Manchester Untitled

Aid for the Blind People

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Design Studio Section: 3

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Executive Summary

A wearable device that would aid blind people in navigating cities is the aim of the Aid for the Blind Project. The tool should safely lead users while offering comprehensive environmental monitoring. There should be a variety of roads, crosswalks, obstacles, traffic signs, and lighting in the surrounding area. The technology should be able to tell a human crossing from the road's lines and traffic indicators. The device should then assess how traffic is moving and the state of traffic lights to decide if the pedestrian crossing is safe. The user should subsequently be informed as to whether or not the crossing is secure. Additionally, the gadget should provide instructions on how to cross the street safely. In addition to these requirements, users should be informed of obstructions verbally so as to prevent potentially harmful collisions, and a different path should be recommended. Additionally, a user-friendly, transportable, and power-efficient consumer device needs to be developed.

The wearable design concept that we suggest had two primary parts namely headset module and walking stick module.

The headset module, which is the initial part, contains the primary section that receives the image of the surroundings, processes it, finds the indicated obstructions and signs, and speaks commands to the user. Primarily cars, traffic signs for indicating pedestrian crossing, traffic lights and pedestrian crossings recognizable from the camera. Currently, artificial intelligence models taken from the internet are capable of detecting cars, traffic signs and traffic lights but not able to detect pedestrian crossings. For detecting pedestrian crossings new models are going to be created. All the tests were made in Jetson Nano, however, codes implemented in Jetson Nano will be transferred to a mobile phone with cloud server. As a result, a user-friendly product will be created. Those procedures will be explained in detail in system design, test results and planning section of this report.

The walking stick module, which senses obstacles and comprehends their distance, information, is the second component. Additionally, two major components will be able to communicate wirelessly with one another. Currently by using ultrasonic-sensors, our product is able to detect obstacles whose height is at least 25 cm and capable of sending distance between obstacle and user to host device with bluetooth. Those sensors will be placed on walking stick such that obstacles whose height is at least 25 cm can be detected.

Manchester Untitled Company made great progress on the project. According to our test results, obstacle detecting in the walking stick module and wireless communication is successfully implemented. In the head set unit we are perfectly detecting cars, moderately detecting traffic signs and traffic lights and deficiently detecting pedestrian crossing. All the tests are made in Jetson Nano, however, the main product for head set units is going to be mobile phones which communicate with cloud servers. It is planned to run all object detection algorithms in the cloud server so that the product will be more simple for users. If we are not able to follow our plan in the headset unit, we will stick with the implementation on Jetson Nano. In order to overcome the inconvenience results obtained from tests a well trained artificial intelligent model is going to be used.

The general planning for the following months has been determined with a time schedule and possible risks that we can overcome in this duration are considered. Therefore, alternative solution plans have been found in order to overcome possible problems.

In this project the main goal is to assist blind people to navigate their motions. In case of breakdown of the product, severe incidence may happen. Especially while a user crossing the pedestrian crossing in case of faulty message results in a traffic accident between car and user. Therefore, several predetermined working conditions are defined. Most important ones are that this product is usable for the location where cars' maximum speed is not higher than 50 km/h, and the product is not usable for dark and rainy days. Those pre-constraints are made to not get interrupted data from the environment.

Introduction

Background of the project

Insufficient warnings for probable dangers cause many undesirable situations that may result in vital cases for the blind people. Considering the unsatisfactory conditions, we have decided to develop a beneficial, comfortably usable device, so that the blind people have equal living standards as others. The fundamental background of the project is to eliminate major drawbacks that blind people interact with in real life. From the motive we have, we consider common fields where our device is the most needed, and how it can be more beneficial for blind people, so that the properties of the device are formed with these bases.

Problem statement

Blind people face numerous challenges in their daily lives, particularly when navigating the city as pedestrians. Some of the issues are related to poorly regulated warnings, heavy traffic, and obstacles on the sidewalks. These issues not only make it difficult for blind people to walk as pedestrians, but they also endanger their lives in some cases. The aid for the blind project seeks to assist blind people in such a way that they can freely walk down the street and safely arrive at their destination. The project will make life easier for people who are blind.

Current status

The project consists of two main subunits, namely “Headset Unit” and “Walking Stick Unit”.

The Headset Unit was expected to detect vehicles such as cars, buses and trucks. In addition to this feature, some traffic signs have also been expected to be classified by the Headset Unit. Moreover, the pedestrian crossing was desired to be determined by this unit and the classification of the pedestrian crossing should have been done in terms of the existence of the traffic lights.

The Walking Stick Unit was expected to detect the obstacles on the road of the user and by using a wireless communication module, the information about the existence of the obstacle was expected to be sent by this unit.

In the Headset Unit, we used the Jetson Nano and one external camera connected to it. Different artificial intelligence models are used in Jetson nano to detect cars, traffic lights, traffic signs and pedestrian crossings. Currently, we are able to detect cars perfectly, traffic lights and traffic signs moderately, and pedestrian crossings deficiently. Also to adjust FPS requirements we implemented a multi-thread structure that runs multiple codes concurrently.

The Walking Stick Unit consists of a microprocessor, an ultrasonic distance measurement sensor, and a bluetooth module. The microprocessor collects the distance data through the ultrasonic sensor and once the data is guaranteed to be true, the MPU sends the data to the Headset Unit via a Bluetooth module. Furthermore, a standard power bank is used to power up the subunit.

The summary of the current status for each subunit is summarized above. However, the currently used devices to run the algorithms are not finally decided devices. These devices were used to check the performance of the algorithms and these algorithms can be used in any of the alternative solution approaches. At this stage, there is no study about the integration of the subunits (communication between subunits, physical placement on the body, main power system).

Scope and organization

Updated design objectives and requirements will be discussed in the design objective and requirements section of this report. Milestones that are completed will be mentioned in system design. Current status in the project will be explained in parts of subsystems. Test results will be indicated in the test result section according to our progress in system design. Then, we will indicate our future plans about the project, schedule it and we will make a risk analysis about it.

Design Objective and Requirements

The design objectives of the overall project are listed below:

- Detection of approaching vehicles, such as cars, trucks and buses.
- Detection of a group of desired traffic signs.
- Detection of pedestrian crossings and classify them according to the existence of the traffic lights.
- Detection of obstacles on the way of the user.
- Design of a wearable, user friendly, energy efficient, and inexpensive device.

The detection of vehicles, desired traffic signs, pedestrian crossings and traffic lights are required since they will make it possible for the system to decide whether the current condition is safe for the user to move. If the current conditions are not safe, the system holds the user until the conditions become safe or it will suggest alternative solutions to the user. Furthermore, the device is designed for daily use. Hence, designing a wearable, user friendly and inexpensive device will make the solution appealing for the target customer profile.

The requirement for detection of approaching vehicles:

- According to the Turkish General Directorate of Highways (KGM), the average stopping distance for a vehicle moving with a speed of 50 km/h (the speed limit in METU campus) is 26.8 meters. By accounting for the driver errors and violation of the traffic rules, it is required for the device to detect vehicles from 30 meters.

The requirements for detection of desired traffic signs:

- According to the Turkish General Directorate of Highways (KGM), there are 69 different traffic signs in Turkey. However, most of them are not required for the device to make decisions about the safety and guidance of the user. Hence the device will detect only the pedestrian crossing signs, speed bump signs and traffic crossing. The mentioned traffic signs are shown in the below three figures. These three traffic signs are a minimal subset of traffic signs for the system to make decisions on safety and guidance of the user.

- To inform the user correctly, the classification quality of the detected traffic signs is essential. Hence the device should detect the signs with %80 accuracy.

Figure 1. Pedestrian Crossing Sign

Figure 2. Speed Bump Sign

Figure 3. Traffic Light Sign

The requirements for detection of pedestrian crossings and its classification:

- For a user to cross the road safely, detection of pedestrian crossings is essential. Hence the device should detect the pedestrian crossings with %80 accuracy.

- Two different types of pedestrian crossing exist in the METU campus. The first type is a standard pedestrian crossing without traffic lights. The second type is a pedestrian crossing with traffic lights. Hence for the user to cross the road safely, two different road crossing methods will be implemented according to pedestrian crossing type. Therefore the device should correctly classify the type of the crossing with %80 accuracy.

The requirements for detection of obstacles:

- The device should detect the obstacles which are higher than 25 cm on the way of the user. The detection of obstacles are essential since the user could get harm from these obstacles.

- The device should detect the existence of the obstacles which are in the 1.5 meter range (distance from the measurement sensor). Even though the obstacle material and shape can distort the distance measurement, detection of their existence is crucial.

- However, the precise distance, height and shape information is not critical.

The requirements for designing a wearable, user friendly, energy efficient, and inexpensive device:

- The target customer will use the device by attaching it to their body. Hence the device should not bother the customer. Therefore, designing a wearable and lightweight device is essential. Furthermore, the device will be attached to the items that are generally used in the daily life of blind people. For example, glasses and walking sticks.

- The device should be used easily by the target customer. Fundamental operations that device perform, can be requested by the user with a button set. Furthermore, the button set will have descriptions encoded with Braille Alphabet. In addition, the systems that require charging need to be charged easily for daily usage.

- By considering the average traveling duration of the users, the device should work for at least 2 hours on runtime. Therefore, each subunit should be designed as a power efficient system.

- The components used in the device should be chosen by considering the budget of the users. Therefore, the total cost of the design is planned to be nearly $200.

System Design

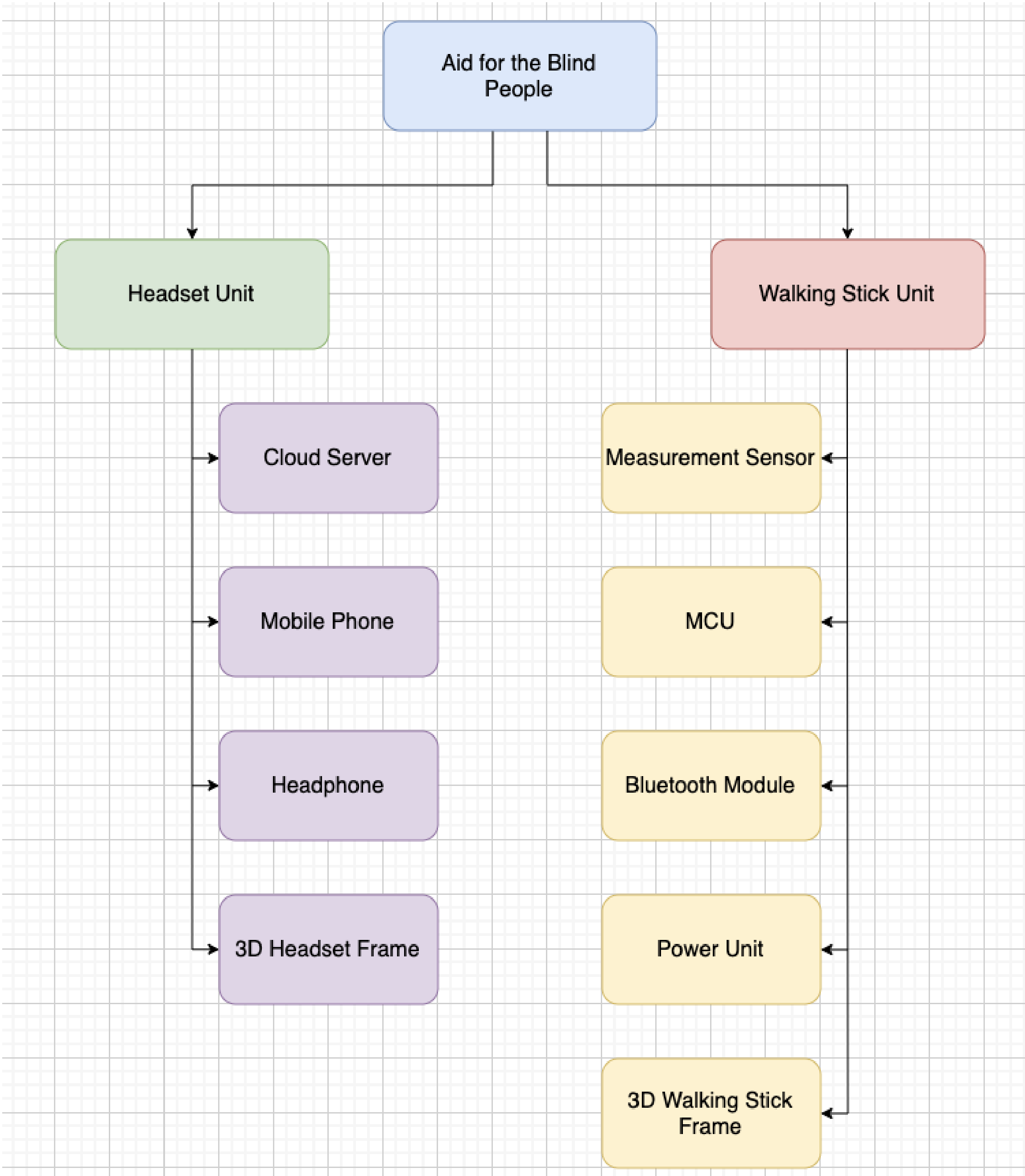

Figure 4: Block Diagram of the Project Design

As we can observe from Figure 4, the project consists of two main units as the first proposed solution to the problem; headset unit and walking stick unit. The headset unit has four subsystems; cloud server, mobile phone, headphone, and 3D headset frame. Mobile phones can be considered as the black box where the connections between subunits are arranged inside. Cloud server unit is the main unit where the algorithm generated for image processing is embedded such that the images taken by the mobile phone camera are transferred via cellular data to the online environment and processed through. This kind of solution for image processing problems is proposed since the algorithm written should be able to be manipulated easily in any time without creating a mobile application and also servers generally provide much more computation power. Thus, a cloud server environment is more suitable for such a case, and it can be reached via PC. The 3D headset frame is where the phone is placed on, and the visual components from the environment are detected from the camera of the phone. Moreover, it can be considered as the main structure that all the headset units are maintained. Headphones are used to transmit sound-based commands to the user such that the user is guided with respect to the detected obstacles and objects. In addition, headphones are connected to the mobile phone via bluetooth for easier usage.

