaller than the one in out critical design report, it can align itself easily.

Detections

In the robot, there are two components to have a knowledge of the surrounding of the robot. This subsystem supplies the most important data for the decision unit. All decisions will be made with respect to the signals taken from

- Camera
- Ultrasound Sensors.

These awareness sensors help the robot find its path in the maze and lead or follow the other robot. The structure of this module is given in Figure 4.
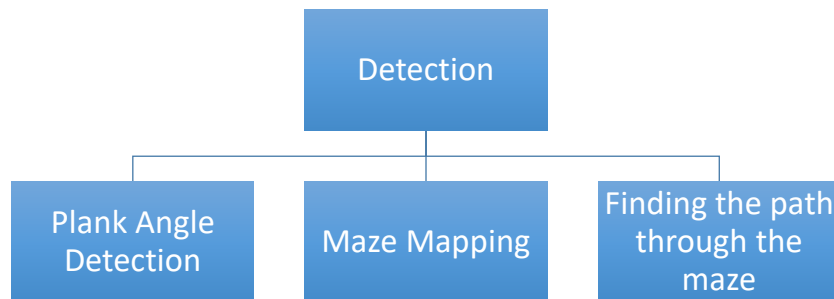
Figure 4: Block Diagram of the Surrounding Awareness Submodule
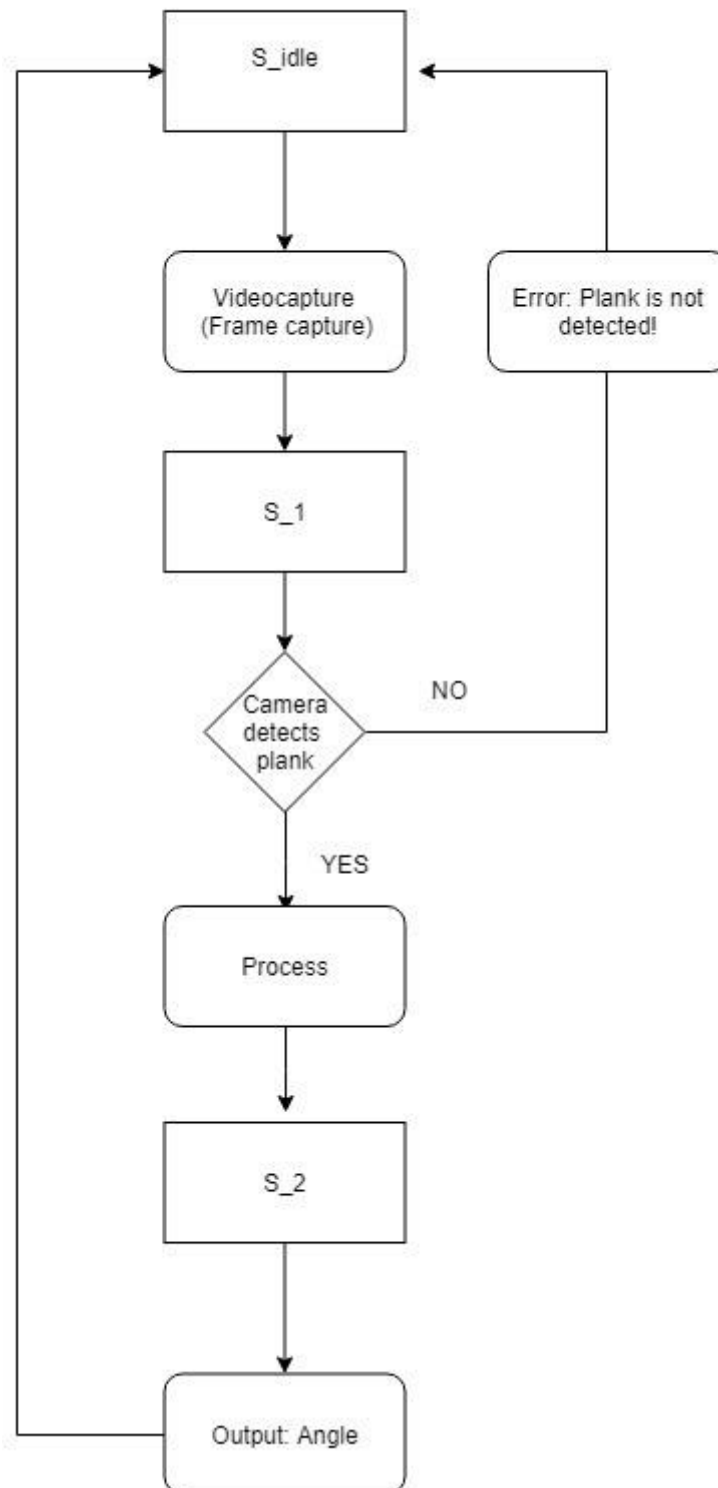
Angle Detection

Figure 5: Flow chart of angle finder using camera the algorithm

In the plank angle detection, the image capture is taken from the camera and processed simultaneously. The main purpose is to achieve the angle of the plank to be able to identify the other robot's moves and the process is illustrated in the Figure 5 above. With interpreting this angle in the critical points of the maze, the robot will be able to find its correct move in the decision unit.

