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Self-Energized Smart Vision Stick for Visually Impaired People

Team Members

Mohammad Hossain Mohammadi
Saif Al Ameri
Sana Ziaei

Project Advisor

Dr. Majid Poshtan

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ABSTRACT

This project report explains the detailed design and implementation of a Self-Energized Smart Vision Stick for Visually Impaired People. The device consists of three main systems which are detection and alert, emergency, and renewable power generation.

The detection and alert system is composed of an ultrasonic sensor that detects surrounding obstacles and sends a signal to a microcontroller for processing. The distance of potential obstacles is calculated and feedback is given to the user accordingly in order to avoid the potential obstacle. The emergency system is composed of a GPS/GPRS/GSM Module that is controlled using a microcontroller. In case of emergencies, the user triggers the emergency system in order to send an SMS to a preset number, which is a close relative of the user, with the GPS coordinates of the user. The renewable power generation system harnesses the motion of the user while moving the stick and converts it to electrical energy that supplies the detection and alert as well as the emergency systems. The power generation is done through linear generators and permanent magnets using Faraday's Law of induction.

Chapter one introduces the project idea and the motivation behind implementing this project into an engineering prototype. Similar projects across other universities are studied and compared for analyzing the positive and negative aspects of the discussed projects. The chapter also illustrates some non-technical constraints and project limitations that need to be considered.

Chapter two illustrates some design alternatives such as the glove and jacket designs compared to the blind stick. The high-level project architecture is also displayed and explained before moving into component selection for the engineering prototype.

Chapter three explains the design details and implementation of the three main features of the vision stick, the Detection and Alert System, the Emergency System, and the Renewable Energy Generation, along with the extra features added. The detection system is capable of differentiating different ranges of objects at ground and waist levels up to a maximum of 130cm from the tip of the stick. The Emergency System is capable of retrieving the GPS coordinates and sending them via an SMS to an emergency contact by the click of a button in under four minutes during 97% of the time. The Renewable Energy Generator is capable of producing 1.6W

of power in an unloaded condition which is more than 11 times stronger than the compared Prototype Generator 1. Extra features which were added to the vision stick are discussed.

Chapter four focuses on the final engineering prototype and explains each part in relation to the separately working features. The challenges and algorithms for combining the code of the Detection and Alert System and the Emergency System are also discussed. Chapter five talks about the performance of the vision stick in terms of the power generation and consumption and the stick's usability.

Chapter six explains the different cost and mass project parameters along with the factors determining mass production in an engineering and economic standpoint. Chapter seven elaborates on the project planning implemented to organize the work of three team members throughout the semester. Chapter 8 concludes the report by illustrating the results of the project and future considerations for improving the project.

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1 INTRODUCTION

1.1 Goal and Motivation

1.1.1 Problem Definition

There are around 285 million people who are considered visually impaired worldwide. Thirty nine million of them are blind and the rest have a considerably low ability to see [**1**]. The lack of visual senses causes many social and psychological challenges that prevent visually-impaired people from having a normal living. They do not have much of privacy and independence since they are accompanied by a member of the family most often. Due to the “unsafe” outdoor environment, they tend to not leave their house very frequently on their own.

1.1.2 Existing Solutions

Two of the most common existing solutions that help the visually-impaired in their daily lives are the white cane and guide dogs. However, each of them has its own short comings. The white cane requires guidance of people in some occasions, depends on hitting objects to identify their locations, and does not identify approaching objects such as bicycles. Similarly, the guide dog is a costly solution and requires routine care. Furthermore, many public transport facilities and areas like busses and malls prohibit pets to enter, creating problems for guide dog owners.

1.1.3 Proposed Solution

Sustaining the positive aspects of the white cane and guide dogs, this project focuses on designing the “Self-Energized Smart Vision Stick” using current technologies. The Self-Energized Smart Vision Stick is a smart tool capable of enhancing the lives of visually-impaired people that can lead to an increase in their daily independence, privacy, and safety. The tool uses distance sensors to detect the distance of surrounding objects with the vision stick and alert the user accordingly. It incorporates an emergency system which is able to provide efficient ways to rescue the user in dangerous situations. As the project name implies, the system is self-energized through embedded electric generators offering a practical solution during low charge situations away from the electric grid. Figure 1 illustrates an overall 3D model of the Self-Energized Smart Vision Stick. In this midterm report, the names “Self-Energized Smart Vision Stick”, smart stick, and vision stick are used interchangeably to represent both the project and the prototype.

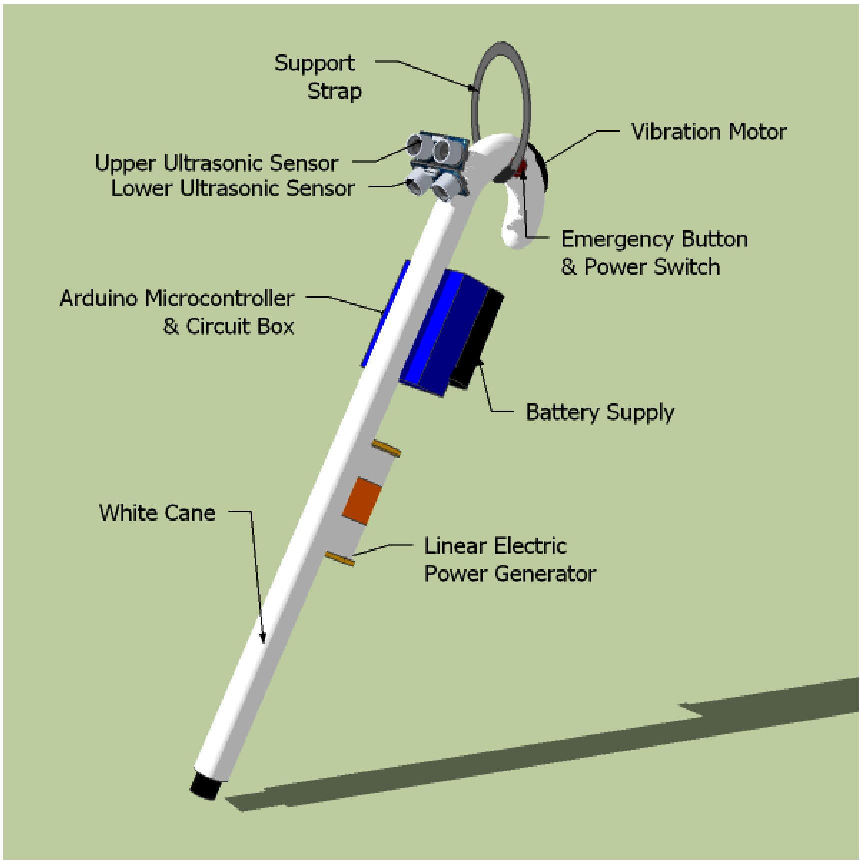


Figure 1: General 3D Model of the Self-Energized Smart Vision Stick

1.1.4 Existing Similar Projects

Motivated by the same idea of a smart stick for visually impaired people, there have been similar projects in other universities, of which two of them are briefly explained in the coming paragraphs where the main features are highlighted.

1.1.4.1 RFID-Enabled Robotic Guide Dog

As shown in Figure 2, this project was carried out by a group of undergraduate students in Central Michigan University, USA. They have designed and built a prototype of a smart cane that can guide visually-impaired people to avoid obstacles using ultrasonic sensors and RFID technology. However, RFID tags need to be installed along streets and signals before the cane can identify and notify the user accordingly of the surrounding environment. In addition, the smart cane is equipped with a heavy bag that carries both the power supply and system circuitry. The user has the option of using gloves that would vibrate to alert the user in addition to vocal feedback [**2**].

An observed issue of this design is the need of new city infrastructure over large areas requiring the installation of numerous RFID tags, thereby increasing the system cost significantly. Also, carrying a bag full of system equipment, which is neither a convenient nor practical solution.