The walking stick unit has five subunits; measurement sensor, MCU (microcontroller unit), bluetooth module, power unit, and 3D walking stick frame. The main structure that holds all the subunits is the 3D walking stick frame. Each subunit is placed with an optimum way so that the stick frame is not much larger to carry, also it should not be an obstacle for the user. The distance data is measured via ultrasonic sensor, whose measurement test results are indicated in the Appendix 2. MCU is the main part where received distance data is processed and interpreted, then the output is sent via bluetooth module. The main algorithm for interpretation is embedded inside the MCU, which is chosen to be STM32. With Tx/Rx connections, STM32 and bluetooth module HC-05 can communicate with each other. The Bluetooth module then transfers the distance data to the mobile phone with the help of 2.4GHz antenna. Power unit feeds the whole unit since the stick frame is uncorrelated from the headset unit, except the bluetooth wireless network. The connections between subunits and two main systems are explained in Figure 6. As we can observe from figure 6, two main units; walking stick module, and headset module are independent from each other except the wireless communication. Wireless communication is provided via bluetooth connection between HC-05 as transmitter, and mobile phone as the receiver. This connection is characterized as the single slave piconet type connection that transmits the existence information of an obstacle provided from the ultrasound sensor to the phone. If the modules are considered separately, interconnections between subunits of each module should be explained. Power unit (controllable power bank) is connected to the MCU component (STM32) via serial power line. This unit feeds the processor part of the whole unit, also the other units relatively since the bluetooth unit and ultrasound unit draw power from the MCU unit. Rather than the power connections, the measurement sensor is connected to the MCU unit via GPIO/NVIC type connection. On the other hand, MCU units and bluetooth units communicate via serial communication UART type connection.

For the headset module, headphones are connected to the mobile phone via bluetooth or serial cables. This connection provides sound transmission from the phone to the headphones, which carries the sound-based commands and directives to the user. The main algorithm is provided in a cloud server, hence the connection between the mobile phone unit and cloud server should occur via cellular data. The general configuration for this solution option can be seen in Figure 7.

Someone should pay attention that the connection types are selected such that they are mainly serial communication types. Moreover, it should be noted that if the Jetson nano option is selected, the connections between subunits should be arranged differently as shown in Figure 8. The main difference in this configuration is that the camera unit is separated from the processor part unlike the mobile phone option, hence an extra connection between the camera and Jetson Nano is needed. The connection between those units can be provided via serial USB cable. If the Jetson nano option is selected, the headset unit is partitioned into two units; googles unit, and bag/belt unit, thus the USB cable connects these two units.

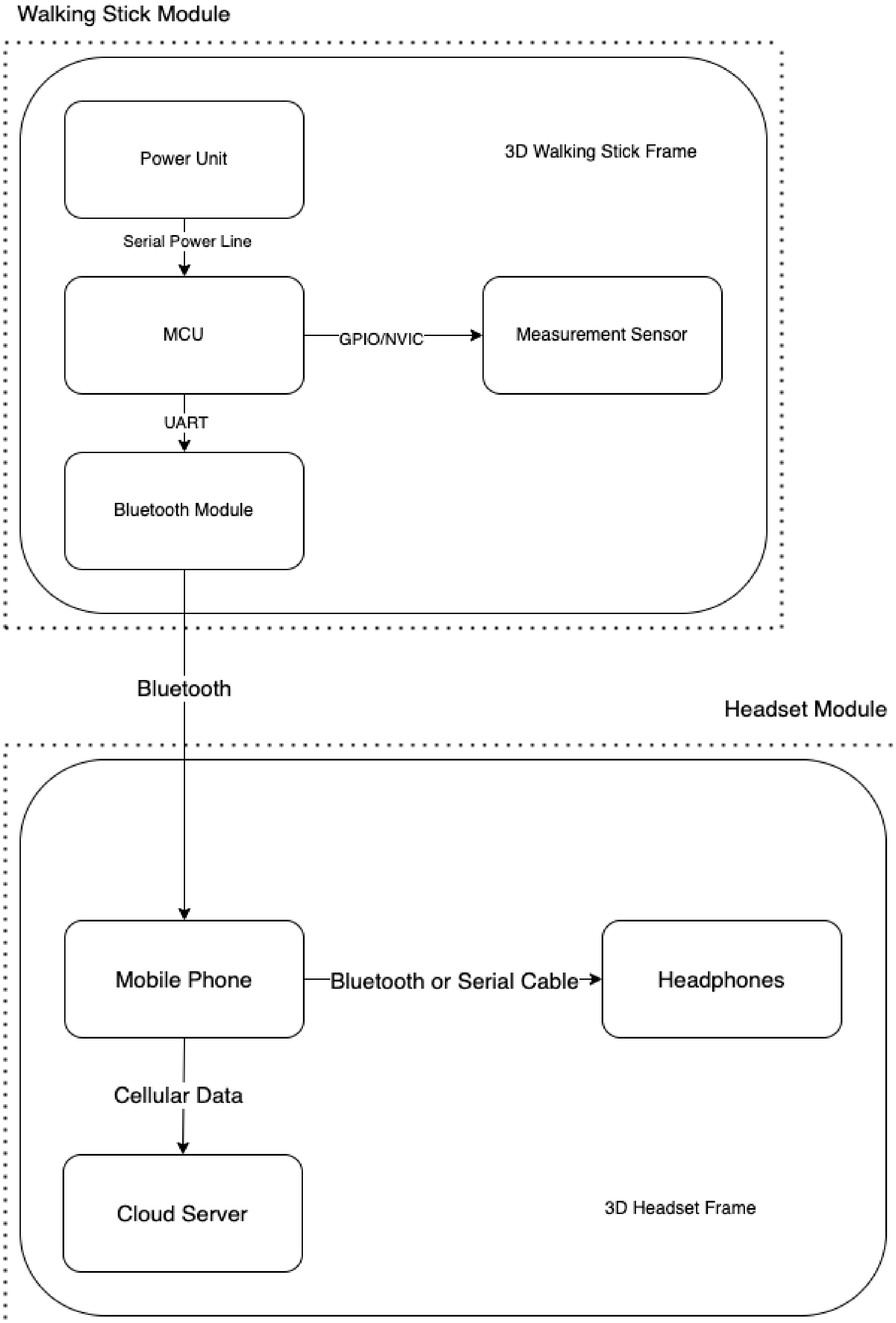

Figure 5: Sub-system Interaction and Interfaces

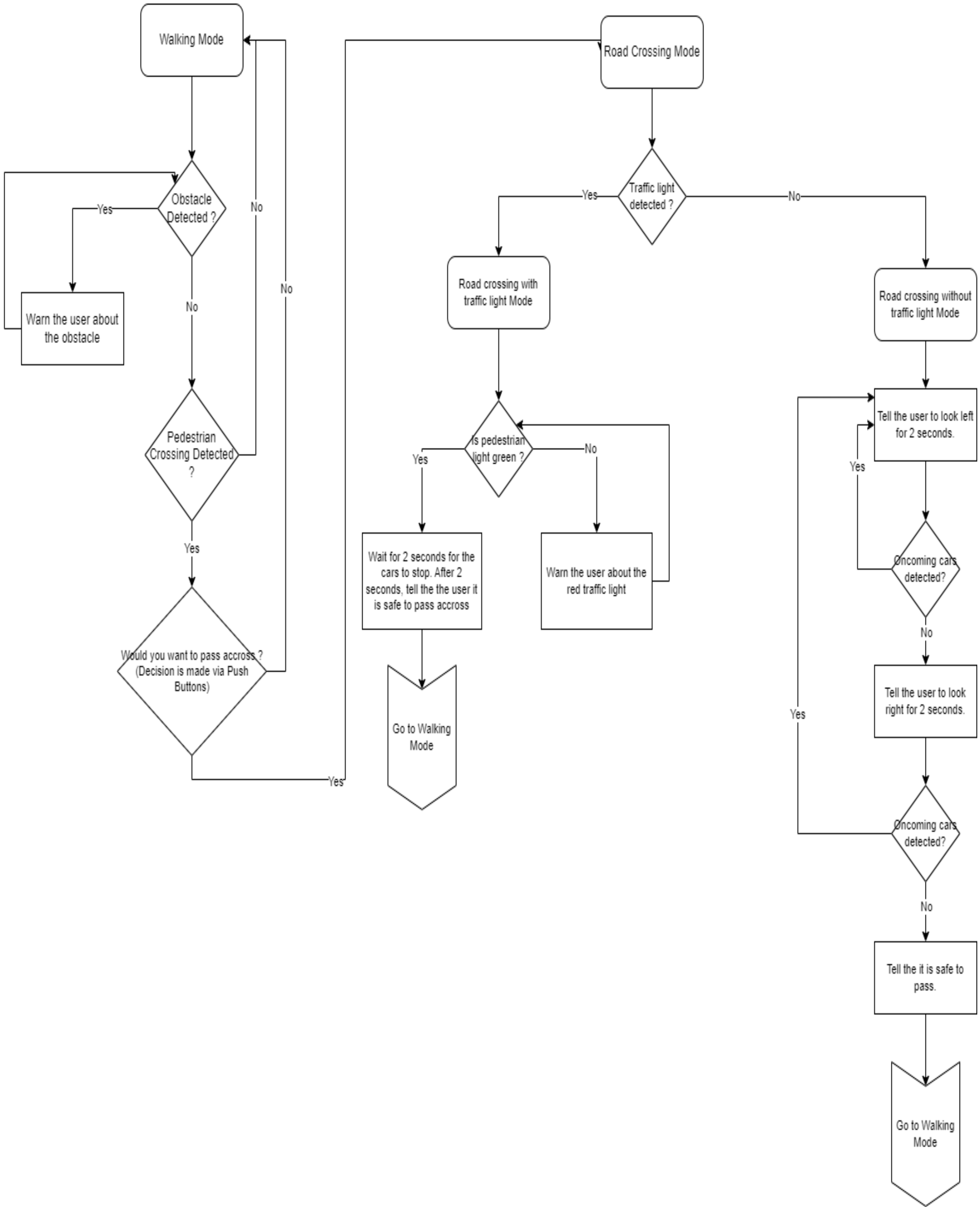

Figure 6: Functional Flow Diagram of System Operations

The functional flow diagram of the system operations is visualized in Figure 6. When the user is in the walking mode, it is asked whether there is an obstacle or not. Depending on the answer coming from the process, the operation changes. If there is an obstacle, the user is warned about the existence of the obstacle based on the distance measured by the sensor. Unless there is an obstacle, the algorithm starts searching for pedestrians crossing around. If there is no pedestrian crossing detected, the system continues to monitor the environment. If a pedestrian crossing is detected, the operation mode is changed to the road crossing mode. This operation mode aims to walk the user over the road safely. The first stage of the road crossing mode is to detect the existence of the traffic light. If a traffic light is detected, then a new interrogation occurs such that the algorithm tries to detect the color of the traffic light. The important part of the interrogation is that what the algorithm tries to detect as green is the color of the pedestrian traffic light, not the traffic light for the cars. If the pedestrian light color is determined as green, the system waits for 2 seconds to ensure the safety, meaning that it checks the road to observe whether there are any cars nearby. If no car is detected, then the system tells the user that it is safe to pass through the road with sound-based directives via headphones. After the positive directive is given, the system goes into the walking mode, which is the initial state of the whole progress. If the pedestrian light is detected as red, then the system warns the user that it is not safe to pass the road.The system goes into a checking loop, and continuously monitors the pedestrian light crossing color until it turns into green color, indicating safety while it is in the road crossing with traffic light mode. On the other hand, if there is no traffic light detected around, then the system changes its operation mode into road crossing without traffic light. The first command the device gives to the user is to check the left side by making the user look to the left for 2 seconds. After 2 seconds of scanning period, the system decides whether there is any oncoming car or not. If there is any oncoming car, the system does not give any directives to the user, and continues to monitor the left side. Whenever it detects that there is no oncoming car, then the system informs the user that the road is safe to pass. After the safe transition of the user is completed, the system goes back to the initial state, which is the walking mode.

The expected weight of the design is 700 gr. The dimensions of the subunits are not perfectly clear; the headset unit is expected to have similar size with a VR glasses and walking stick unit is expected to be a box with dimension 20 cm x 10 cm x 10 cm. The total battery duration of the device is estimated as 2 hours.