For this, we firstly developed an algorithm to be able to detect the correct angle. As the camera within the robot will see the plank in an uneven pattern, this image needs to be fixed so that we could find the angle in a more reliable way. The procedure is given below,

I.   The colorful image is taken as an input
II.   The input image is masked as processing in the grayscale is much more practical.
III.   The uneven masked is image is applied some transforms to get a more linear shape.
IV.   Angle finding algorithm is applied to the transformed image.

An example of this process can be observed in Figure 6.

(a) (b)

(c) (d)
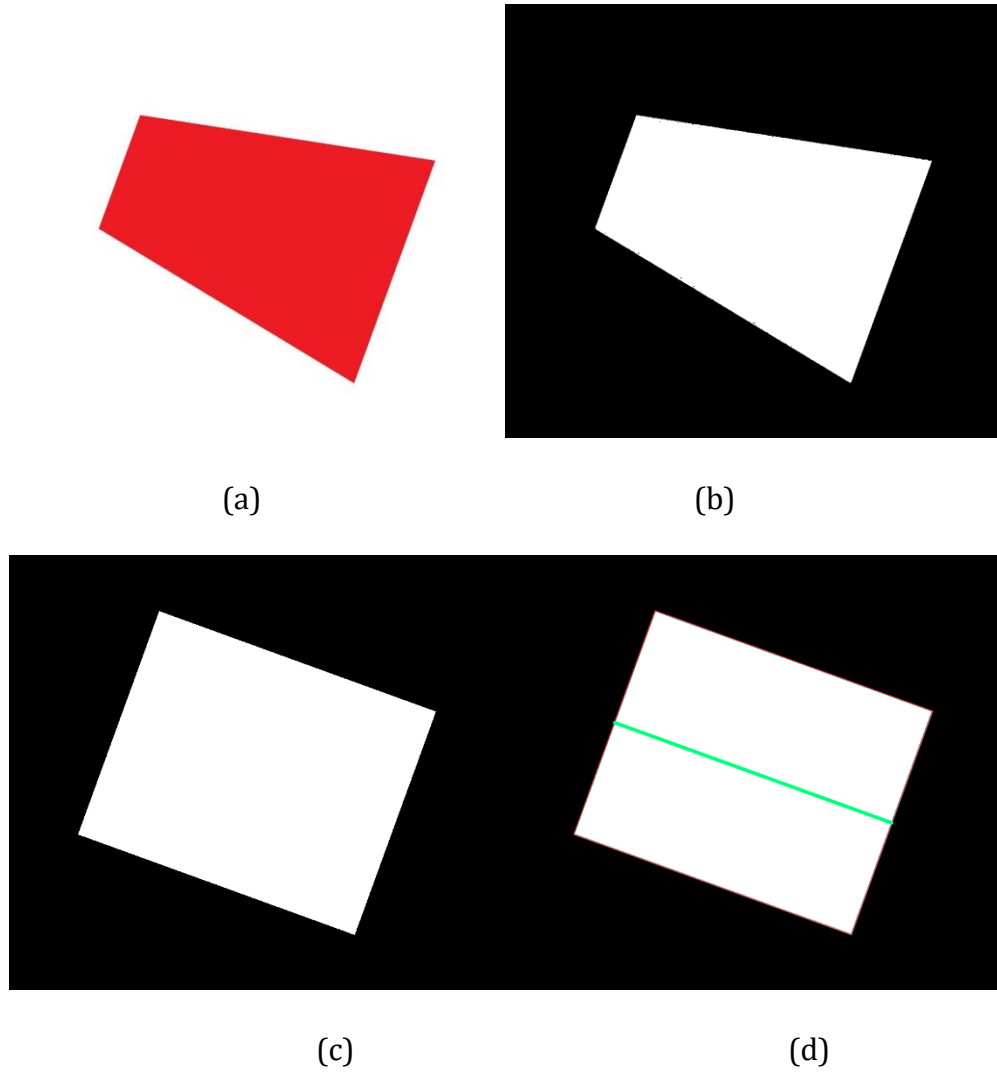
Figure 6: *The original input image (a), the masked version of the input image (b), the transformed version the input image, not uneven (c), and angle-detecting algorithm applied to the transformed image (d).*

After the angle of the plank is detected, this information is sent to the decision unit so that the decision unit sends the necessary signals to the motor driver.