Figure 2: RFID-Enabled Robotic Guide Dog Project [2]

1.1.4.2 Assistive Cane for Visually-Impaired People

As in Figure 3, this project was completed by a group of students from Universiti Tun Hussein Onn, Malaysia. It functions as a cane detecting surrounding objects and alerting the user using ultrasonic sensors. A distinctive feature is the cane's ability to detect if there is water collection in a specific area using water sensors. The cane is designed to be foldable such that it can be carried around more conveniently when not used [**3**]. Moreover, the cane's design has basic functionality and does not have many additional distinguishing features.

Figure 3: Assistive Cane for Visually Impaired People [3]

1.2 Constraints

There are several non-technical issues that need to be considered while designing the Self-Energized Smart Vision Stick.

1.2.1 Cost

Since the target user or customer is a visually impaired person who normally has a low income rate, the device should be inexpensive and affordable. After the mass production, the smart stick should have a maximum price of *US$500*.

1.2.2 Portability

The device should be portable and light due to its use in different places over long time periods. In comparison with common portable objects, the stick's weight should not exceed *1.5kg*.

1.2.3 Ease of Use

The device should be easy to use and operate for the user. Since the purpose of the entire project is to simplify the life of the visually-impaired, it would be unreasonable to present to them a technologically-advanced tool. Also, there should be a user manual that explains the functionalities of the device and provides training lessons on how to use it.

1.2.4 Power Consumption

Since the device depends on the motion of the user to supply power to the system, the overall power consumption of the device during its operation should be low. It should not exceed the amount of power generated by normal movements of the stick for detecting objects.

1.3 Limitations

Even though the proposed solution of the "Self-Energized Smart Vision Stick" has several positive aspects for aiding visually-impaired people, it inherently has certain limitations which must be addressed. Even though distance sensors can be used to sense the proximity of surrounding objects, it cannot feed in as much information as the human eye is capable of. The modifications on the blind cane cannot be a complete replacement for the human vision, and would add extra information for the user. Also, the renewable energy generation on the vision stick cannot be directly compared with the power utility. Portable power generation for the human hand is not able to produce the same amount of power as the mains supply provides.

2 SYSTEM DESIGN OVERVIEW

2.1 System Design

The system design chapter focuses on the design components of the Self-Energized Smart Vision Stick. In section one, alternative designs are presented and assessed based on certain considerations. In section two, the overall system block diagram and chosen components for the midterm design is discussed. This will serve as an opening to the next chapter which will discuss the technical aspects of the design.

2.1.1 Alternative Designs

In this section, the alternative designs for the Self-Energized Smart Vision Stick are presented and compared to the chosen stick design. This allows the superiority of the final design to be depicted and reasons for overruling the alternative designs to be justified.

Gloves Detection

The first alternative design is the glove detection as illustrated in Figure 4. The idea behind this design is to install sensors and vibration motors on the glove. Once the glove detects an object, it should vibrate accordingly to alert the user that there is an object ahead. Nonetheless, this design has its own limitations when considering certain situations. For instance, it will be difficult for the gloves to detect sudden drops and other obstacles that other solutions can alert. Also, it would force the user to always wear gloves. Therefore, it was not chosen as the optimum tool to help the visually impaired.

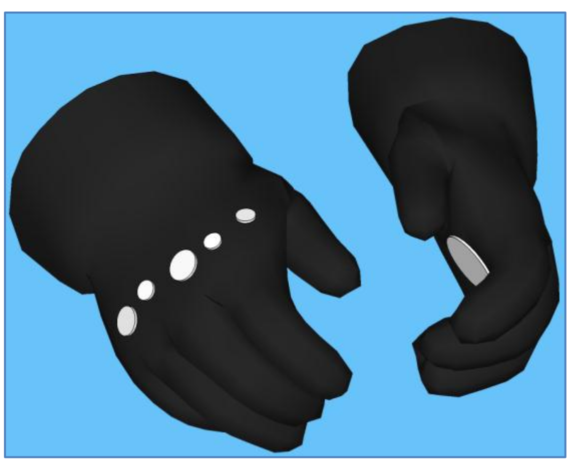


Figure 4: 3D Model of Glove Detection Design [4]

Shirt Detection

As shown in Figure 5, the shirt detector design has distance sensors all over the shirt. Similar to the glove design, distance sensors and vibration motors are used to detect and alert the blind for object proximity. Only the sensors that sense object nearby will vibrate which will allow the visually impaired to know the location of the object without carrying any tool by hand. However, the blind will have only one type of shirt to wear. Also, if the visually impaired person sits down and someone passes by they might be alerted when there is no need to do so. That fact with the relatively inaccurate sensing and feedback means that a better solution should be considered. Hence, this design was not chosen as the best solution for the visually impaired.

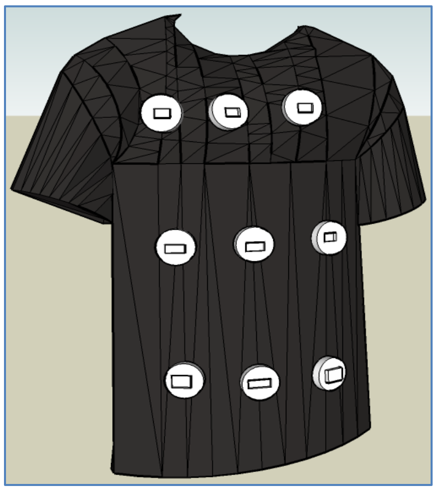


Figure 5: 3D Model of Shirt Detection Design [5]

2.2 Overall High Block Diagram

The block diagram in Figure 6 serves a vital role in understanding the building blocks of the Self-Energized Smart Vision Stick system. At the heart of the block diagram is the brain of the vision stick, the microcontroller, which is responsible for all the logical operations that will be needed to execute the design. On the left of the diagram is the detection and alert section. Distance sensors will be responsible for detecting the distance of the objects and feeding it as an input to the microcontroller to be processed. The microcontroller will then signal the actuation motor to respond accordingly as an output signal to the detection system. On the right of the diagram is the emergency section. A manual trigger will initiate the microcontroller's communication with the transmitting module to signal for help. Lastly, the bottom of the block diagram represents the renewable kinetic energy element of the vision stick. Kinetic energy will be harvested from the user to charge a battery bank. The battery bank can then power the microcontroller which sustains the rest of the system.

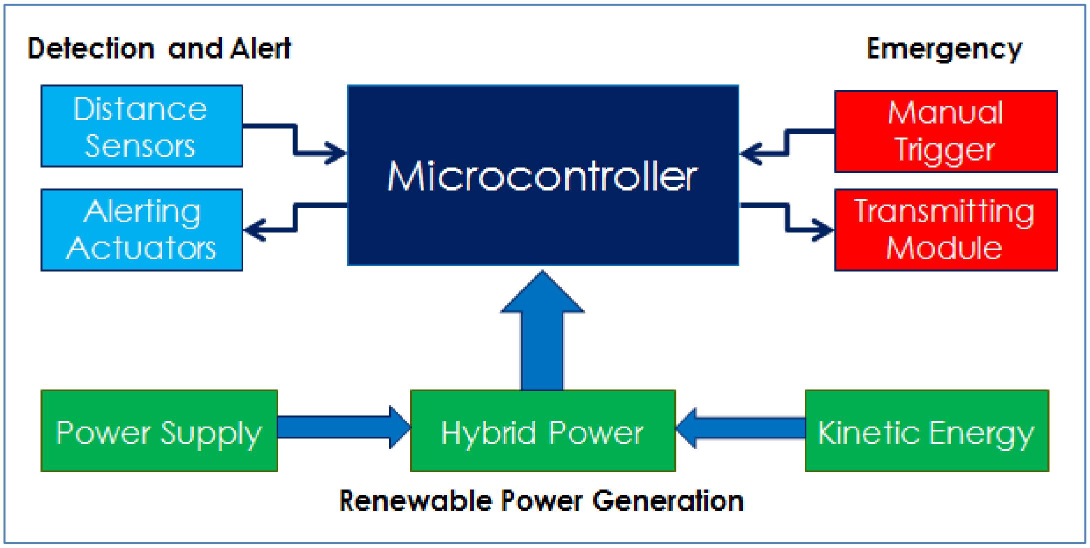


Figure 6: Overall System Block Diagram of the Vision Stick

2.3 Component Selection

In this section, the selection of each component as part of the Self-Energized Smart Vision Stick System is justified by assessing different alternatives.