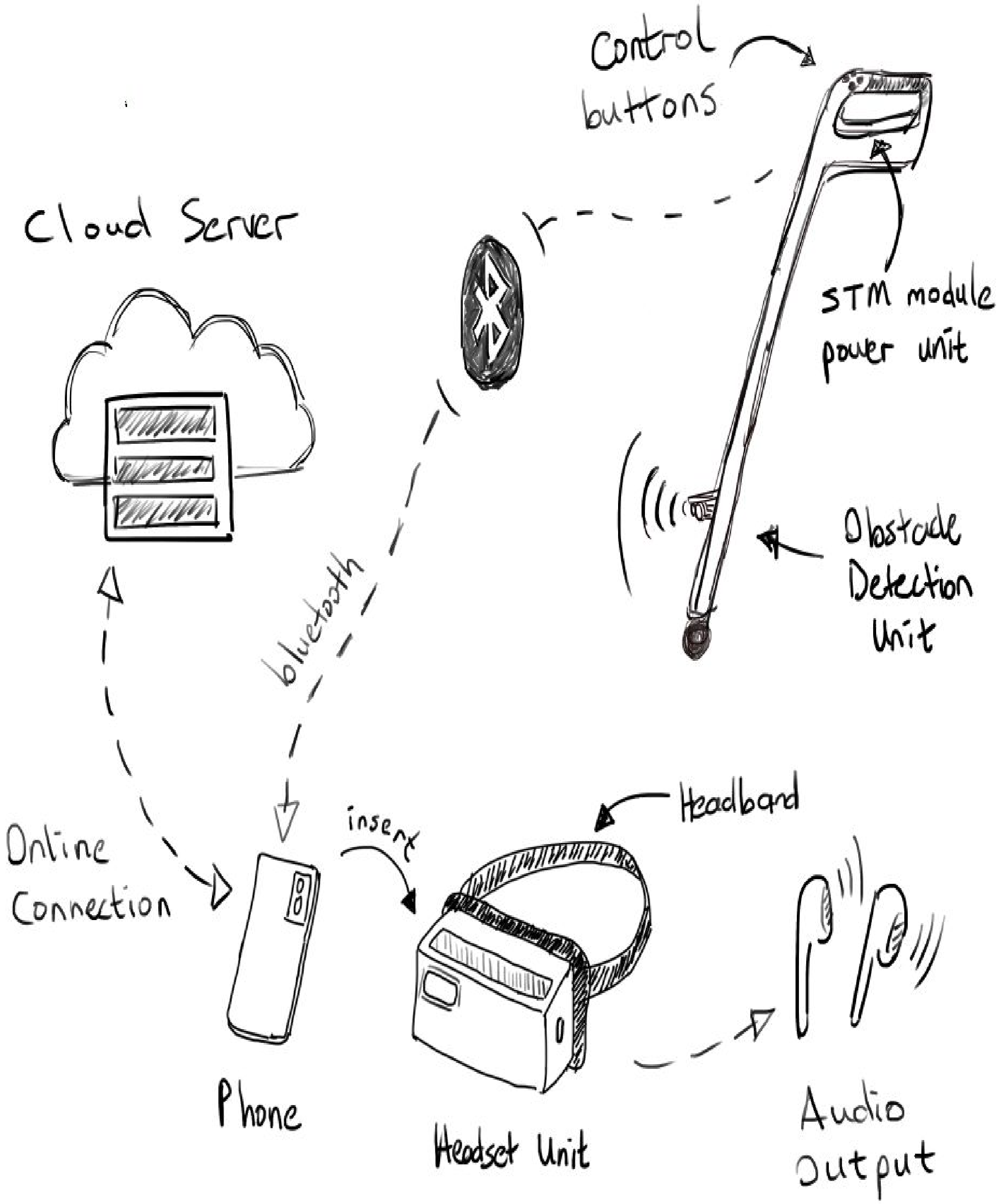

Figure 7: System Connection Representation with Mobile Phone Proposal

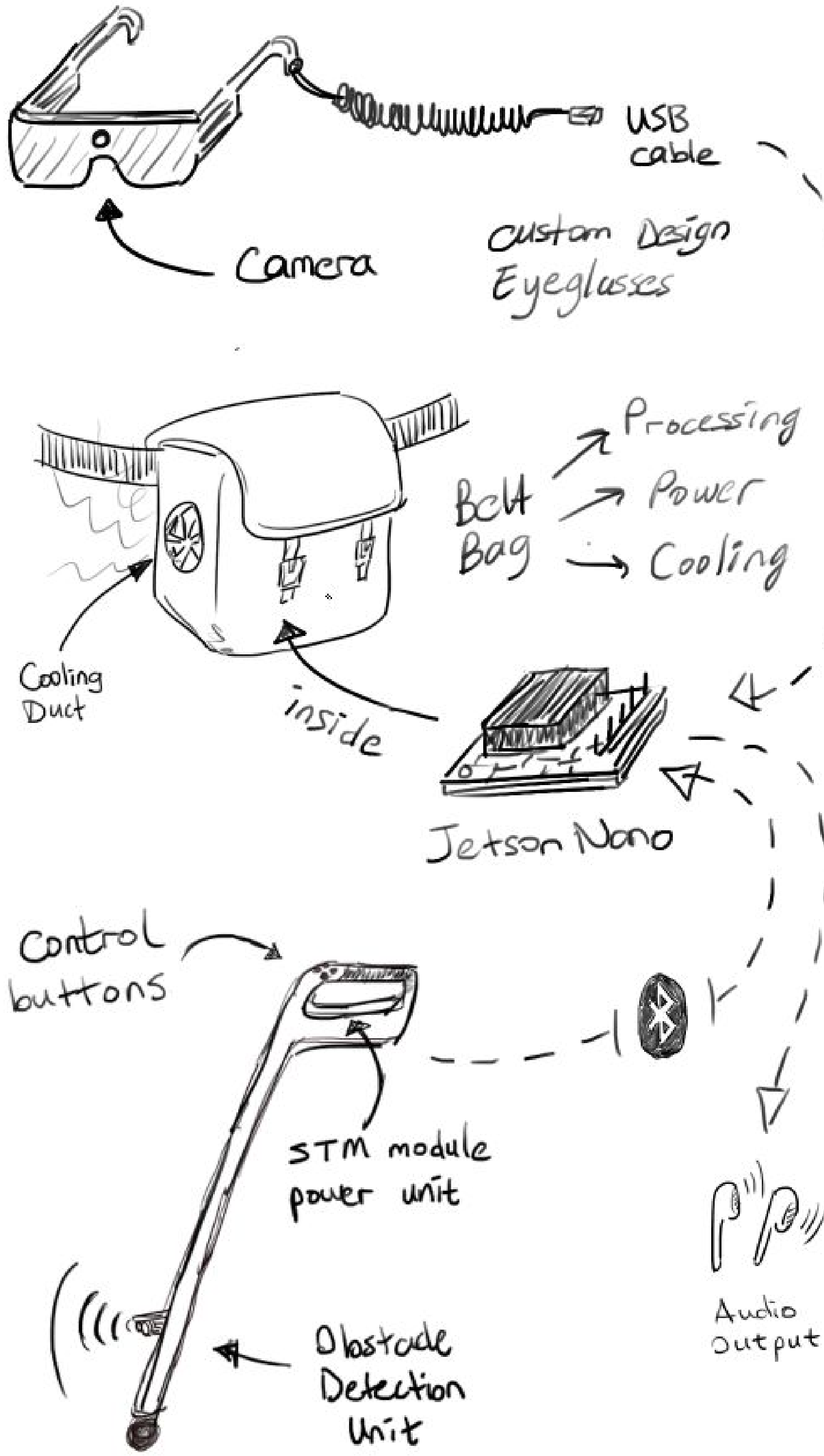

Figure 8:System Connection Representation with Jatson Nano Proposal

Headset Unit

Headset unit includes the main process unit. Events that are happening nearby are recorded by a camera. It is sent to the processor. In this processor, predetermined objects are recognized and inform the user with a sound message. Also obstacles which are detected from the walking stick unit will pass through the processor and corresponding sound messages will be delivered to the user. Sound will be delivered by a headphone. There are two options for processors which are either using the Jetson Nano or a mobile phone.

Mobile Phone Option

This option will be our first choice. Since most of the mobile phones already have bluetooth connection and pre implemented camera there will be no need for external bluetooth connection or an external camera. Moreover, cellular data will be used to send data captured from camera to a cloud server. Main process will be held in a cloud server and processed data will be sent back to the mobile phone. Sound messages will be created on the mobile phone according to data received and will be sent to headphones. cloud server, will use the trained artificial intelligent model that is capable of detecting cars, specific traffic signs (signs that indicate there are pedestrian crossings), traffic lights and pedestrian crossings. This model will be trained and the trained version will be implemented on the cloud server. Codes that are written in the mobile phone will be in JavaScript. We will probably use a wrapper for converting Python code into Java.

Jetson Nano Option

This option will be our alternative choice. All tests were conducted on Jetson Nano to observe whether we are able to detect objects with a camera. Some pretrained artificial intelligence models were used to detect cars, specific traffic signs (signs that indicate there are pedestrian crossings), traffic lights and pedestrian crossings. Those models are successful while detecting cars but they are not good at detecting traffic signs, traffic lights and pedestrian crossings. Therefore, we will train our artificial intelligence model to detect specific objects.

In this option, a cloud server will not be used and all the process will be carried out in Jetson Nano. Compared with our primary options, we need to implement a bluetooth card and an external camera since Jetson Nano does not have those capabilities. Moreover, power is provided from an external sub unit which will be a belt bag unit. There will be a power supplier in this unit and connections will be made by cables.

Walking Stick Unit

Ultrasonic Measurement Sensor Option

HC-SR04 Ultrasonic Measurement sensor is a price-effective measurement sensor. This sensor just requires a trigger pulse for measurement. After the trigger pulse, the sensor sends ultrasonic waves to the object and makes it output high. Until the waves come back to the sensor the output remains high, and then becomes low again. The duration of the high output pulse should be measured with the microcontroller (NUCLEO-L432KC) to obtain the distance data. Therefore, the output signal of the measurement sensor is connected to a GPIO pin with a double edge interrupt feature. The noises of the measurements are eliminated in the microcontroller with buffering algorithms. The data is stored in the microcontroller registers and when an obstacle is detected this information is sent to the HC-05 bluetooth module via UART connections (Rx/Tx). The HC-05 bluetooth module can be directly communicated with each Headset Module solution directly. The power system of this module is a power bank. This unit requires a very low power value; therefore, some power banks cannot sense the drawn current and close it self automatically. To overcome this problem, some circuit manipulation techniques are used. Some user interface operations should be done with push buttons. These buttons will be directly connected to the GPIO pins of the MCU.

Lidar Sensor Option

Lidar Sensor is an optical measurement sensor that sends a laser beam to the object and returns the data about the distance information. The communication with the Lidar sensor should be done with UART protocol. Therefore, NUCLEO-L432KC can be again used in this solution option and the rest of the solution will be the same as in the Ultrasonic Measurement Sensor Option.

Test Results

Test Results of Walking Stick Unit

The Walking Stick unit is responsible for detecting relatively small obstacles around the user. We used an ultrasonic sensor to sense those obstacles. Also we implemented an external bluetooth device to establish communication between the headset unit and walking stick unit. Moreover, we are able to send the distance data to any other host device by using bluetooth. The tests we conducted on the walking stick unit is mainly about whether we are able to detect obstacles in specific distances. In those tests different kinds of obstacles are used in different angles. Object types that are going to be used in the tests are planar object, cylindrical object, sharp edged object and sound absorbing object.