An illustration of this process can be seen in the command prompt in Figure 7.

Figure 7: Angle Detection Output of the Plank.

All this algorithm process was debugged and developed on the computers. Then, we made a demonstration on the real robot, to see whether it could find the angle of the plank in a correct manner. Figure 8 given below is a basic demonstration of the algorithm on the Raspberry Pi 3, while all the robot components are integrated.
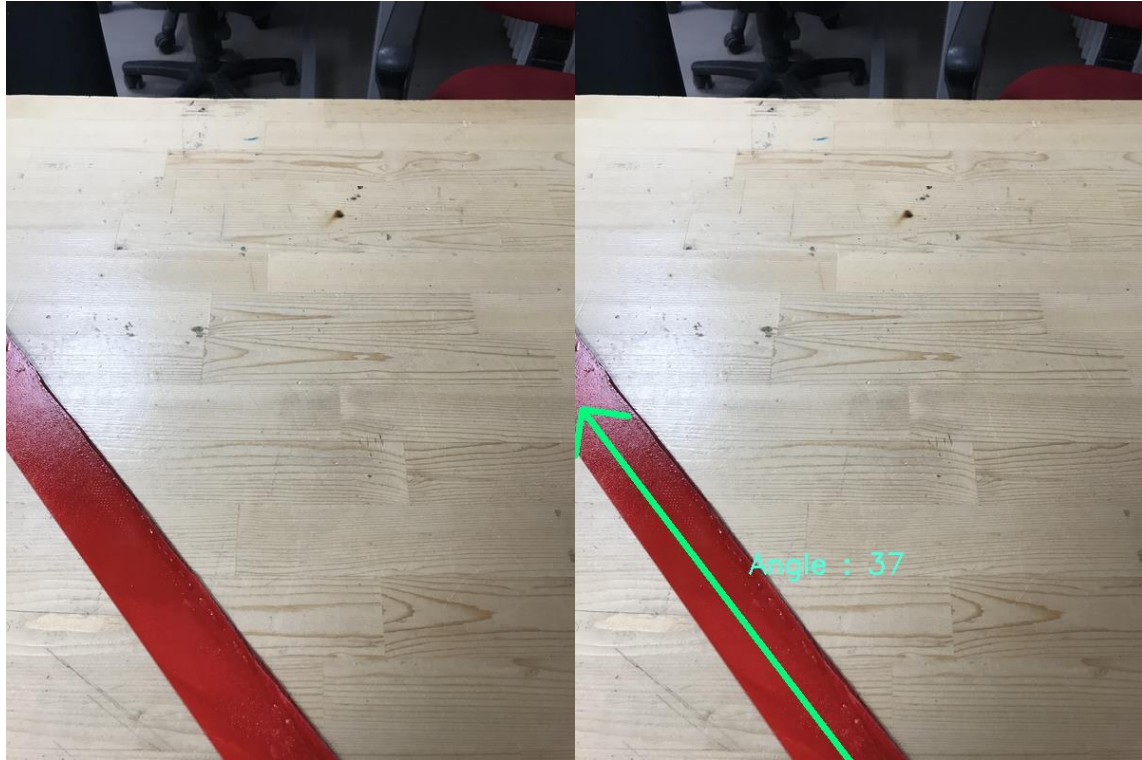
(a)   (b)
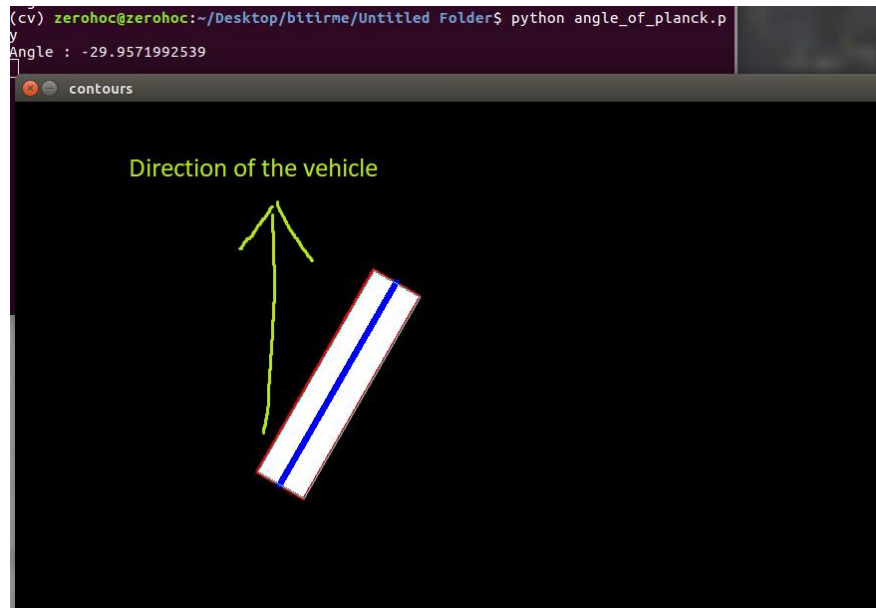
Figure 8: Demonstration of the Angle Detection Algorithm on the Robot.