Microcontroller

The Raspberry Pi and Arduino Mega microcontrollers in Figure 7 were both excellent candidates as processors for the Self-Energized Smart Vision Stick project. They are both open source and come with a wealth of online documentation and help. On one hand, the Raspberry Pi is a System-On-Chip (SOC) that has a full Linux OS with common peripherals. It is also more powerful than the Arduino in computation power, but this means that the Raspberry Pi comes with unneeded components which are not efficient for the project. Unfortunately, the GSM peripheral for the Raspberry Pi was very expensive and it was out of stock. On the other hand, the Arduino is a cheaper microcontroller, has more plug and play (UPnP) peripherals, and an easier IDE to use. In addition, the design team has previous experience with Arduino. However, there are some documentation issues with the Arduino peripherals where certain online example codes do not behave as expected. Nonetheless, the availability of Arduino and all needed peripherals along with its advantages makes Arduino a better microcontroller choice.

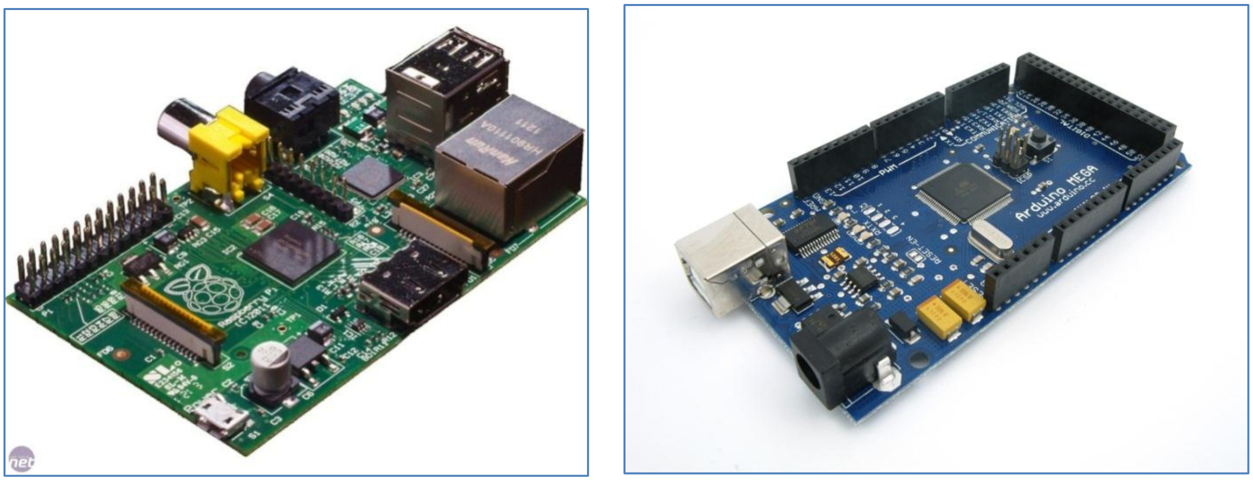


Figure 7: Comparison between Raspberry Pi shown left [6] and Arduino Mega Microcontroller shown right [7]

Ultrasonic Sensor

Two different object detecting technologies, which operate similar to each another, are infrared and ultrasonic sensors. Ultrasonic sensors, as shown in Figure 8, consist of a sonar transmitter and a receiver. After the transmitter emits a sonar wave, the echo from the surrounding object is picked up by the receiver microphone. By using the measured time taken between the send and receive wave signals and the speed of sound, the distance between the sensor and the object can be calculated.

The main difference between the operation of ultrasonic and infrared sensors is that ultrasonic sensors use sound waves, and infrared sensors use infrared waves in operation. Infrared light is more directed and narrow which enables it to be useful for flat surfaces, while sound waves can handle non-flat surfaces which are more practical for object proximity detection. In addition, ultrasonic sensors have a wider detection range of about 40 degrees. The Parallax Ping ultrasonic sensor operates at 40 kHz. This is beyond the human hearing frequency range and will cause no disturbance in public. Moreover, the industrial noise is usually at hundreds of kHz in frequency. This means that it will not affect the performance of the ultrasonic sensor [**3**]. Hence, Parallax Ping ultrasonic sensors were chosen for the detection part of this project instead of infrared ones.

Figure 8: Parallax Ping Ultra Sonic Sensor [8]

Vibration Motor

Upon successful detection of object proximities with the smart stick, the visually impaired must be notified of the distance ranges via an alerting feedback. Headphone notification is a good candidate due to the broad amount of information that can be delivered. A variety of outputs sounds can be used to identify different distance proximities, which may confuse the visually impaired due to its more complex learning curve. On the other hand, a vibration motor as illustrated in Figure 9 is simpler to understand for children and elder people. Also, it operates more effectively in noisy areas where the sound signals are hard to hear and also for unfortunately visually impaired and deaf people. Hence, vibration motors were chosen for the alerting stage of the smart stick project.

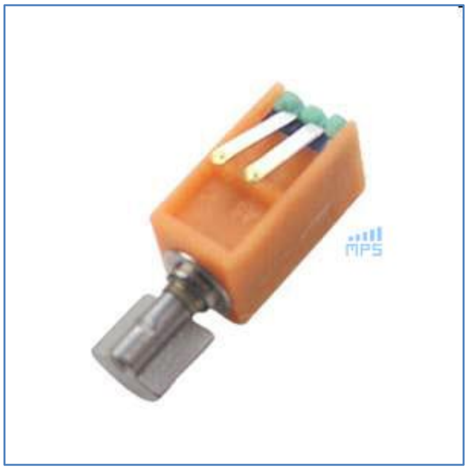


Figure 9: Sample Vibration Motor [9]

Manual Trigger

A touch sensor was considered as manual trigger for the project. However, upon closer examination, a push button was determined to be a better alternative, for it allowed the user to acknowledge when the button has been pressed. In addition, the push button is simpler and has less chance of error when executing the push. This is especially important as this button signifies emergency and it will alert the authorities.

Emergency Module

The emergency module should be able to successfully notify the authorities and identify the location of the blind person in need of help. The first proposed way is to use an FM Transmitter Module to transmit a help signal once it is triggered. Another way was to use a GPS/GPRS/GSM Module shown in Figure 10 which has built in GSM and GPS capabilities as well as a small antenna. It also operates on existing infrastructures and provides an accurate location coordinate for the vision stick. In addition, the GPS/GPRS/GSM Module allows for flexible modes of operation such as different degree of help. For instance, one mode can be to send an SMS to the police for help, and the other is to send an SMS to the user's family to find the visually impaired person. Hence, the GPS/GPRS/GSM Module provides a better solution for the visually impaired.

Figure 10: GPS/GPRS/GSM Module [10]

3 DETAILED SYSTEM DESIGN

In this section, the three main parts of the vision stick, the detection and alert system, the emergency system, and the renewable energy generation, are discussed, explained and analyzed in more depth. Moreover, another section illustrates some extra features that were added to the design. Experimental results are also presented with a current practical solution.

3.1 Detection and Alert System

3.1.1 System Architecture and Flowchart

The system architecture of the detection and alert system is summarized in Figure 11. As shown, the detection and alert system uses PING))) ultrasonic sensors to detect surrounding obstacles. The signals are sent to the Arduino Mega microcontroller to assess the situation. The feedback is sent to the user through a vibration motor to alert him or her from noticeable-size obstacles.