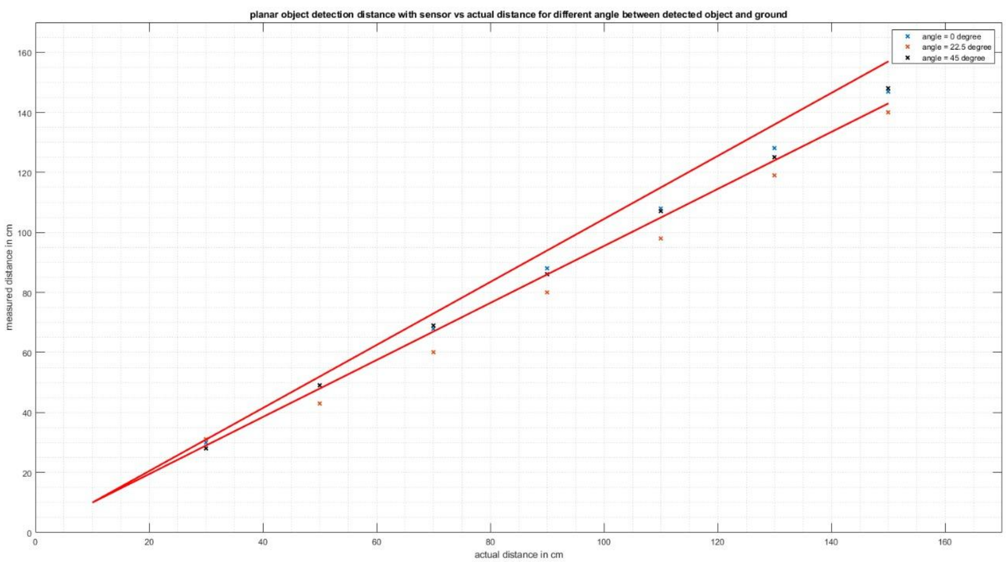

Figure 9:Graph of Measured Distance vs Real Distance for Planar Obstacle Detection Test In Different Angles

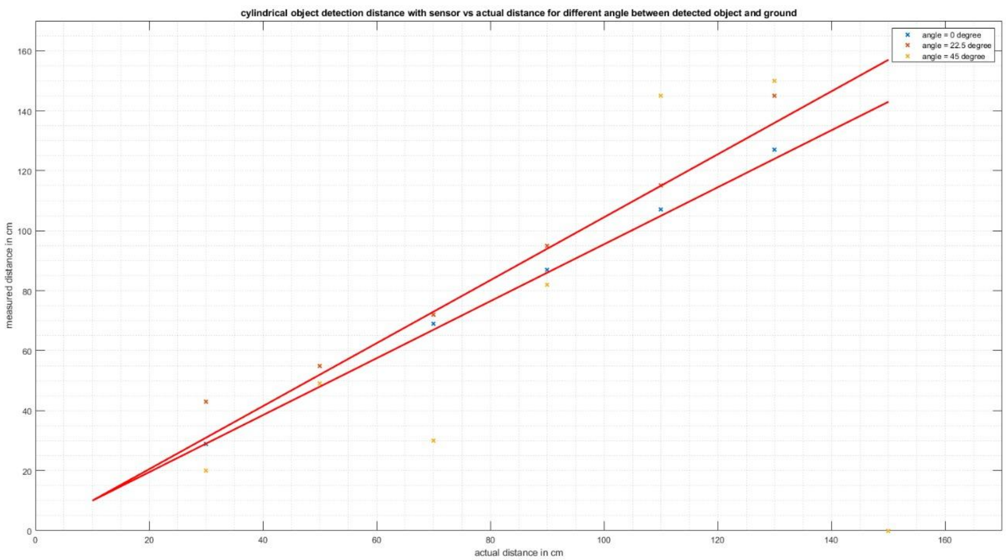

Figure 10: Graph of Measured Distance vs Real Distance for Cylindrical Obstacle Detection Test In Different Angles

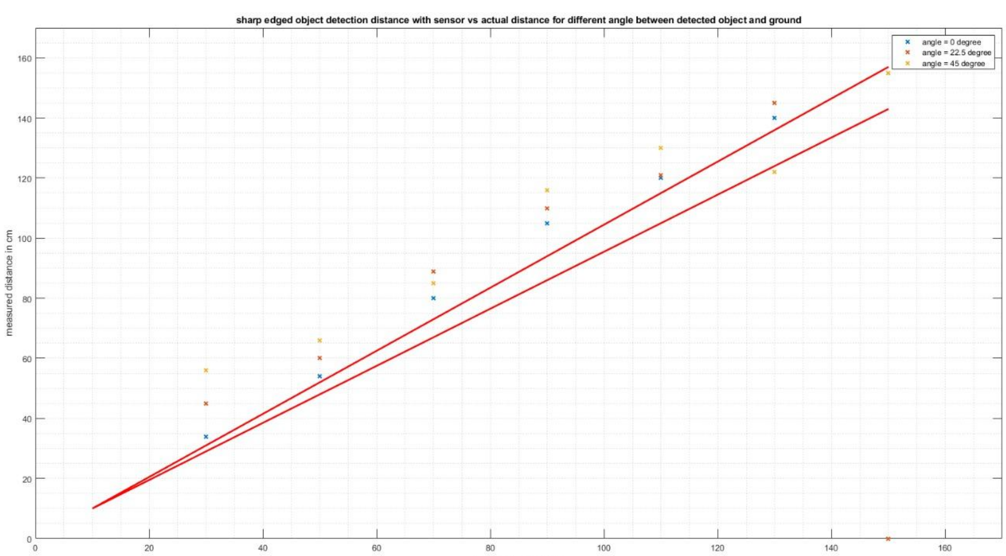

Figure 11: Graph of Measured Distance vs Real Distance for Sharp Edged Obstacle Detection Test In Different Angles

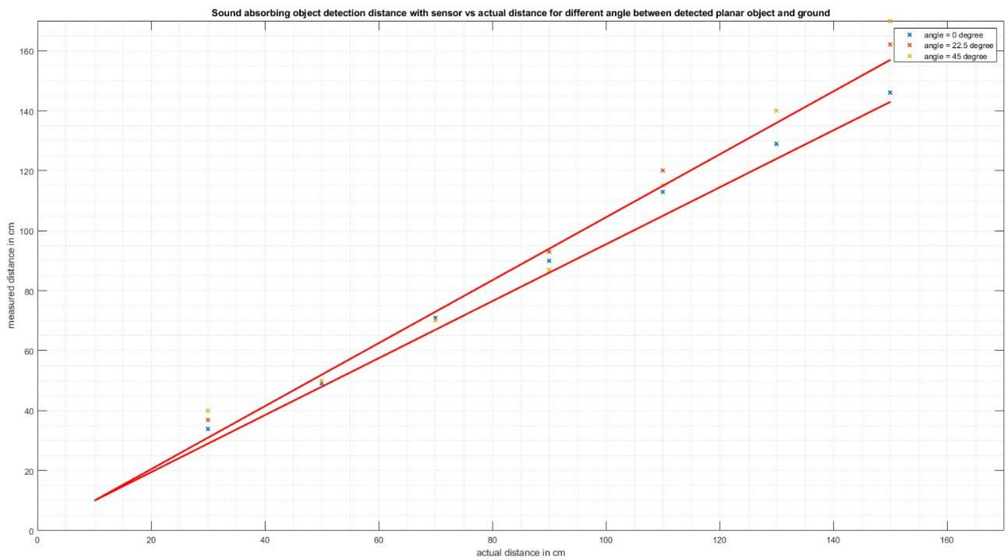

Figure 12: Graph of Measured Distance vs Real Distance for Sound Absorbing Obstacle Detection Test In Different Angles

According to results obtained from tests, planar surface objects are more detectable than other ones. Moreover, most convenient distance records are taken when the objects are oriented in 0 degree. Red lines in figure 9,10,11 and 12 show expectation distance boundaries.

Test Results of Headset Unit

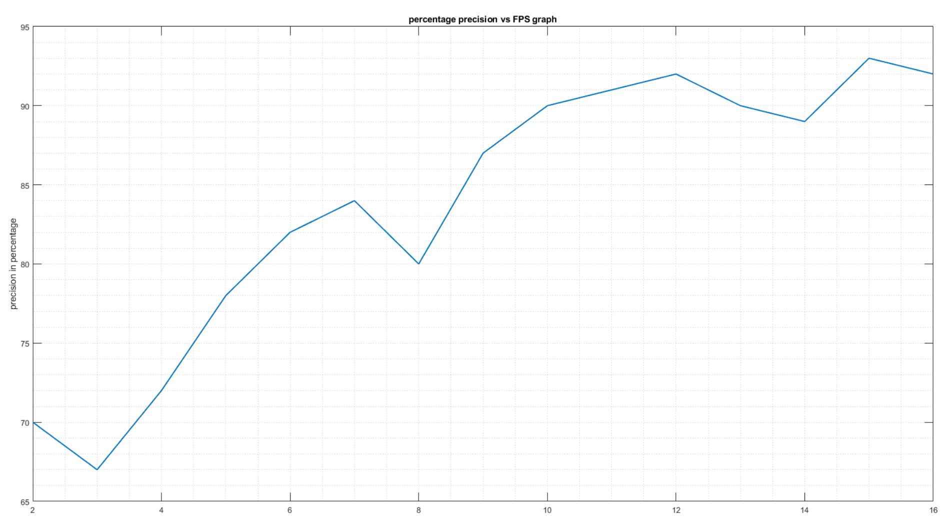

Figure 13: Graph of Percentage Precision vs FPS While Detecting Objects

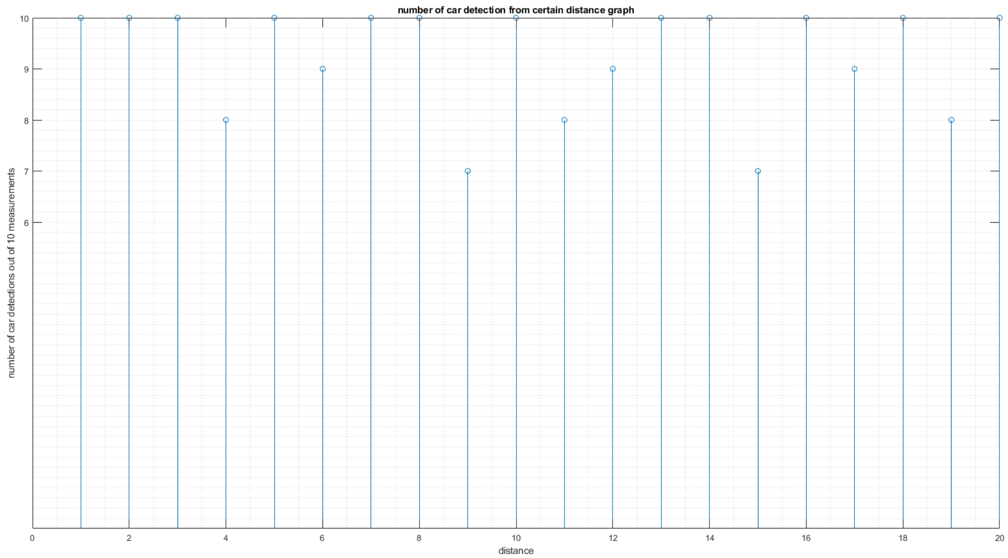

Figure 14: Graph of Number of Car Detection vs Distance out of 10 Cars

According to Figure 14 car detection performance is above expectations. Also from the tables that is indicated in appendix 2: tests section car detection performance is proper. On the other hand, detection of traffic signs and traffic lights are not that convenient. Furthermore, the AI models taken from the internet fail while detecting pedestrian crossings. From Figure 13, we can come to a conclusion that as the FPS of the video increases, accuracy of the detecting increases.

Planning

Schedule

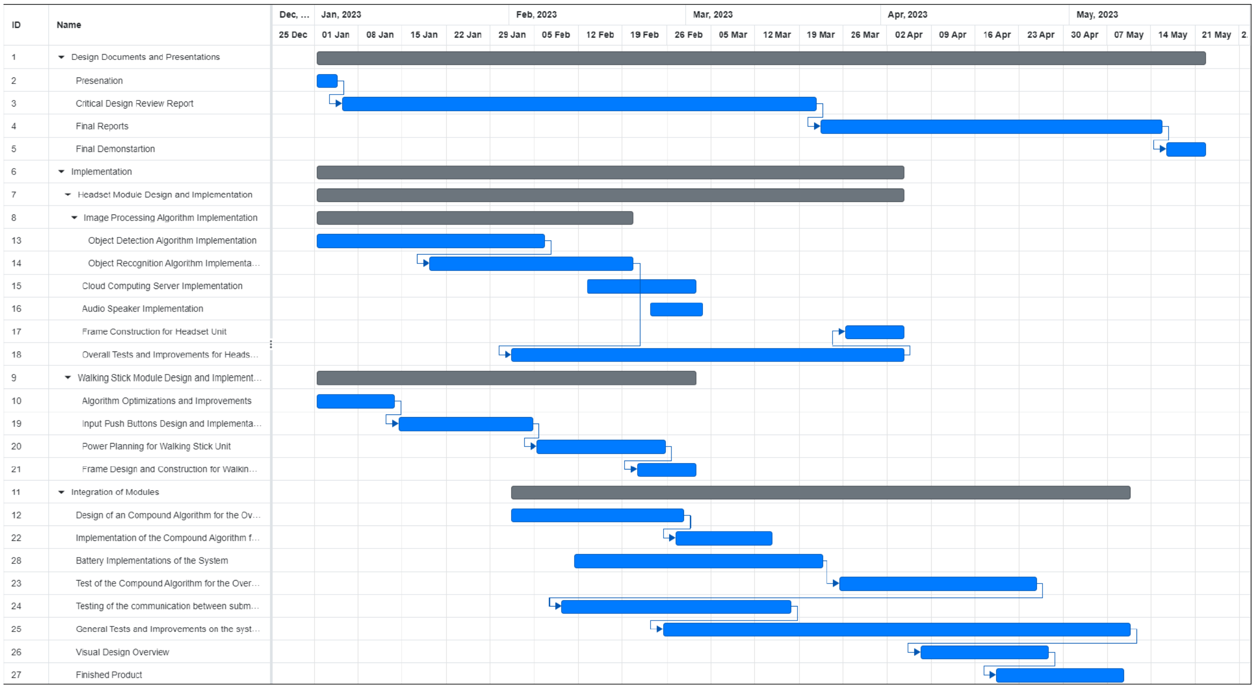

Figure 15: Gantt Chart for the Project Timeline

As depicted in Figure 15., the main tasks for the remaining time are the followings:

- Design Documents and Presentations
- Implementation of Submodules
- Integration of the overall system

These main tasks will be conducted in parallel. While implementing the object detection and recognition algorithms for the Headset Unit; Algorithm optimizations,Input push button design and implementation and power planning for the Walking Stick module will be implemented in parallel. After these tasks are completed, the design and manufacturing process for the frame constructions of two submodules will be conducted.