The camera captures the plank from the top view (a), and then the angle detection algorithm is applied to find the angle (b).

Maze Mapping

Besides the angle detection of the plank, we also use the camera to map the maze from the top view. Maze mapping is important because it eases to decide what the robot should do as its next move. For this mission, the camera used in the angle detection cannot be used, as the perspectives are quite different. Therefore, we will use another webcam camera to map the maze located higher than the angle-detecting camera. A visual illustration of this mapping is given in Figure 9.
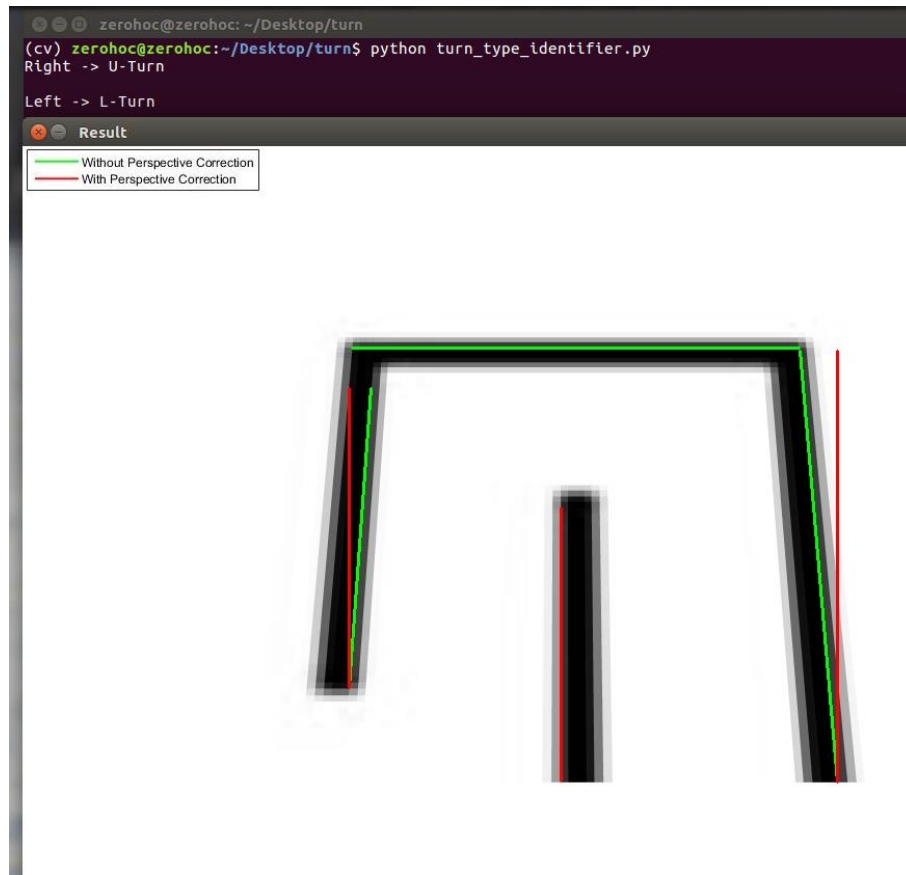
Figure 9: Maze Mapping Algorithm Visualization.

After mapping the path, this information is used to save a few movements which the robot completed. This becomes an important issue especially when there is a L or U turn. In the Figure 9, it is also available to observe these movement detections made.