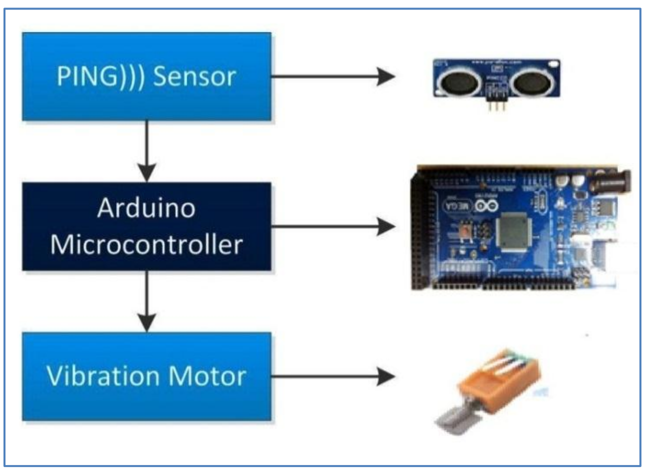


Figure 11: Detection and Alert System Architecture [7] [8] [9]

The process of detecting obstacles and alerting the user accordingly is illustrated in Figure 12. As seen in the flowchart, the system starts by powering the microcontroller and runs in a continuous loop. In the loop, the ultrasonic sensors continuously sense the surrounding objects using the ultrasonic transceivers and the signals are fed into the microcontroller. Next, the distance of the object is computed and compared to the predetermined feedback ranges. If the computed distance falls within the ranges, the user is alerted. Otherwise, the next distance is computed and compared.

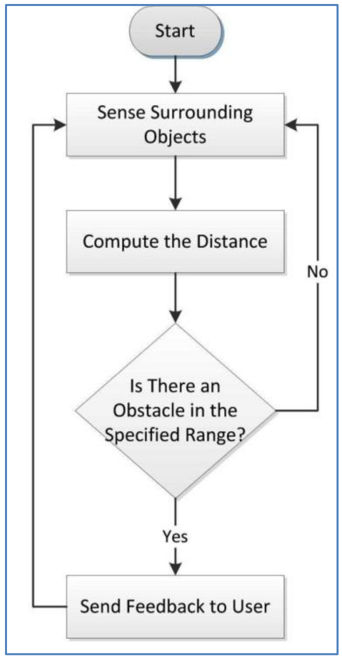


Figure 12: Detection and Alert System Flowchart

3.1.2 PING))) Ultrasonic Sensor

3.1.2.1 Communication Protocol

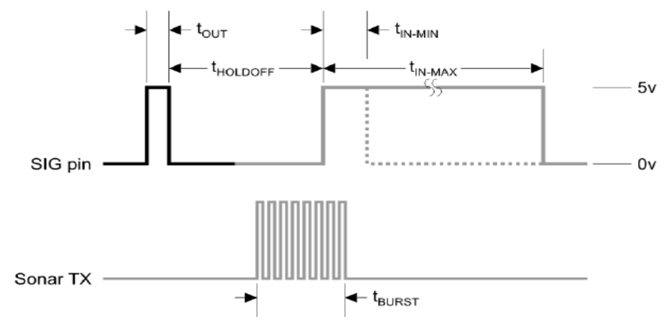
The principle behind ultrasonic sensors is that they transmit sonar waves and receive their reflection of an object. The time difference between transmitting and receiving the wave is used to calculate how far the object is from the sensor using the following formula:

$$\boldsymbol{Distance} = \frac{1}{2}\, \boldsymbol{v} \times \Delta \boldsymbol{T} \qquad \text{(Eq. 1)}$$

Where:

- $\boldsymbol{v}$: The speed of sound in air which is approximately equal to 340 m/s
- $\Delta\boldsymbol{T}$: The measured time difference is seconds

The PING))) sensor operates in the same manner as explained above. Initially, it requires a trigger pulse from the microcontroller in order to send a short 40 kHz burst. After the burst is reflected off the object and an echo is detected, the sensor sends an output signal to the microcontroller indicating the end of the pulse. The length of the pulse provides the required information which is time. Figure 13 illustrates PING))) sensor's pulses meanings and the limitations on the pulsation durations.



	Host Device	Input Trigger Pulse	t_{OUT}	2 µs (min), 5 µs typical
	PING))) Sensor	Echo Holdoff	$t_{HOLDOFF}$	750 µs
		Burst Frequency	t_{BURST}	200 µs @ 40 kHz
		Echo Return Pulse Minimum	t_{IN-MIN}	115 µs
		Echo Return Pulse Maximum	t_{IN-MAX}	18.5 ms
		Delay before next measurement		200 µs

Figure 13: Communication Protocol of PING))) Sensor [11]

3.1.2.2 Sensitivity Analysis

The PING))) sensor is one of the major components of the design. In order to have a better understanding of the behavior and limitations of the sensor, sensitivity analysis was done on the sensor. This analysis helps in realizing the response of the sensor to different objects and enhancing the search for errors at later stages of the design. In this analysis, several variables in objects were identified that were thought to have a direct effect on the ultrasonic wave reflection; hence, the distance readings. The affecting variables include shape, dimensions, material, and color of the object. The method of One-Factor-At-a-Time (OFAT) was used to test the effect of each of the above-mentioned variables by keeping the rest of the variables unchanged. Three distinctive tests were carried out; namely, shape test, material test, and color test. Moreover, the sensor was tested for common daily objects and the measurements were noted. All of the tests were done under room temperature in a closed environment. The tests compare the real horizontal distances of the object from the sensor with the measured distances.

3.1.2.2.1 Shape Test

In this test, six different objects of same material but different shapes were selected. The dimensions of the objects were close in order to have a valid comparison among the results. Figure 14 illustrates the results of the test. The horizontal axis shows the vertical distance of the object from the sensor while the vertical axis shows the difference between the real and the measured distances. The results show that the reflection surfaces of objects have a great impact on the detection of the object. For instance, a flat surface, represented as a cube in the test, can be detected at longer distances compared to tilted or curved surfaces, represented as a pyramid and a cylinder respectively. A summary of the test results for objects of different shapes is illustrated in Table 1. After analyzing the results, the following conclusion is made: ***the shape or, mainly, the reflective surface of the object greatly affects the PING))) sensor's maximum distance detection.***