Furthermore, the design of the system level compound algorithm will be performed in parallel to testing of the two submodules. After this step is completed battery implementations of the system and testing of the system level compound algorithm will be completed.

Finally, system level tests will be performed and the required optimizations will be done based on our tests. As the final step, the visual aspect of the device will be improved.

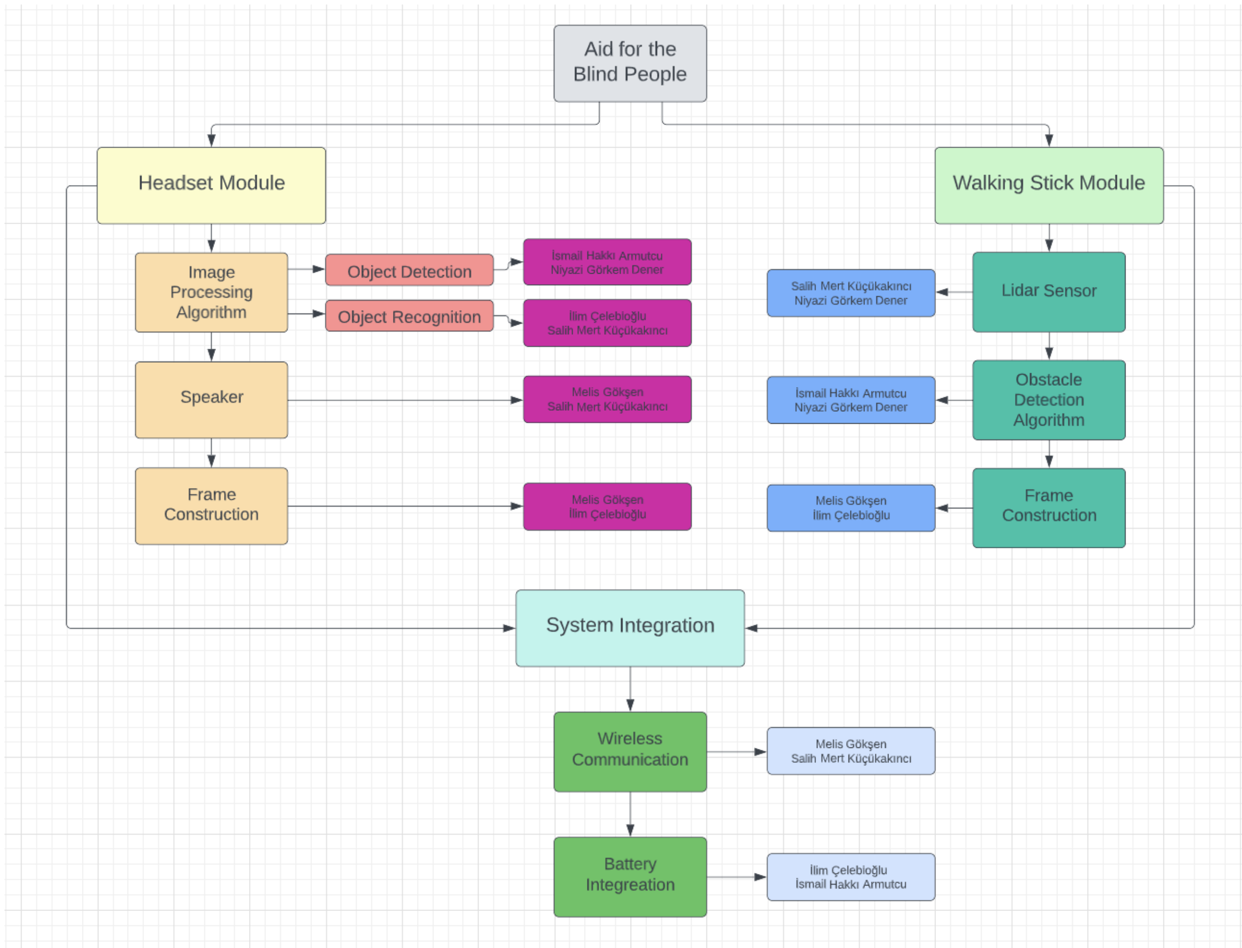

Figure 16: Task Distribution Chart of the Project

As depicted in Figure 16, the task distribution of the project to the group members is done considering the expertise of the group members.

Risk Analysis

Technical Risks:

For the main solution, the following are the technical risks:

- Battery Implementation Problems
- AI training problems for object recognition algorithm

For the battery implementation problems, designing a power electronic circuitry is a challenging task. Hence due to the component nonidealities and design flaws, there will be voltage and current fluctuations on the power input of the devices. Hence one possible risk related to the aforementioned problem is that the device could shut down during the operation. However, since the main solution uses a mobile phone, the shutting down risk is minimal. In the case of such a case, one alternative approach is checking the battery voltage level and if a low voltage level is detected, the user will be warned about the shutdown process.

For the AI training problems, the device will not recognize objects with %100 accuracy. Hence in the case of a false recognition or even not recognizing the object, there will be some risks concerning the safety of the user. However, this risk is minimal. To even minimize the risk, if a condition that negatively affects the quality of the images is detected (such as low light, rainy or foggy weather, an object blocking the camera etc.), the users will be warned about their safety.

Cost Risks:

- Turkish Lira and US Dollar Inflation

Due to the Turkish Lira and/or US Dollar Inflation, the costs of the electronic components are increasing dramatically. This phenomenon could negatively affect the budget expectations for the project. However, to minimize the risk, the most expensive components are ordered already.

Timeline Risks:

- Not being able to complete the algorithm implementation for the cloud server.
- Logistic related timeline risks

There is a risk of not being able to complete the algorithm implementation for the cloud server. In the case of such an event, the design choice 2 will be used. Since the object detection and recognition algorithms are working on both of the design choices, the risk could be minimized by simply using the design choice 2.

The second timeline related risks stem from the logistics of the purchase of the electronic components. Due to the electronic chip crisis, the availability of some electronic components are not always instant. Hence to minimize the mentioned risks, all the electronic components are pre ordered.

Cost Analysis

Design Choice 1:

- Phone: $100
- MCU: $15
- Ultrasonic Distance Measurement Sensor: $2
- Bluetooth Module: $4
- Frame constructions and walking stick: $25
- Server Costs: $1 per month

Grand Total Excluding the server cost: $146

Design Choice 2:

- Jetson Nano: $110
- MCU: $15
- Ultrasonic Distance Measurement Sensor: $2
- Bluetooth Module: $4
- Frame constructions and walking stick: $25
- Belt bag and cooling system for Jetson Nano: $10

Grand Total: $156

Both design choices are below the estimated $200 budget.

Ethical Concerns

- Concerns regarding the safety of the user.
- Concerns regarding the privacy of personal rights of the user.

The system will be used in busy roads and intense traffic. Hence there is always a minor risk of wrong decisions by the system. In such cases, the safety of the user will be endangered. However, the aim of the project is to design a system that will **aid** blind people. The directions given by the system are always a suggestion and there is always some risk of wrong decision.

Regarding the privacy of the personal rights of the user, the system will use the camera that is located on the user's phone. Hence the risk of privacy violation is the same as in the case of the user’s phone being hacked.

Conclusion

“Aid for the Blind” project aims to assist blind people to navigate their motions and sense their environment. To achieve this goal, the product produced by the Manchester Untitled company must satisfy certain conditions. Our team members conducted several tests on the current progress product. As a result of those tests, we draw our main and alternative roadmaps. Those roadmaps mainly depend on the process unit that we chose for the headset unit. Options for the process unit are either using Jetson Nano or a mobile phone. Our main objective is to complete this project by using mobile phones because it is more profitable and user friendly. Using Jetson Nano, on the other hand, would be more expensive due to the fact that it requires an extra subunit of power supplier and more inconvenient in terms of weight and space that is required to install our project with Jetson Nano.

At the moment, our test results show that detection of small obstacles is possible with the walking stick unit whose sensor is an ultrasonic-sensor. Furthermore, we are able to detect cars, traffic lights, traffic signs and pedestrian crossings. In terms of detectability cars are perfect; traffic lights and traffic signs moderate and pedestrian crossing poor. In order to improve our performance we will develop our AI model to our either mobile phone or Jetson Nano. In the case we use mobile phones, we will implement our model to cloud servers and in other cases this model will be implemented in Jetson Nano.

At this point we are believing that we make great progress on the project and as we continue work on the project like that, our efforts pan out a perfect product that aids blind people.

Appendix 1: Weighted Objective Tree

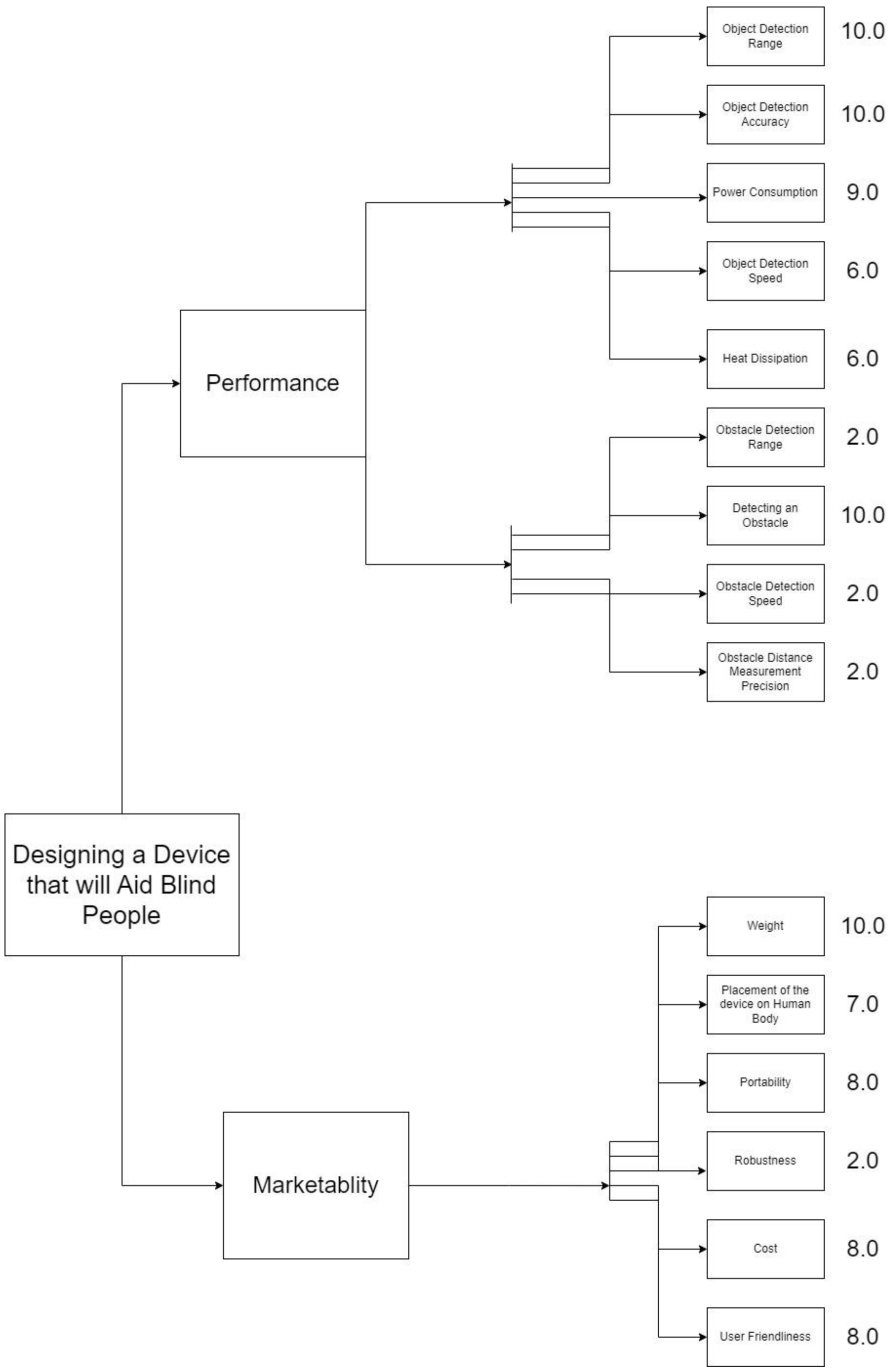

Figure 17: Weighted Objective Tree for the Project

	Weight (MW1)	Placement of the device on human body (MP2)	Portability (MP3)
1 Excellent	500 gr	The device can take measurements from an appropriate position, such as head, chest or a tool that the users already utilize in their daily lives.	All possible communications are done wirelessly. Device will not bother the user while carrying. The device can be used without carrying extra equipment such as charging adapters, extra batteries etc..
0.8 Good	700 gr	The device can take measurements from an appropriate position, such as head, chest. Users must buy an extra tool to use the device.	Most of the possible communications are done wirelessly. Device will slightly bother the user while carrying due to connections. The device can be used without carrying extra equipment such as extra batteries etc..
0.6 Satisfactory	900 gr	The device can take measurements from an appropriate position, such as head, chest. Users must buy multiple extra tools to use the device.	Most of the possible communications are done wirelessly. The device will bother the user while carrying due to sizes of the equipment. The device can be used without carrying extra equipment such as extra batteries etc..
0.4 Average	1100 gr	The device can take measurements from an inappropriate position, such as joints or the body parts that are moving constantly. The user will not buy extra tools.	Some of the possible communications are done wirelessly. The device will bother the user while carrying due to sizes of the equipment. The device will be used by carrying extra equipment such as extra batteries etc..
0.2 Unacceptable	1300 gr	The device will partially block the movement of the user. Also the user will buy extra tools.	None of the possible communications are done wirelessly. The device will bother the user while carrying due to sizes of the equipment. The device must be used by carrying extra equipment such as extra batteries etc..
0.0 Failure	>1500 gr	The device will block the movement of the users completely.	The device will not be portable.