Plank Placement

The constriction on plank placement was declared in the Standard Committee Report. Between the two holes, there is 400mm distance and the holes are with 10mm diameter. The important point of plank placement is that every group must be able to use the other group's plank too. When this case is considered, we needed a generic solution. Thus, we came up with the idea of using a ball bearing whose outer diameter is 10mm and inner diameter is 3mm. 3mm of inner diameter provides us also efficiency in the usage of resources as in the other parts of the robot we also use 3mm screws. The plank is fixed using a screw and a ring nut. The plank fixation is showed in the Figure 10 below.
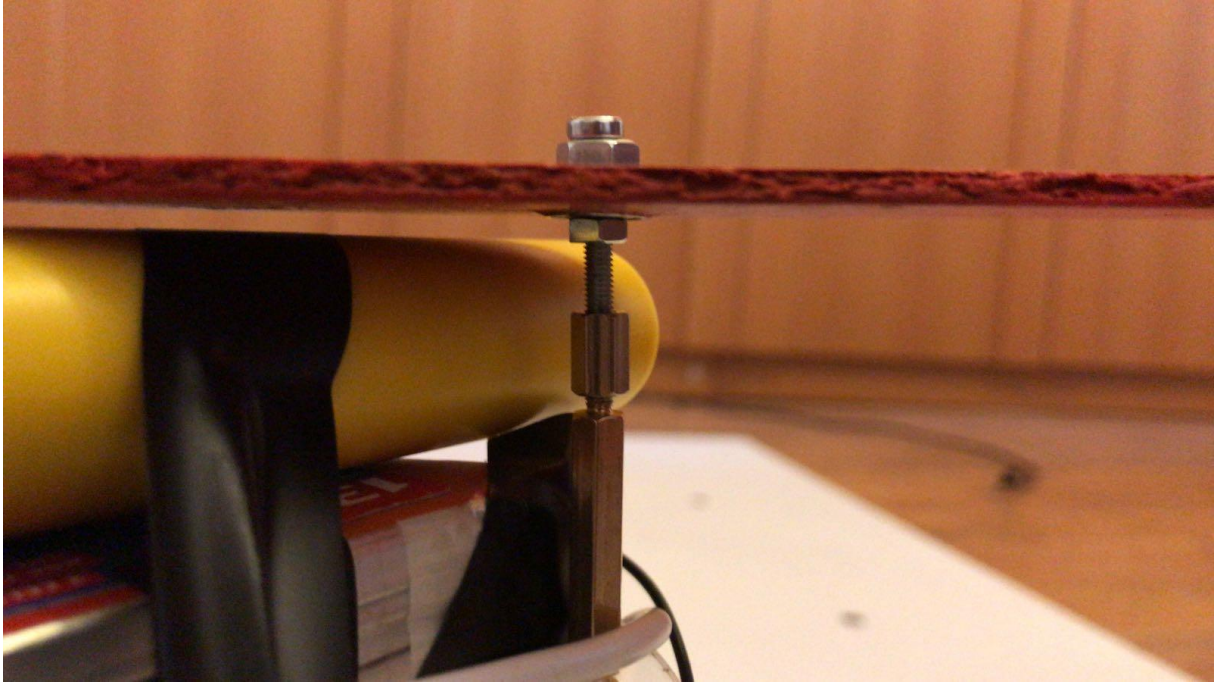
Figure 10: Plank fixation on the robot

Maze Construction

Base of maze is made of four wooden plates. One can consider maze like 5 by 5 chessboard. [1] As can be seen in the Figure 11, one part of the wall can be placed. Every wall is 250mm. There are four notches around the holders. Thus, one can easily slide the wall through the holder. The dimensions are perfectly matches with Standard Committee rules.
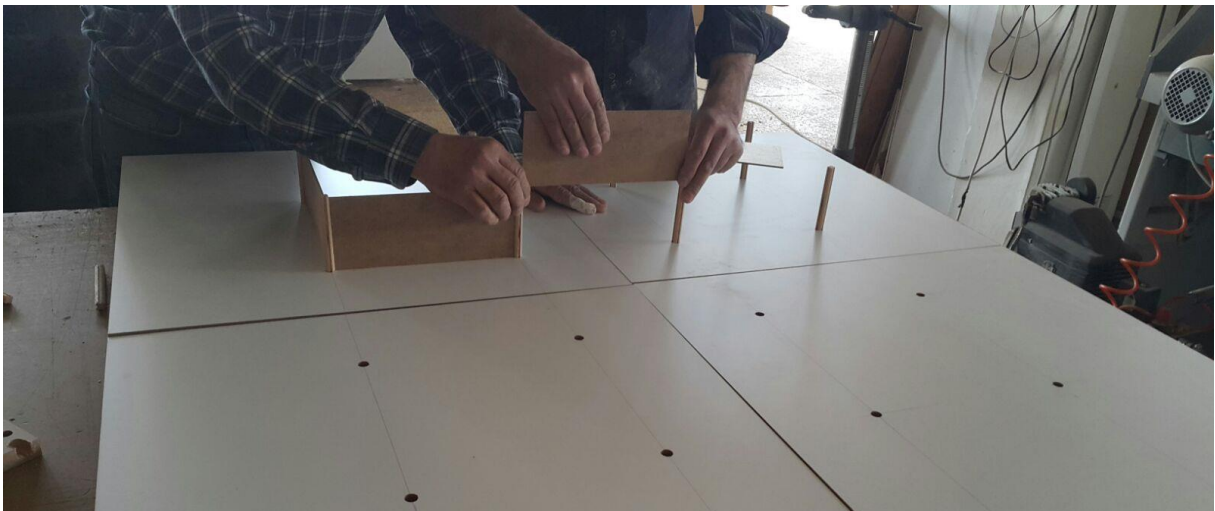

Figure 11: Maze Construction

Modification to Critical Design

In the Critical Design Report, the design proposals are finalized. After the Critical Design Report, we did many improvements to our robot while staying in the borders of our proposals. The most significant design update is chassis of the robot. We ended critical design session with a two-layered 150mm x 150mm square chassis. Although, the robot was able to complete its travel through maze, as a precaution we designed a new three-layered chassis with a circular shape of 100 mm diameter. This update provided us more freedom in the maze and by this update; we are now able to observe the effects of Bang-Bang control more clearly.