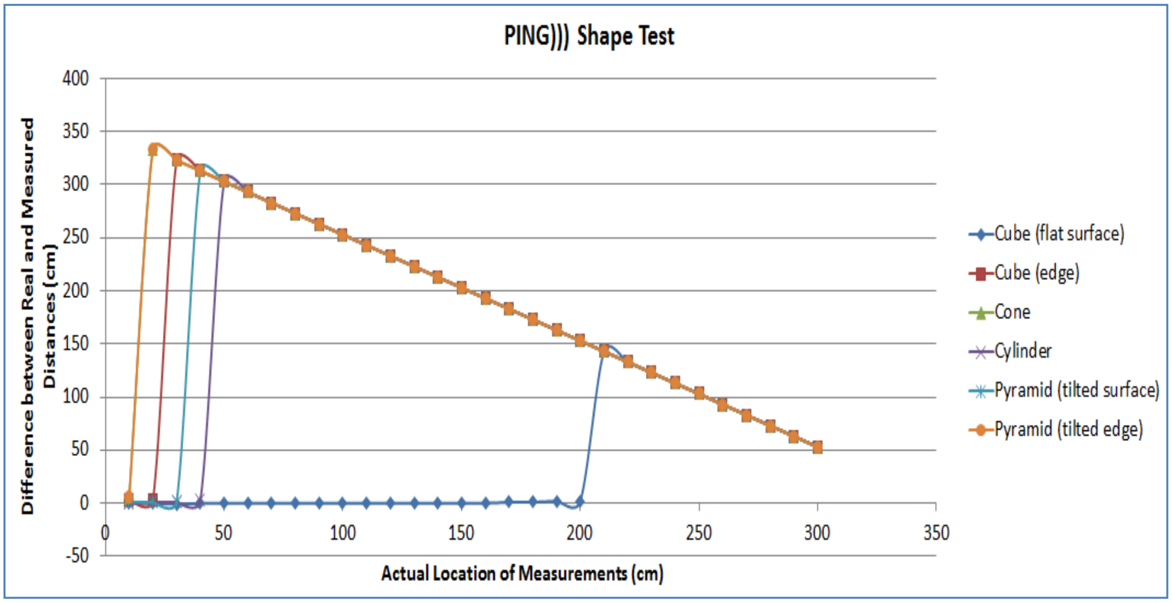


Figure 14: Graph of PING))) Shape Test Results

Table 1: Summary of PING))) Test Shape Results

Shape	Maximum Distance Detection (cm)	Dimensions
Cube (flat surface)	200	4×4×4 cm
Cube (edge)	20	4×4×4 cm
Cone	10	Base: r = 2cm, H= 4.1cm
Cylinder	40	Base: r = 2cm, H = 4cm
Pyramid (tilted surface)	30	Base: 4×4cm, H = 3.7 cm
Pyramid (tilted edge)	10	Base: 4×4cm, H = 3.7 cm

3.1.2.2.2 Material Test

For this test, eight different materials of 4×4cm flat surface objects were selected. The materials were selected according to their common occurrence in daily environment. Detailed results such as the ones for shape test are available in Appendix A. After analyzing the results, the following conclusion is made: ***the material of the object affects the PING))) sensor's maximum distance measurement and slightly affects the accuracy.***

3.1.2.2.3 Color Test

For this test, eight different colors of 4×4cm flat surface objects were selected. Detailed results such as the ones for shape test are available in Appendix A. After analyzing the results, the following conclusion is made: ***the color of the object does not affect the PING))) sensor's distance measurement accuracy.***

3.1.2.2.4 Common Objects Test

In this test, seven common objects from the surrounding environment were selected such as a bag, a ball, and hence forward. The colors, material, surfaces, and dimensions of these objects vary in order to have a rough estimate of the detection ability of the sensor for real daily obstacles. Detailed results such as the ones for shape test are available in Appendix A. After analyzing the results, the following conclusion is made: ***the PING))) sensor can detect objects as far as three meters with very good accuracy.***

3.1.2.3 Defining the Range

In order to model the PING))) sensor while designing the stick, it is important to identify the range at which the sensor can detect object. For this purpose a test was done to identify the maximum range of the sensor using a 4×4cm flat surface paper at room temperature. The results of the test are illustrated in Figure 15 where a second order polynomial regression was used to have a more visually appealing representation of the measured range. In the graph, the PING))) sensor is placed at the origin.

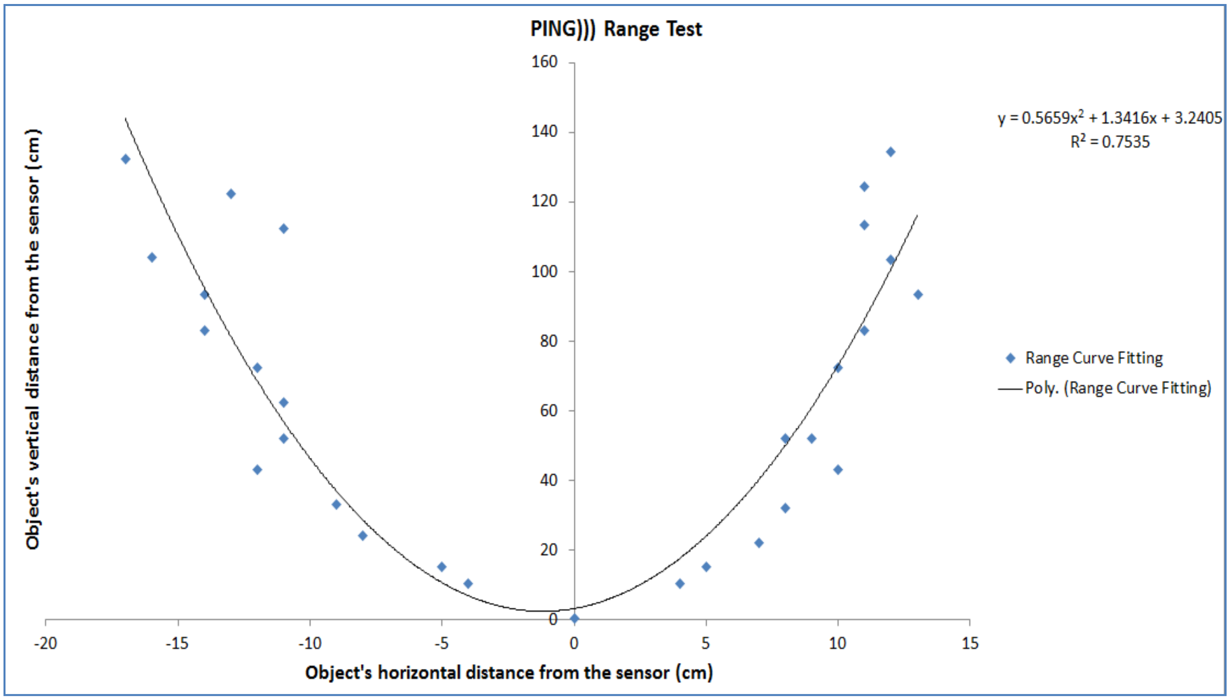


Figure 15: Range of PING))) Sensor

From the above result, the PING))) sensor range can be modeled as depicted in Figure 16.

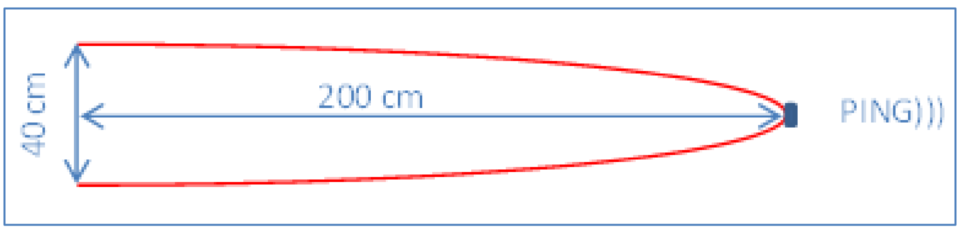


Figure 16: Modeled Range of PING))) Sensor

Although the PING))) sensor can detect relatively big objects up to three meters, only two meters of range were considered. The following reasons justify the two-meter choice:

- From the tests, common objects were detected up to two meters
- Two meters is approximately seven feet which is enough distance to avoid any obstacle
- Giving feedback for more than two meters would cause discomfort and probably confusion for the user since the stick would be vibrating more frequently

3.1.3 Vibration Motor

Vibration motors were considered as feedback tools for alerting the user in case of existing obstacles on the way. The type of vibration motor used is called Eccentric Rotating Mass (ERM) Vibration Motor. It is a DC motor that has non-symmetric mass connected to the rotating shaft. A schematic of the internal structure of the motor is shown in Figure 17.