Table 1: Objective Metrics for the Marketability Part 1

	Robustness (MR4)	Cost (MC5)	User Friendliness (MU6)
1 Excellent	The device will be durable against water, dust and impacts. The device will be packed into a protective case.	$150	The device will be easily rechargeable. It can be controlled easily by the user. It gives clear and concise audio feedback to the user. Overall, it will be intuitively usable.
08 Good	The device will be durable against dust and impacts.The device will be packed into a protective case. However it will not be water resistant.	$160	It can be controlled easily by the user. It gives clear and concise audio feedback to the user. Overall, it will be intuitively usable. However, the recharging process will be complex (replacing multiple batteries).
0.6 Satisfactory	The device will be durable against dust and impacts.The device will be packed into a protective case. However it will not be water resistant.	$170	It gives clear and concise audio feedback to the user. It will be easily rechargeable. However, it will not be intuitive to use.
0.4 Average	The device will be packed into a protective case. However it will not be water and dust resistant.	$180	It gives clear and concise audio feedback to the user. It will need an extra recharging unit. However, it will not be intuitive to use. (Excessive number of buttons)
0.2 Unacceptable	The device will be packed into a protective case. There is no protection against impacts, dust and water.	$190	The audio feedback will be insufficient, the recharging process will be complex. It will not be intuitive to use.
0.0 Failure	The device will break down while using.	>$200	The audio feedback will be insufficient. The device will not be rechargeable. It will not be intuitive to use.

Table 2: Objective Metrics for the Marketability Part 2

	Object Detection Range (PO1)	Object Detection Accuracy (PO2)	Power Consumption (Battery Lasting Duration) (PP3)
1 Excellent	30 m	%99	3 hour
0.8 Good	24 m	%90	2 hour
0.6 Satisfactory	18 m	%80	1.5 hour
0.4 Average	12 m	%70	1 hour
0.2 Unacceptable	6 m	%50	30 minute
0 Failure	Not Detected	<%25	< 30 minute

Table 3: Objective Metrics for the Performance Part 1

	Object Detection Speed (FPS) (PO4)	Heat Dissipation (Celcius) (PH5)	Obstacle Detection Range (PO6)
1 Excellent	30 FPS	Medium Temperature	2 m
0.8 Good	24 FPS	Medium Temperature + 2 C	1 m
0.6 Satisfactory	18 FPS	Medium Temperature + 5 C	0.8 m
0.4 Average	12 FPS	Medium Temperature + 8 C	0.5 m
0.2 Unacceptable	6 FPS	Medium Temperature + 10 C	0.2 m
0 Failure	Not Detected	Above + 10 C	Not Detected

Table 4: Objective Metrics for the Performance Part 2

	Detecting an Obstacle (PD7)	Obstacle Detection Speed (PO8)	Obstacle Distance Measurement Precision (PO9)
1 Excellent	10 out of 10	50 ms	+- 1 cm
0.8 Good	8 out of 10	80 ms	+- 3 cm
0.6 Satisfactory	6 out of 10	100 ms	+- 5 cm
0.4 Average	4 out of 10	150 ms	+- 10 cm
0.2 Unacceptable	Not Detected	500 ms	+- 15 cm
0 Failure	Not Detected	>1 sec	Not Detected

Table 5: Objective Metrics for the Performance Part 3

	PO1 10.0	PO2 10.0	PP3 9.0	PO4 6.0	PH5 6.0	PO6 6.0	PD7 10.0	PO8 2.0	PO9 2.0	Performance Total
Design Choice 1	1.0	0.6	1.0	1.0	0.8	0.6	0.8	0.6	0.3	49.2
Design Choice 2	1.0	0.6	0.5	0.5	0.7	1.0	1.0	0.6	0.8	46.5

Table 6: Weights for the Performance Part

	MW1 10.0	MP2 7.0	MP3 8.0	MR4 2.0	MC5 8.0	MU6 8.0	Marketability Total
Design Choice 1	0.8	1.0	1.0	0.4	1.0	1.0	39.8
Design Choice 2	0.3	0.9	0.8	0.4	0.2	0.7	23.7

Table 7: Weights for the Marketability Part

	Performance Total	Marketability Total	Grand Total
Design Choice 1	49.2	39.8	89.0
Design Choice 2	46.5	23.7	70.2

Table 8: Total Weights

Appendix 2: Tests

Location	Middle East Technical University
Date	19 - 23 December 2022
Time	02:00 PM
Description	General submodule testing of the proposed design
Aim	Finding out the possible problems in each subunits and improving the systems according to the test results
Expected Outcome	Obtaining expected results from each subunit with minimum error margin
Participants	İlim Çelebioğlu, Melis Gökşen, Niyazi Görkem Dener, Salih Mert Küçükakıncı, İsmail Hakkı Armutcu

Test Devices & Tools

1. Measurement Tape and Iphone Measure Application (Measure)

Ground truth: The distances and heights of the detected objects are measured with a measurement tape. After that, these distances are measured with Measure Application and the performance of the application can be verified. After that, due to fast measurements of the Measure Application, the following measurements will be held with the mobile phone.

2. Iphone Measure Application (Levels)

Ground truth: The angle of the ultrasonic distance sensor will be measured with Measurement Application (Levels) of the Iphone as well. The calibration of the application will be done by putting the mobile phone on a vertical plane such as a table.

3. STM32CubeIDE on Host Computer

Ground truth: By using the Live Expressions feature of the Debugger in STM32CubeIDE, the real time outputs of the subunits can be displayed. This system is the main development interface of our subunit microprocessor. No calibration is required.

4. Bluetooth Terminal HC-05 on Host Device

Ground truth: This application is the mobile application of our Bluetooth Module to test our bluetooth module. By using this application, the data can be displayed on a mobile phone's screen. The calibration will be done by AT commands.

5. FPS Measurement Tool on Host Device

Ground truth: A well known FPS measurement algorithm will be used to obtain the camera performance of our system while the object detection algorithm is running. The system parameters will be predefined for calibration of the algorithm.

Test Environment

As the test environment, the desired detected objects are mainly chosen from the Middle East Technical University Campus area. The environment consists of pedestrian crossings, traffic lights, speed bump signs, and cars, whose existence and shape should be detected as the testing process. Coming cars as the potential dangers for the user should be detected and the user must be warned. The aim of the test environment is to test the image detecting/distance measurement modules.

Test Parameters

Parameter	Range	Step Size	Number of Points
Obstacle Detection Distance	[30 cm, 150 cm]	20 cm	7
Shape of the Obstacle	Objects with different shapes will be tested due to the nature of the ultrasonic waves	A planar object A cylindrical object An object with sharp edge An object that absorbs the sound waves	4
Performance of the Ultrasonic Distance Sensor Varying with Relative Angle with Respect to Ground	[0 degrees,45 degrees]	22,5 degrees	3
Car Detection Distance	[1 m, 20 m]	1 m	20
Car Detection Accuracy vs Distance	[1 m, 20 m]	1 m	20
Traffic Lights Detection Distance	[1 m, 21 m]	2 m	11
Pedestrian Crossing Detection Distance	[1 m, 21 m]	2 m	11
Traffic sign Detection Distance	[1 m, 21 m]	2 m	11
Image Processing Algorithm Precision vs FPS	[2 FPS, 16 FPS]	1 FPS	15

Test Procedure

1. Measuring the distance of a planar object from different distances with varying angles as described above.
2. Measuring the distance of a cylindrical object from different distances with varying angles as described above.
3. Measuring the distance of a sharp object from different distances with varying angles as described above.
4. Measuring the distance of a sound absorbing object from different distances with varying angles as described above.
5. Detect a car starting from 1 m to 20 m.
6. Detect multiple cars which are at the same distance to obtain the accuracy of the detection algorithm.
7. Detecting traffic lights, traffic signs and pedestrian crossings starting from 1 m to 21 m.
8. Fixing the fps rate of the algorithm to test its precision as mentioned above.

Test Data

Table 1: Obstacle Detection Distance and Angle for a Planar Object

Obstacle Detection Distance and Angle for a Planar Object	Actual Performance	Expected Performance	Error (absolute)
30 cm and 0.00 degrees	30 cm	29-31 cm	0 cm
30 cm and 22.5 degrees	31 cm	29-31 cm	1 cm
30 cm and 45.0 degrees	28 cm	29-31 cm	2 cm
50 cm and 0.00 degrees	49 cm	48-52 cm	1 cm
50 cm and 22.5 degrees	43 cm	48-52 cm	7 cm
50 cm and 45.0 degrees	49 cm	48-52 cm	1 cm
70 cm and 0.00 degrees	68 cm	67-73 cm	2 cm
70 cm and 22.5 degrees	60 cm	67-73 cm	10 cm
70 cm and 45.0 degrees	69 cm	67-73 cm	1 cm
90 cm and 0.00 degrees	88 cm	86-94 cm	2 cm
90 cm and 22.5 degrees	80 cm	86-94 cm	10 cm
90 cm and 45.0 degrees	86 cm	86-94 cm	4 cm
110 cm and 0.00 degrees	108 cm	105-115 cm	2 cm
110 cm and 22.5 degrees	98 cm	105-115 cm	12 cm
110 cm and 45.0 degrees	107 cm	105-115 cm	3 cm
130 cm and 0.00 degrees	128 cm	124-136 cm	8 cm
130 cm and 22.5 degrees	119 cm	124-136 cm	1 cm
130 cm and 45.0 degrees	125 cm	124-136 cm	5 cm
150 cm and 0.00 degrees	147 cm	143-157 cm	3 cm
150 cm and 22.5 degrees	140 cm	143-157 cm	10 cm
150 cm and 45.0 degrees	148 cm	143-157 cm	2 cm

Table 2: Obstacle Detection Distance and Angle for a Cylindrical Object

Obstacle Detection Distance and Angle for a Cylindrical Object	Actual Performance	Expected Performance	Error (absolute)
30 cm and 0.00 degrees	29 cm	29-31 cm	1 cm
30 cm and 22.5 degrees	43 cm	29-31 cm	13 cm
30 cm and 45.0 degrees	20 cm	29-31 cm	10 cm
50 cm and 0.00 degrees	49 cm	48-52 cm	1 cm
50 cm and 22.5 degrees	55 cm	48-52 cm	5 cm
50 cm and 45.0 degrees	49 cm	48-52 cm	1 cm
70 cm and 0.00 degrees	69 cm	67-73 cm	1 cm
70 cm and 22.5 degrees	72 cm	67-73 cm	2 cm
70 cm and 45.0 degrees	30 cm	67-73 cm	40 cm
90 cm and 0.00 degrees	87 cm	86-94 cm	3 cm
90 cm and 22.5 degrees	95 cm	86-94 cm	5 cm
90 cm and 45.0 degrees	82 cm	86-94 cm	8 cm
110 cm and 0.00 degrees	107 cm	105-115 cm	3 cm
110 cm and 22.5 degrees	115 cm	105-115 cm	5 cm
110 cm and 45.0 degrees	145 cm	105-115 cm	35 cm
130 cm and 0.00 degrees	127 cm	124-136 cm	3 cm
130 cm and 22.5 degrees	145 cm	124-136 cm	15 cm
130 cm and 45.0 degrees	150 cm	124-136 cm	20 cm
150 cm and 0.00 degrees	NA	143-157 cm	-
150 cm and 22.5 degrees	NA	143-157 cm	-
150 cm and 45.0 degrees	NA	143-157 cm	-

Table 3: Obstacle Detection Distance and Angle for a Sharp Edged Object

Obstacle Detection Distance and Angle for a Sharp Edged Object	Actual Performance	Expected Performance	Error (absolute)
30 cm and 0.00 degrees	34 cm	29-31 cm	4 cm
30 cm and 22.5 degrees	45 cm	29-31 cm	15 cm
30 cm and 45.0 degrees	56 cm	29-31 cm	26 cm
50 cm and 0.00 degrees	54 cm	48-52 cm	4 cm
50 cm and 22.5 degrees	60 cm	48-52 cm	10 cm
50 cm and 45.0 degrees	66 cm	48-52 cm	16 cm
70 cm and 0.00 degrees	80 cm	67-73 cm	10 cm
70 cm and 22.5 degrees	89 cm	67-73 cm	19 cm
70 cm and 45.0 degrees	85 cm	67-73 cm	15 cm
90 cm and 0.00 degrees	105 cm	86-94 cm	15 cm
90 cm and 22.5 degrees	110 cm	86-94 cm	20 cm
90 cm and 45.0 degrees	116 cm	86-94 cm	26 cm
110 cm and 0.00 degrees	120 cm	105-115 cm	10 cm
110 cm and 22.5 degrees	121 cm	105-115 cm	11 cm
110 cm and 45.0 degrees	130 cm	105-115 cm	20 cm
130 cm and 0.00 degrees	140 cm	124-136 cm	10 cm
130 cm and 22.5 degrees	145 cm	124-136 cm	15 cm
130 cm and 45.0 degrees	122 cm	124-136 cm	8 cm
150 cm and 0.00 degrees	NA	143-157 cm	-
150 cm and 22.5 degrees	NA	143-157 cm	-
150 cm and 45.0 degrees	155 cm	143-157 cm	5 cm