Apart from the chassis update, we also continued improving the codes to solve the maze. Previously, we were using a code understands the upcoming turn type and calls the related code. In the new script, we wrote a generic code that applies all the turns except two special cases.

Requirement Analysis

All the requirements decided in the standard committee are evaluated in the Table 1.

Table 1: Requirement Analysis of the Project

# OF STANDARD	PROJECT STANDARDS	STATUS
1	Color of the ground and walls should be white.	Satisfied
2	Height of walls should be100 mm.	Satisfied
3	Upper side of walls (between 90mm height – 100mm height) should be black.	Satisfied
4	Top of every wall pieces should have 1 cm width and should be black.	Satisfied
5	Plank should have 3 mm thickness, 50 mm width and 500 mm length.	Satisfied

6	Color of the plank should be red and material of plank should be hardboard.	Satisfied
7	Shape of the holding point should be circle. Diameter of this circle should be10mm. Length between centers of the holes is 400 mm.	Satisfied
8	Robots of companies should fit into a square. This square has a 23cm side length.	Satisfied
9	Height of the holding point should be 17cm.	Satisfied
11	The maze should be modular and reconfigurable. In other words, walls can be removed or added on the platform.	Satisfied
12	Every team should design their own robot, maze and plank	Satisfied
13	Every robot should be able to operate in each other's maze and each other's plank.	Not satisfied yet
14	If the state changes, robots should behave accordingly.	Satisfied
15	Robots should move respect to right wall.	Satisfied
16	The total cost of the project must be less than 200 USD.	Satisfied

Test and Subsystem Evaluation

Movement of the Robot

Movement tests of the robot have been performed since the first implementation stage of robot. With the feedback of several errors encountered, the movement performance of the robot has increased day by day. With the final implemented version of the robot, the movement tests were passed successfully.

In the first implemented robot chassis, a motor driving algorithm was not used. Instead, we used direct driving in a basic way. In that stage, this application was adequate to follow the straight road. However, when the turning algorithms were implemented, significant problems regarding to the driving algorithm appeared. At that stage, Bang-Bang algorithm was preferred and implemented as the driving algorithm of the robot.

The logic behind this algorithm is to switch abruptly between two states, which is in our scenario turning left and right. This type of controller algorithm is also known as the hysteresis controller algorithm.

After implementing this type of controller, some modifications were done to increase the stability of the robot while making turns in the maze.

Some test results regarding to our latest updated controller algorithm can be found in Appendix A.

Detection of Plank

Plank is detected using the camera. The test proof of the system's functionality can be observed from the Figures 7 and 8. Sometimes, detection is affected by the environmental light sources. Reflections, sometimes, misleads the detection of the plank.

Power

In our robot, there are two types of power suppliers. One of them is Li-Po Battery, supplies energy for wheels, and the other one is power bank, which supplies energy for Raspberrypi3. Since there is no component that sinks power dramatically, voltage and current concerns is not crucial for our design. The Li-Po Battery can serve more than 1.5 hours with full performance.