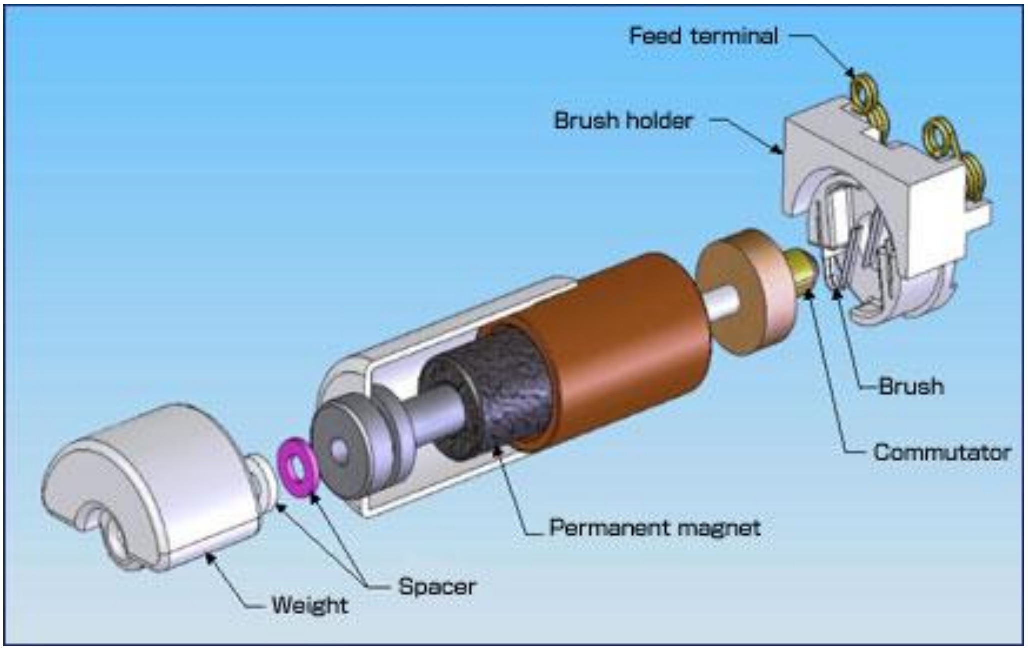


Figure 17: Inner Part of ERM Motor [12]

While rotation, the centripetal force of the non-symmetric mass will lead to a total centrifugal force which would eventually cause motor displacement which is interpreted as the vibration motion [**13**]. Three types of vibration motors were considered which are normally used in mobile phones. Each of the motors was tested at different power supplies and the intensity of vibration was noted for each. Detailed results are shown in Appendix A. Eventually, the vibration motor with lowest power consumption was selected. The IV characteristic of the selected motor is shown in Figure 18.

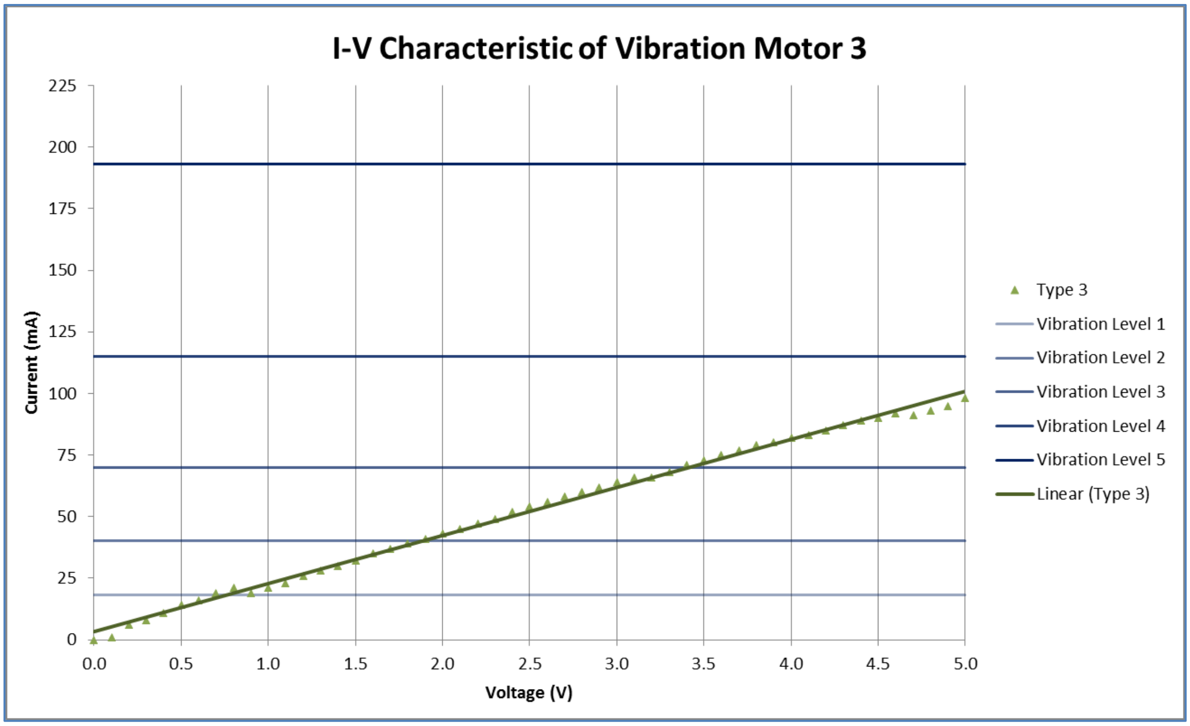


Figure 18: Graph of I-V Characteristics for Vibration Motor Type 3

3.1.4 Arduino Mega Microcontroller

The Arduino Mega microcontroller is the interface that interprets the results read from the PING))) sensor and gives appropriate feedback to the user through vibration motors. Initially, some training was required in order to learn how the microcontroller is programmed using Arduino Software with C language. After familiarizing with the device, codes were written for interfacing with the PING))) sensor and the vibration motor that is discussed in the next subsections.

3.1.4.1 Interfacing with PING))) Sensor

As it was explained in the section of PING))) Sensor Communication Protocol, the microcontroller controls the operation of the sensor by triggering the initial pulse. The block diagram in Figure 19 illustrates the logic used by the microcontroller for controlling the PING))) sensor and calculating the distance using serial communication.

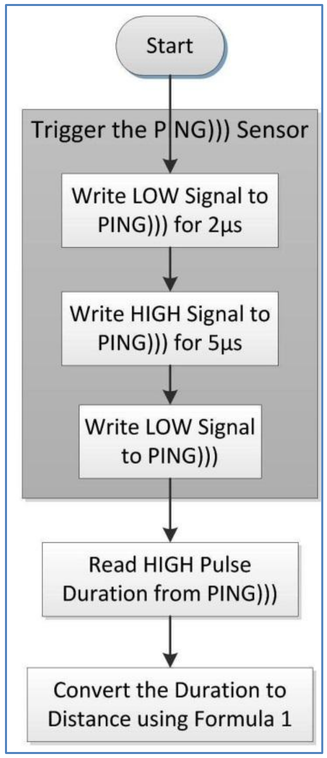


Figure 19: Flowchart for Controlling PING))) Sensor

3.1.4.2 Interfacing with Vibration Motor

The vibration motor has a basic interface where digital I/O pins are set up to be output pins in order to set the motor as either HIGH or LOW with different delays. The result would be vibrating the motor with distinctive pulses for different feedback interpretations.

The feedback that is sent to the user through the vibration motor has different interpretations based on the distance of the detected object. The range of the measured distances was considered to be two meters as discussed before. The two meter range was divided into four sub-ranges and the following feedback signal meanings:

1. Range 1: continuous vibration of the motor
2. Range 2: HIGH signal for 350ms then LOW signal for 350ms
3. Range 3: HIGH signal for 350ms then LOW signal for 700ms
4. Range 4: HIGH signal for 350ms then LOW signal for 1400ms

The selected ranges are illustrated in Figure 20: Vibration motor feedback ranges . The selection of range distances was based on observation and experimentation of different range distances. For a very close obstacle to the user and the stick, range 1 was selected to be 110 cm. For close, distant, and far obstacles, each of ranges 2, 3, and 4 were selected to be 30 cm. Beyond the 2m distance, the vibration motor does not give any feedback indicating that the obstacles are out of range and are not recognizable hazards that would obstruct the user's mobility.