Table 4: Obstacle Detection Distance and Angle for a Sound Absorbing Object

Obstacle Detection Distance and Angle for a Sound Absorbing Object	Actual Performance	Expected Performance	Error (absolute)
30 cm and 0.00 degrees	34 cm	29-31 cm	4 cm
30 cm and 22.5 degrees	37 cm	29-31 cm	7 cm
30 cm and 45.0 degrees	40 cm	29-31 cm	10 cm
50 cm and 0.00 degrees	49 cm	48-52 cm	1 cm
50 cm and 22.5 degrees	50 cm	48-52 cm	0 cm
50 cm and 45.0 degrees	50 cm	48-52 cm	0 cm
70 cm and 0.00 degrees	71 cm	67-63 cm	1 cm
70 cm and 22.5 degrees	70 cm	67-63 cm	0 cm
70 cm and 45.0 degrees	70 cm	67-63 cm	0 cm
90 cm and 0.00 degrees	90 cm	86-94 cm	0 cm
90 cm and 22.5 degrees	93 cm	86-94 cm	3 cm
90 cm and 45.0 degrees	87 cm	86-94 cm	3 cm
110 cm and 0.00 degrees	113 cm	105-115 cm	3 cm
110 cm and 22.5 degrees	120 cm	105-115 cm	10 cm
110 cm and 45.0 degrees	115 cm	105-115 cm	5 cm
130 cm and 0.00 degrees	129 cm	124-136 cm	1 cm
130 cm and 22.5 degrees	140 cm	124-136 cm	10 cm
130 cm and 45.0 degrees	140 cm	124-136 cm	10 cm
150 cm and 0.00 degrees	146 cm	143-157 cm	4 cm
150 cm and 22.5 degrees	162 cm	143-157 cm	12 cm
150 cm and 45.0 degrees	170 cm	143-157 cm	20 cm

Table 5: Car Detection Distance

Car Detection Distance	Actual Performance (Detected/ Not Detected)	Expected Performance (Detected/ Not Detected)	Error (absolute)
1 m	✓	✓	True positive
2 m	✓	✓	True positive
3 m	✓	✓	True positive
4 m	✓	✓	True positive
5 m	✓	✓	True positive
6 m	✓	✓	True positive
7 m	✓	✓	True positive
8 m	✓	✓	True positive
9 m	✓	✓	True positive
10 m	✓	✓	True positive
11 m	✓	✓	True positive
12 m	✓	✓	True positive
13 m	✓	✓	True positive
14 m	✓	✓	True positive
15 m	✓	✓	True positive
16 m	✓	x	False negative
17 m	✓	x	False negative
18 m	✓	x	False negative
19 m	✓	x	False negative
20 m	✓	x	False negative

Table 6: Car Detection Distance vs Accuracy

Car Detection Distance vs Accuracy	Actual Performance (Out of 10)	Expected Performance (Out of 10)	Error (in percentage)
1 m	10	10	0 %
2 m	10	10	0 %
3 m	10	10	0 %
4 m	8	10	20 %
5 m	10	10	0 %
6 m	9	10	10 %
7 m	10	10	0 %
8 m	10	10	0 %
9 m	7	10	30 %
10 m	10	10	0 %
11 m	8	10	20 %
12 m	9	10	10 %
13 m	10	10	0 %
14 m	10	10	0 %
15 m	7	10	30 %
16 m	10	9	0 %
17 m	9	9	0 %
18 m	10	9	0 %
19 m	8	8	0 %
20 m	10	8	0 %

Table 7: Traffic Lights Detection Distance

Traffic Lights Detection Distance	Actual Performance (Detected/ Not Detected)	Expected Performance (Detected/ Not Detected)	Estimation comparison result
1 m	✓	✓	True positive
3 m	✓	✓	True positive
5 m	✓	✓	True positive
7 m	x	✓	False positive
9 m	x	✓	False positive
11 m	✓	✓	True positive
13 m	x	✓	False positive
15 m	x	✓	False positive
17 m	x	x	True negative
19 m	x	x	True negative
21 m	x	x	True negative

Table 8: Pedestrian Crossing Detection Distance

Pedestrian Crossing Detection Distance	Actual Performance (Detected/ Not Detected)	Expected Performance (Detected/ Not Detected)	Estimation comparison result
1 m	✓	✓	True positive
3 m	x	✓	False positive
5 m	x	✓	False positive
7 m	x	✓	False positive
9 m	x	✓	False positive
11 m	x	✓	False positive
13 m	x	x	True negative
15 m	x	x	True negative
17 m	x	x	True negative
19 m	x	x	True negative
21 m	x	x	True negative

Table 9: Traffic Sign Detection Distance

Traffic sign Detection Distance	Actual Performance (Detected/ Not Detected)	Expected Performance (Detected/ Not Detected)	Estimation comparison result
1 m	✓	✓	True positive
3 m	x	✓	False positive
5 m	x	✓	False positive
7 m	✓	✓	True positive
9 m	x	✓	False positive
11 m	x	✓	False positive
13 m	x	x	True negative
15 m	x	x	True negative
17 m	✓	x	False negative
19 m	x	x	True negative
21 m	x	x	True negative

Table 10: Image Processing Algorithm Precision vs FPS

Image Processing Algorithm Precision vs FPS	Actual Performance (Precision)	Expected Performance (Precision)	Error (absolute in percentage)
2 FPS	70 %	75-80%	7.5 %
3 FPS	67 %	75-80%	10.5 %
4 FPS	72 %	75-80%	5.5 %
5 FPS	78 %	80-85%	4.5 %
6 FPS	82 %	80-85%	0.5 %
7 FPS	84 %	80-85%	1.5 %
8 FPS	80 %	80-85%	2.5 %
9 FPS	87 %	85-90%	0.5 %
10 FPS	90 %	85-90%	2.5 %
11 FPS	91 %	85-90%	3.5 %
12 FPS	92 %	90-100%	3 %
13 FPS	90 %	90-100%	5 %
14 FPS	89 %	90-100%	6 %
15 FPS	93 %	90-100%	2 %
16 FPS	92 %	90-100%	3 %

Data Analysis

For the traffic sign, traffic light and pedestrian crossing detection distance tests using tables given above is more appropriate. Estimation results are written in terms of confusion matrix terms. There are four cases which are if estimation is “true” and simulation result is also “true” then, it is true positive; if estimation is “true” but simulation result is “false” then, it is false positive; if estimation is “false” but simulation result is “true” then, it is false negative; if estimation is “false” and simulation result is “false” then it is true negative. We used a rough measurement method while taking the data like we measure 1 step length and find the total distance by multiplying total numbers of steps by step length. For FPS accuracy analysis, car detection distance accuracy and object detection distance for different types of objects and orientations following graphs can be analyzed.

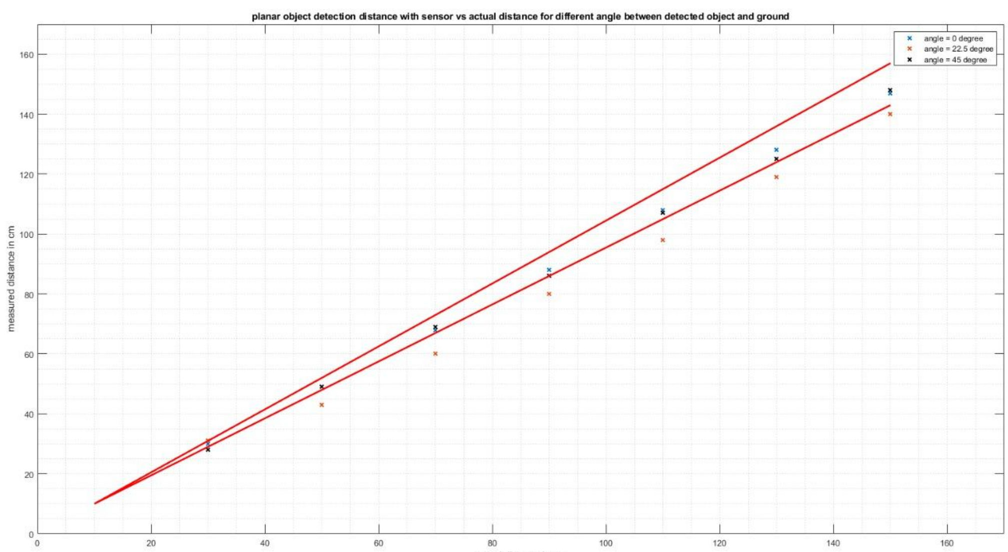

Figure 1: Graph of Measured Distance vs Real Distance for Planar Obstacle Detection Test In Different Angles

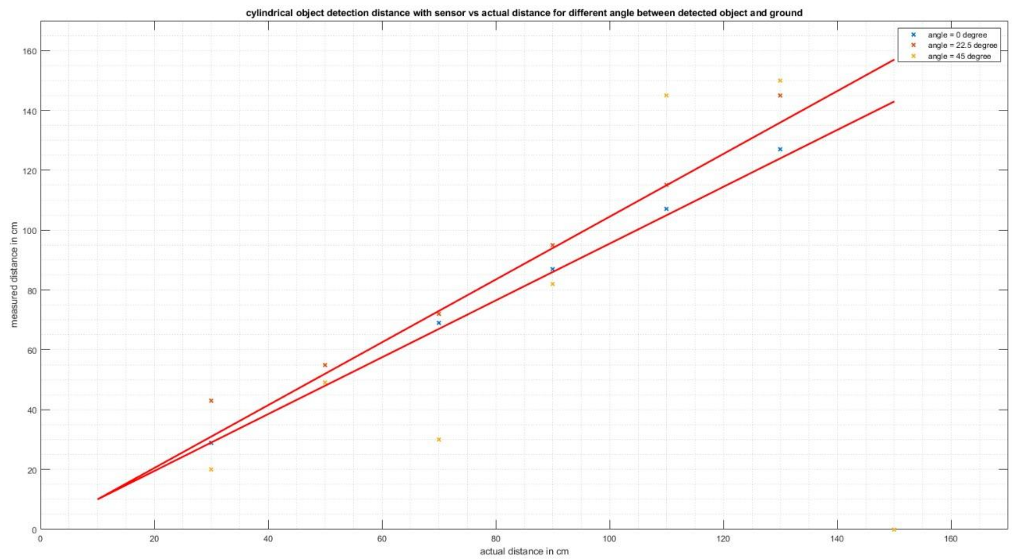

Figure 2: Graph of Measured Distance vs Real Distance for Cylindrical Obstacle Detection Test In Different Angles

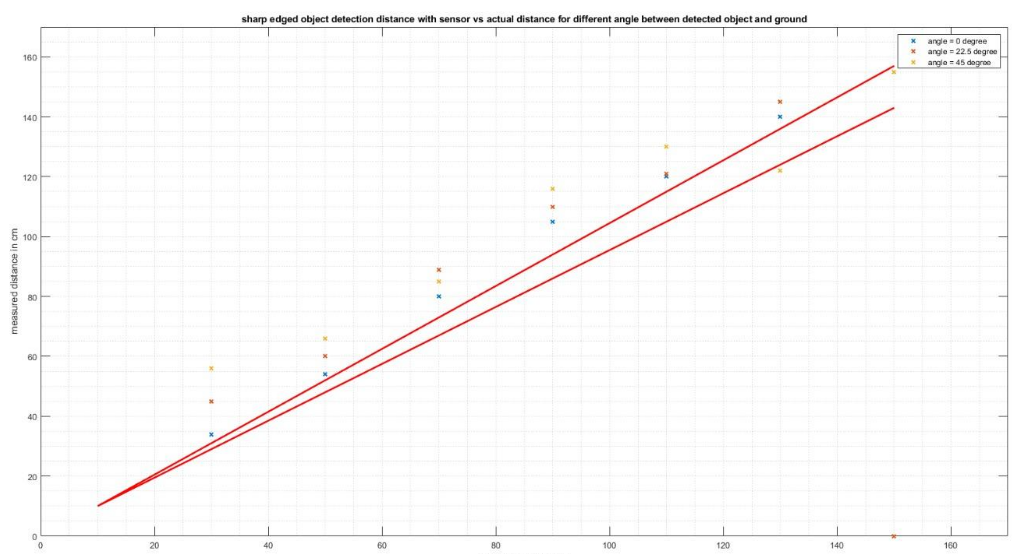

Figure 3: Graph of Measured Distance vs Real Distance for Sharp Edged Obstacle Detection Test In Different Angles