Safety Issues

- Li-Po Batteries in the robot may explode or start a fire or release poisonous gases during usage of the robot.
- Li-Po batteries may explode or start a fire or release poisonous gases during charging them.
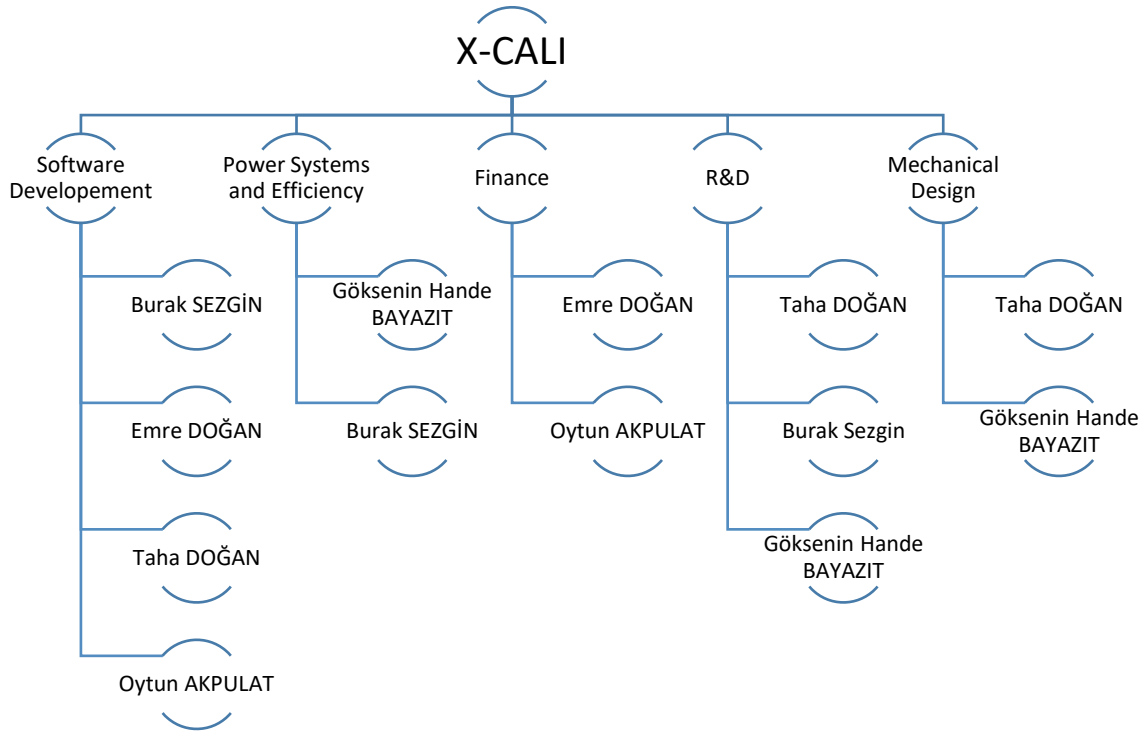- Overheating of microcontrollers may cause burns on the skin.

Organizational Plan

Figure 12: Organizational Structure of **X-Cali**

Application of the Product

X-Calibot is a product to be used in many fields where there is a necessity of carrying long & heavy loads.

In the last decade, the online shopping became the most preferred way to buy or sell items. This situation brought the necessity of having very large sized warehouses for these e-shopping companies. As the size of these warehouses became larger and larger, the necessity of more workers in these places increased. However, this leads to employ more workers and decreases efficiency. Therefore, X-Calibot brings a safe and cheap way to carry long and heavy loads within these warehouses. So that, the carrying operation can be done without employing large number of workers.

Another application of the product is in the defense industry. There are many companies producing weapons (especially long rifles), missiles and rockets all around the world. These products are too heavy for people to carry. Moreover, it is too dangerous for people to carry such products with the risk of high explosibility. X-Calibot offers a much safer and

easier way to carry these products. In the plank region of the X-Calibot, there is a box that each type of product can be placed to be transmitted to the desired position.

List of Deliverables

List of deliverables, including User Manual, is given in the Appendix B.

Cost Analysis

In the Table 2, cost analysis of the final product is given.

Table 2: Cost Analysis of the Project

Product Name	Price / Product	Quantity	Total Price
Raspberry Pi 3	Ł181.65	1	Ł181.65
HC-SR04 Arduino Ultrasonic Distance Sensor	Ł5.50	4	Ł22.00
Webcam	Ł20.00	2	Ł40.00
Motors	Ł40.00	2	Ł80.00
L298N Motor Driver	Ł12.00	1	Ł12.00
Mad wheel	Ł5.00	2	Ł10.00
Robot Chassis	Ł15.00	1	Ł15.00
Jumper Cables	Ł5.00 (/set)	2	Ł10.00
11.1V 1300mA LIPO Battery	Ł69.50	1	Ł69.50
LIPO Battery Charger	Ł45.00	1	Ł45.00
Power Bank 5000MAH			Ł60,00
24V-5V 3A DC to DC USB Power Module	Ł6.65	1	Ł6.65
Screw set	Ł30.00	1	Ł30.00
Plank and ball bearings	Ł20.00	1	Ł20.00

Maze construction			Ł150.00
		TOTAL PRICE	Ł751,80

Please note that, we were allowed to spend up to $200,-. Total price is, according to today's currency, $177, 59.

Conclusion

This final report was prepared by members of the X-Cali in order to inform the customers about the design and construction processes of the product. Circuit diagrams, flow charts that explain subsystems, test and subsystem evaluation, result of the performance tests and cost analysis are provided.

Our solution approach for angle detection was also explained in this report. The solution includes two cameras and image processing. Angle of the plank will be determined with the data coming from camera. After that angle, data will be processed in RaspberryPi.

Ultimate goal of X-Cali is to become a valuable company in the electronics market in the world. We will work hard for this purpose and we hope that we will succeed.