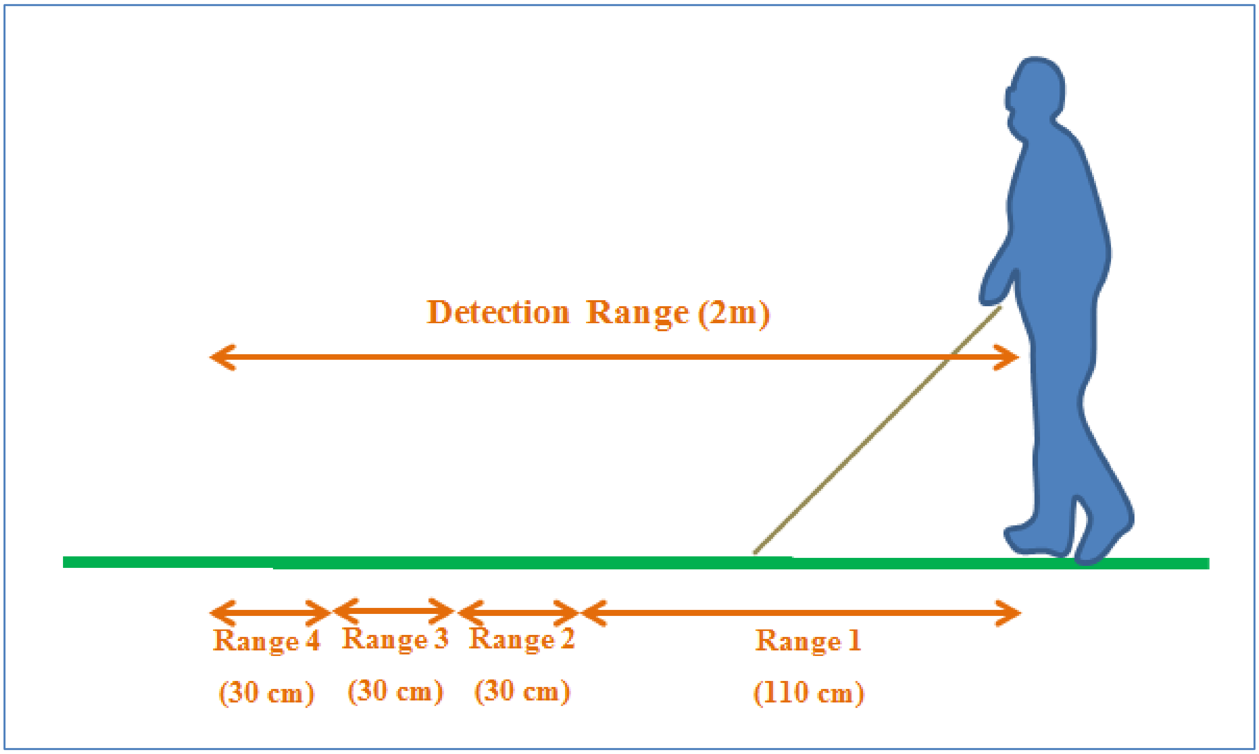


Figure 20: Vibration motor feedback ranges

For the fully commented code of Arduino Mega microcontroller with the PING))) sensor and the vibration motor interfaces refer to Appendix B.

3.1.4.3 Microcontroller Pin Connection

The following pin connections, as shown in Figure 21, are made with the microcontroller in order to control the PING))) sensor and the vibration motor.

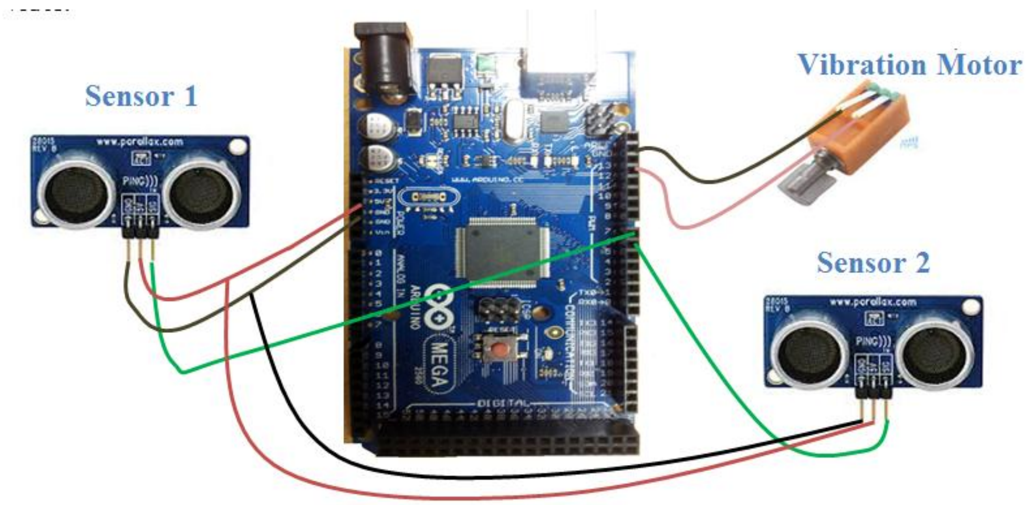


Figure 21: Arduino Mega Microcontroller Connections [7] [8] [9] [11] [14]

3.1.5 Stick Design

3.1.5.1 Length of the stick

Normally, the length of the white cane is adjusted to the height of the user where the length is taken to be from ground to the sternum of the person as illustrated in Figure 22 [**15**].

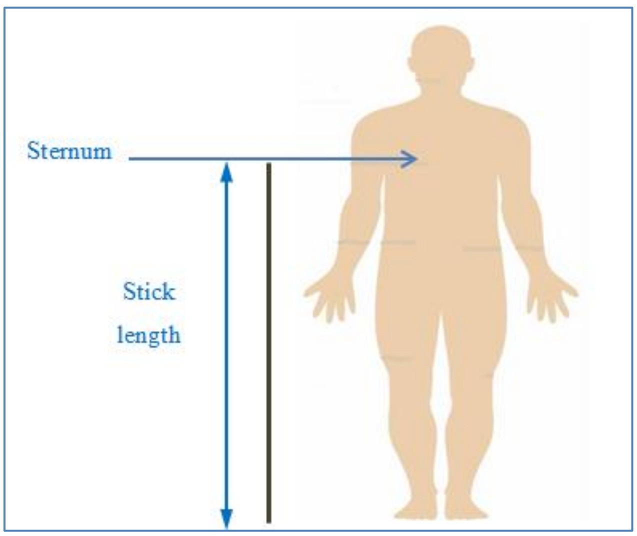


Figure 22: Length of the White Cane with Reference to the User's Height [16]

For the length of the vision stick, few approximations and assumptions were made:

- The average height of a person is considered to be 170 cm **[**17**]**
- The proportion of sternum height to the height of the user was assumed to be 2/3
- From the above numbers, the length of the stick is found: $(2/3)\times 170 = 113.33 \approx 115$ cm
- 5 cm were added to the length as a tolerance factor

From the above analysis, the final length of the stick was chosen to be 120cm.

3.1.5.2 Sensor Placement

Using the PING))) sensor range model and stick average length, an approximate model for the user and the stick can be depicted. This depiction would help in deciding the best sensor placement on the stick.