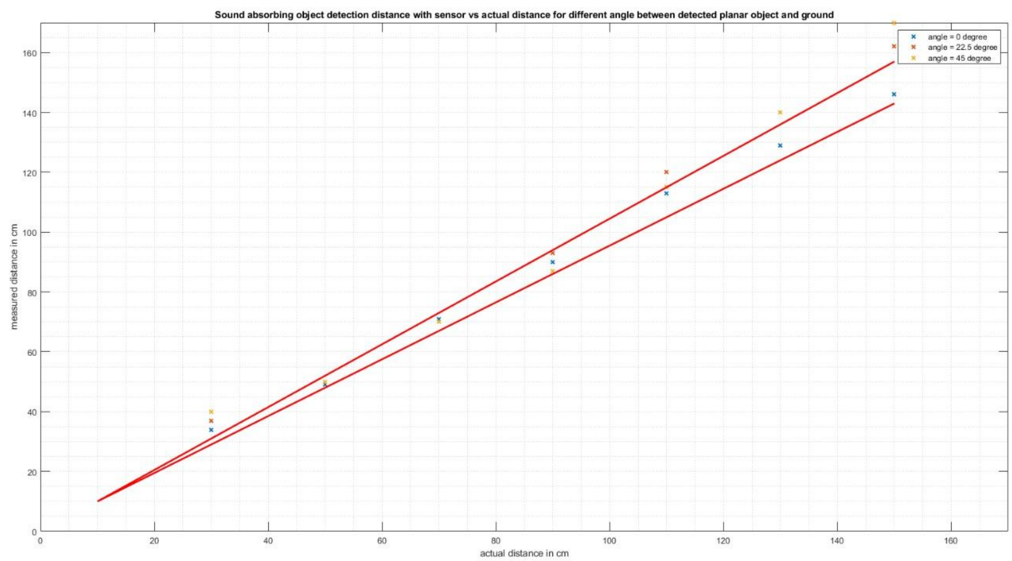

Figure 4: Graph of Measured Distance vs Real Distance for Sound Absorbing Obstacle Detection Test In Different Angles

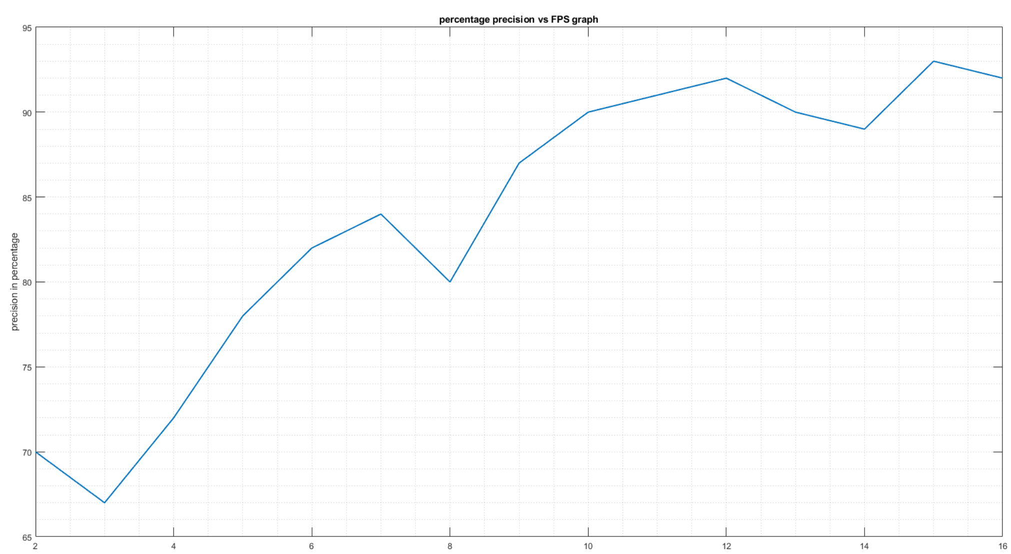

Figure 5: Graph of Percentage Precision vs FPS While Detecting Objects

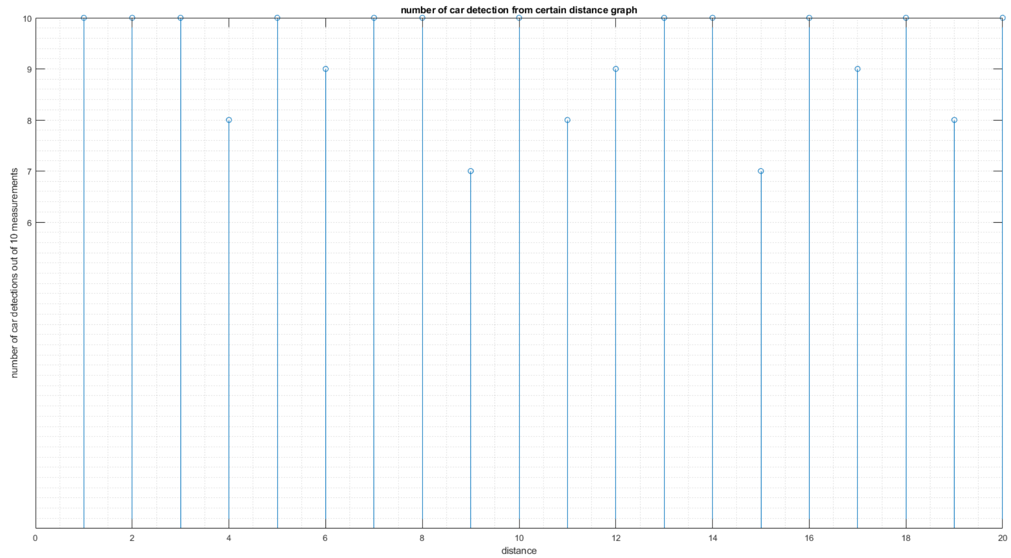

Figure 6: Graph of Number of Car Detection vs Distance Out of 10 Cars

Red lines in Figure 1,2,3 and 4 represent the expectation distance boundaries.

Results and Discussion

According to tables 5, 7, 8, and 9, we can say that artificial intelligence models that are used to detect cars, traffic signs, traffic lights and pedestrian crossings are very successful in detecting cars. For traffic signs and traffic lights it does not work well. Furthermore, for detecting pedestrian crossings AI models that are taken from the internet are not sufficient.

Moreover, according to graph 6 we are able to detect almost all cars that are crossing from a certain distance ahead of the camera. From graph 5, we can observe that as the FPS increases detection accuracy increases proportionally.

In the walking stick unit, all of the test results are obtained with the graphs shown in 1,2,3 and 4. According to those graphs, the distance of planar objects with orientation of “0” degree measured more accurately than other ones as expected. Furthermore, for sharp edged objects we get worse measurement results according to our expectations.

Appendix 3: Detailed Information on Bluetooth

Bluetooth Protocol

The Bluetooth device that is chosen is HC-05, which uses Bluetooth Version 2.0 + EDR (Enhanced Data Rate) Protocol. This version of the bluetooth differs from the previous versions such that the transmission capability is 2 or 3 times larger with a faster phase Shift keying (PSK) modulation. For older versions, data transmission rate is 721 kbit/sec, whereas in versions 2.0 and 2.1, transmission rate is improved to 2.1Mbit/sec. In version 2 family, bluetooth devices make the connection, sometimes more than one connection automatically, and the end user has to confirm the connection.

In addition, version 2.0 + EDR defines a property called 'Sniff Subrating' which extends the battery life by reducing the active duty cycle. Especially when the bluetooth device performs as slave role, the power consumption is significantly higher than the master role due to the active listening that slave has to perform. However, when the bluetooth device works with sniff mode, the rate of the power consumption is reduced than the default case with 2.0+EDR protocol.

Bluetooth Modulation

The bluetooth module HC-05 uses Gaussian Frequency Shift Keying (GFSK) Modulation, which is a type of digital modulation. GFSK is a type of frequency shift keying (FSK) modulation type which uses a Gaussian filter to shape the pulses before they are modulated. The logic behind the frequency shift keying is that it encodes data as a series of frequency changes in a carrier. One advantage of using frequency for modulation is to encode data; noise usually changes the amplitude of a signal. Additionally, GFSK modulated signal is much cleaner than the FSK modulated signal since GFSK filters out spurious to a much narrower transmission bandwidth than FSK.

Frequency Hopping-Spread Spectrum (FHSS)

Frequency-hopping spread spectrum is designed for robust operation in noisy environments by transmitting short packets at different frequencies across wide portions of channel bandwidth. The exact form and implementation of the frequency-hopping sequence are different for each radio system. The most widely used sequence is the binary offset code, which is used in Bluetooth and IEEE 802.15 protocol. The bluetooth module, HC-05, has the feature of adaptive frequency hopping.

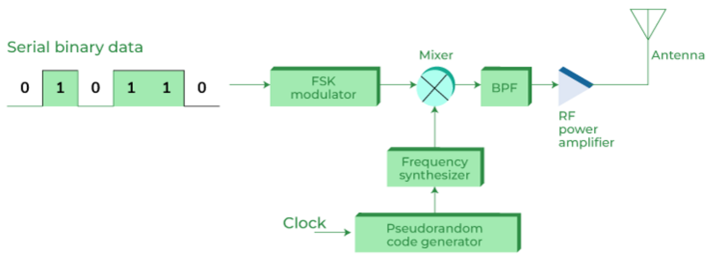

Figure 1: Frequency Hopping with FSK Modulation Scheme

Serial Communication Protocols

- **Universally Serial Asynchronous Receiver/Transmitter (USART) and Transistor-Transistor Logic (TTL)**

Asynchronous serial communication is sometimes referred to as Transistor-Transistor Logic (TTL) serial, where the high voltage level is logic 1, and the low voltage equates to logic 0. Almost every microcontroller on the market today has at least one Universal Asynchronous Receiver-Transmitter (UART) for serial communication. The rate at which a serial communication takes place is called a baud rate. UART in the bluetooth module HC-05 is arranged to transmit one bit at a time with a specified baud rate of 9600 bps (bits per second), hence it is easy to interface with any microcontroller that supports USART such as STM32 in our case. Microcontrollers typically sense a high voltage level at +3.3 or +5.0 volts for serial communication. Thus, every 1/9600th of a second, a receiver will look at the line and determine if it's high or low-level voltage and translate that into a bit or 1 or 0. In TTL series communication, a low voltage level means a 0-bit value and a high voltage level means a 1-bit value.

- **IEEE 802.15.1 Standardized Protocol (Wireless Medium Access Control (MAC) and Physical Layer (PHY) specifications for Wireless Personal Area Networks (WPAN))**

The Institute of Electrical and Electronics Engineers (IEEE) proposes IEEE 802.15 standard for the working group of wireless specialty networks (WSNs), such as wireless personal area networks (WPANs), Bluetooth, Internet of Things networks, mesh networks, body area networks, wearables, visible light communications, among others. Those groups set the standards for common types of wireless technologies used for personal area networks. IEEE 802.15.1 is specified for Bluetooth and Bluetooth Low Energy (BLE) technologies. Bluetooth Special Interest group (SIG) must certify a product before it can be marketed as a Bluetooth device to the consumer or business market since IEEE 802.15.1 protocol is not maintained anymore. That certification helps ensure that all Bluetooth devices work in a standardized way and provide a similar experience for consumers.

Bluetooth Module (HC-05) Hardware Features

- Uses Serial Port Protocol (SPP)
- Default Baud Rate: 9600 bps
- Data Bits: 8
- Stop Bit: 1
- No parity
- Low Power: 1.8V
- Operating Voltage: +3.3 / +5V
- Operating Current: 30mA
- Bit error sensitivity: -80dBm
- RF transmission power: +4dBm
- Default Operation Mode: Slave (Single Slave Piconet)
- Able to send short bursts of data in extremely noisy environment
- 3Mbps Modulation with integrated 2.4GHz radio transceiver

Appendix 4: Detailed Information on UART Protocol

For the main processor of the walking stick module, STM32 is selected as the micro controller unit. The main components of the stick unit; sensor (ultrasound sensor), STM32, power unit, and bluetooth are visualized in the figure below as one of the proposed solutions. STM32 organizes the components and works as the brain of the corresponding module. The communication ports between bluetooth module HC-05 and STM32 are provided with Tx (data transmission port)/Rx (data receiver port) connections of each component. Since STM32 can also communicate with UART serial protocol, and they are both +3.3V TTL levels, they can be connected via Tx to Rx, and Rx to Tx respectively. A serial bus consists of just two wires - one for sending data and another for receiving. As such, serial devices should have two serial pins: the receiver, Rx, and the transmitter, Tx. Actually, Tx and Rx cable structures are the same. The difference of the data flow direction comes from the connection sides. When we connect Tx to Tx port, no data can flow through, hence no data transmission can be done. When microcontrollers and other low-level ICs communicate serially they usually do so at a TTL (transistor-transistor logic) level. TTL serial signals exist between a microcontroller's voltage supply range - usually 0V to 3.3V or 5V. A signal at the VCC level (3.3V, 5V, etc.) indicates either an idle line, a bit of value 1, or a stop bit. A 0V (GND) signal represents either a start bit or a data bit of value 0. A serial interface where both devices may send and receive data is either full-duplex or half-duplex. Half-duplex communication means serial devices must take turns sending and receiving, which is valid for the case between STM32 and HC-05.