In conclusion, we can state that our robot is ready except small modifications. Some minor modifications may be done. When the final version of our robot is available, we believe that people will be highly interested in our robot.

References

[1]   Standard Committee Report

Appendices

Appendix A

Going through a straight street by itself

In this test, the robot is supposed to enter a straight maze corridor and leave it successfully.

We applied this test 15 times and according to our observations, the robot completed the trials with 87% success rate. There are two unsuccessful attempts where the bang-bang controller had failed.

Making the L turn by itself

In this test, the robot is supposed to complete an L turn itself. For this purpose, we use the data coming from the ultrasound sensors.

On the real maze platform, we applied this test fifteen times. Thirteen of these trials were successful. Reasons leading these errors can be seen from the Table 1.

Table 3: Different Situations Occurred during the L turn tests.

HIT/FAIL?, Error Type	Frequency
Detected the wall and made the L turn. However, due to excessive turning (about 120°), it failed.	1
Everything worked fine. However, the cables within the chassis mislead the ultrasound sensors.	1
Everything worked fine.	13

Making the U turn by itself

In the U-turn tests, a process similar to the L turn was followed and the results can be observed below in Table 2.

Table 4: Different Situations Occurred during the U-turn tests

HIT/FAIL?, Error Type	Frequency
Detected the wall and made the first L turn. However, due to excessive turning it had problems in the second L turn.	2
It successfully completed the U-turn. However, after the turn, it had problems on straight path movement.	1
Everything worked fine.	12

Making the U turn by itself

List

The first robot of X-Cali is designed for general usage. There is no specific client profile for our product. The robot can be used for different purposes such as gaming or educational purposes.

The expected deliverables of the work packages of our project can be seen in Table 7.

Table 5: Expected Deliverables of the Work Packages of the Project

The Work Package	Corresponding Deliverable	Status
Research	Tentative Report	Completed
Component Tests	Results and analysis of the component test	Completed for the ultrasonic sensors and RP3. Test plan is achieved.
Communications Subsystem Design	Results of the procedure of receiving& processing data	Not completed.
Mechanical Subsystem Design	Driving tests and analysis of the robot	Completed. Test plan is achieved.
Software Subsystem Design	Documentation of the algorithms and debugging results	Started but not completed.
Overall System Implementation & Tests	A robot completing the labyrinth by itself	Not completed yet.
Demonstration	A robot completing the labyrinth collaboratively with the other groups. The product within its package.	Not completed.

The package of our product includes the main body of the robot, a plank, user manual, two spare tires, a backup battery and a remote controller deciding the robot to become master or slave. The product will be prepared in 10 weekdays after the order. Users can find all the necessary information about the product in the user manual.

You can contact us via our web site http://www.xcali.ml.

WHAT IS IN THE BOX?

- X-Calibot
- 11.1 V Li-Po battery
- 5000 mAh power bank
- USB cable
- Wooden plank
- User manual

GETTING STARTED WITH YOUR X-CALIBOT

1. Connect the power bank to RaspberryPi.
2. Make sure that green and red LED's on RaspberryPi blink.
3. Connect the Li-Po battery to the same colored supply terminals of motor driver.
4. Couple the wooden plank to the holding point on top of X-Calibot.
5. Choose the playing mode (master or slave) by using the switch on top of X-Calibot.
6. Place your X-Calibot in a maze.
7. Enjoy!

WARNINGS

- X-Calibot is not suitable for use of children under 5 years old. Keep X-Calibot out of reach of children under 5 years old.
- Do not use your X-Calibot for longer than 3 hours. Charge the Li-Po battery immediately after having used it. Undervolted batteries may explode and may be harmful.

- In case you notice a thickening on your battery, stop running your X-Calibot, disconnect the battery and contact X-Cali Customer Care.

- Make sure that you have connected the terminals of the battery correctly; polarity reversal may ruin your X-Calibot.

- Do not leave the plank on the holding point of your X-Calibot while not running it. Weight of the plank may be harmful for your device.

- In case you notice smoke or burning smell while running your X-Calibot, immediately disconnect the battery and the power bank and contact X-Cali Customer Care.

DISCLAIMER

X-Calibot is produced, calibrated and tested under room conditions and white fluorescent light. X-Cali Inc. do not accept any responsibilities for any kind of malfunctions of X-Calibot caused by operation under any other environmental conditions.

Power supply units of X-Calibot are designed and produced specifically for X-Calibot. Any power supply units other than box content are not suitable for X-Calibot. X-Cali Inc. do not accept any responsibilities for possible damages on X-Calibot caused by different power supply units.

Using guide of device is clearly described in User Manual. X-Cali Inc. do not accept any responsibilities for possible damages on X-Calibot caused by user error.

In case of any ambiguity, please contact X-Cali Customer Care.