Initially, the placement of the sensor should be decided. Three different placements for the sensor are illustrated in Figure 23; namely, sensor at the bottom of the stick, sensor at the middle of the stick, and sensor at the top of the stick. Each of the arrangements is assessed below:

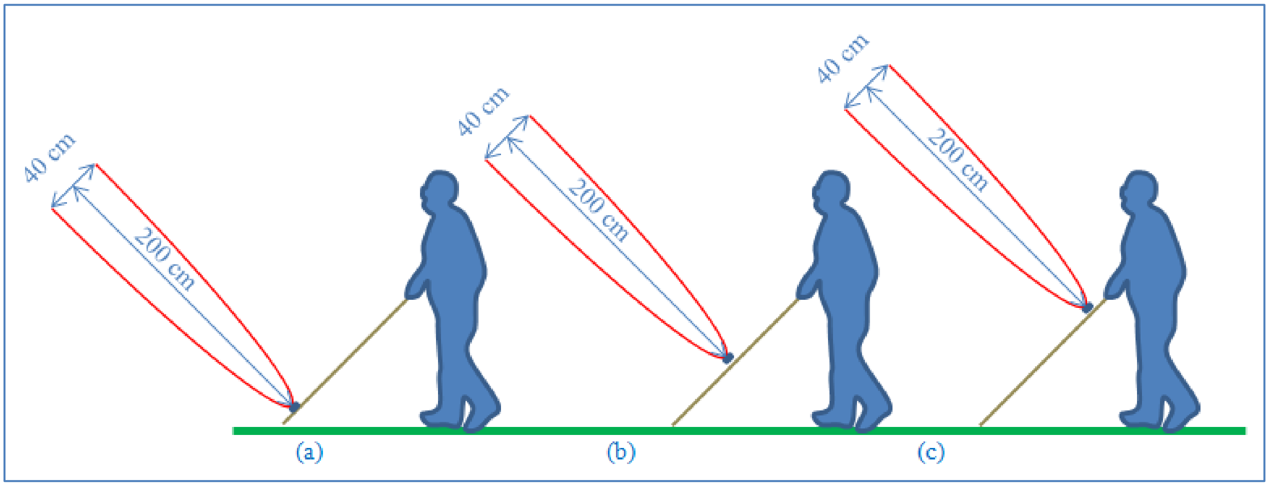


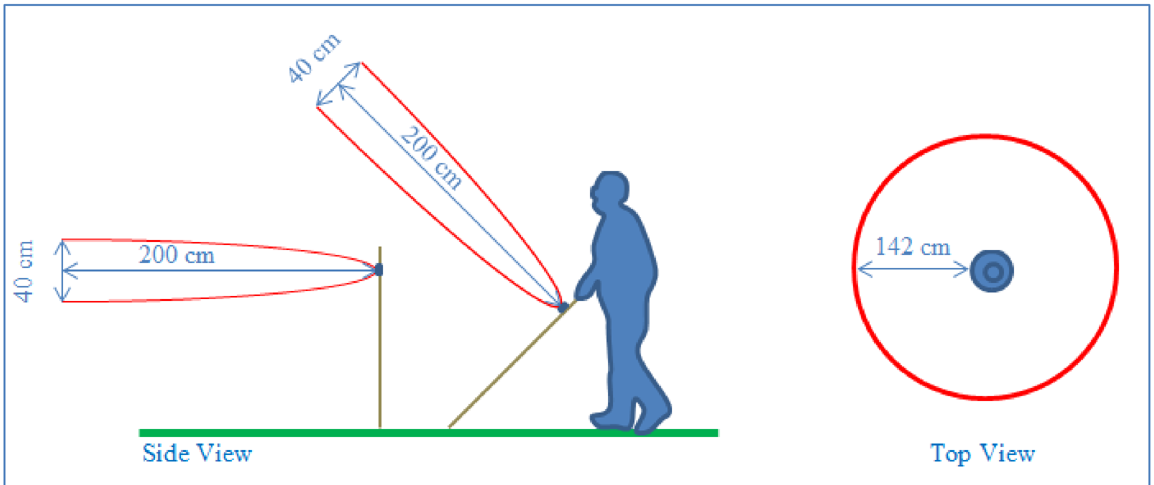
Figure 23: Sensor Placements on the Stick: Sensor (a) at the Bottom of the Stick, (b) at the Middle of the Stick, (c) at the Top of the Stick

- Arrangement (a):
  - The sensor is too close to ground
  - It might be difficult for the user to have a sense of the distance of the obstacles since the sensor is far from him or her
  - The sensor is at risk of damage since the tip of the stick would frequently hit the surrounding objects and is likely to touch different mediums such as water
- Arrangement (b):
  - It might be difficult for the user to have a sense of the distance of the obstacles since the sensor is distant from him or her
  - The sensor is likely to hit side objects so it would be less durable
- Arrangement (c):
  - There would be more control over the direction of the sensor and more understanding of the indicated distances
  - The sensor would be at less risk of damage since it is close to the handle and is not likely to hit surrounding objects; therefore, it would be more durable
  - In case it is needed, the length of the stick can be adjusted from the bottom without interference with the sensor connections

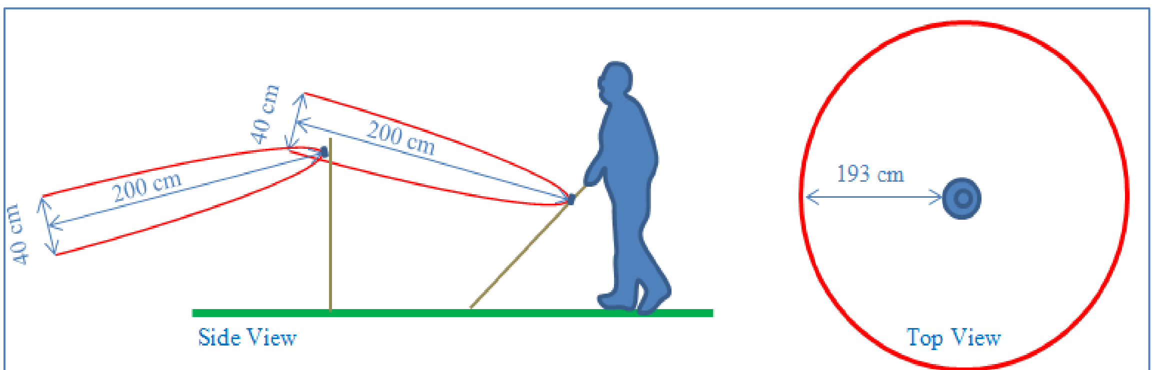
From the above discussion, arrangement (c) was selected for sensor placement on the stick.

3.1.5.3 Sensor Angle

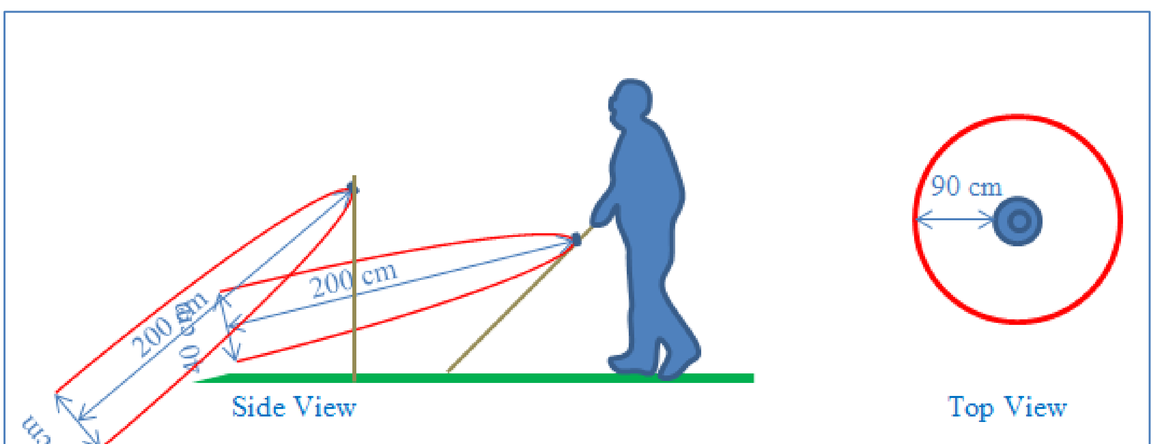
In this section, the angle at which the sensor is positioned is selected. Figure 24 illustrates four different arrangements of sensor angles with reference to the stick. In each case, the side view and the top view of the user are shown. The side view illustrates the direction of the sensor. The top view illustrates the circular range at which the sensor can cover as the user moves the stick radially while standing at the center.


40 cm
200 cm
40 cm
200 cm
142 cm
Side View
Top View

(a)


40 cm
200 cm
200 cm
40 cm
193 cm
Side View
Top View

(b)


200 cm
200 cm
40 cm
90 cm
Side View
Top View

(c)

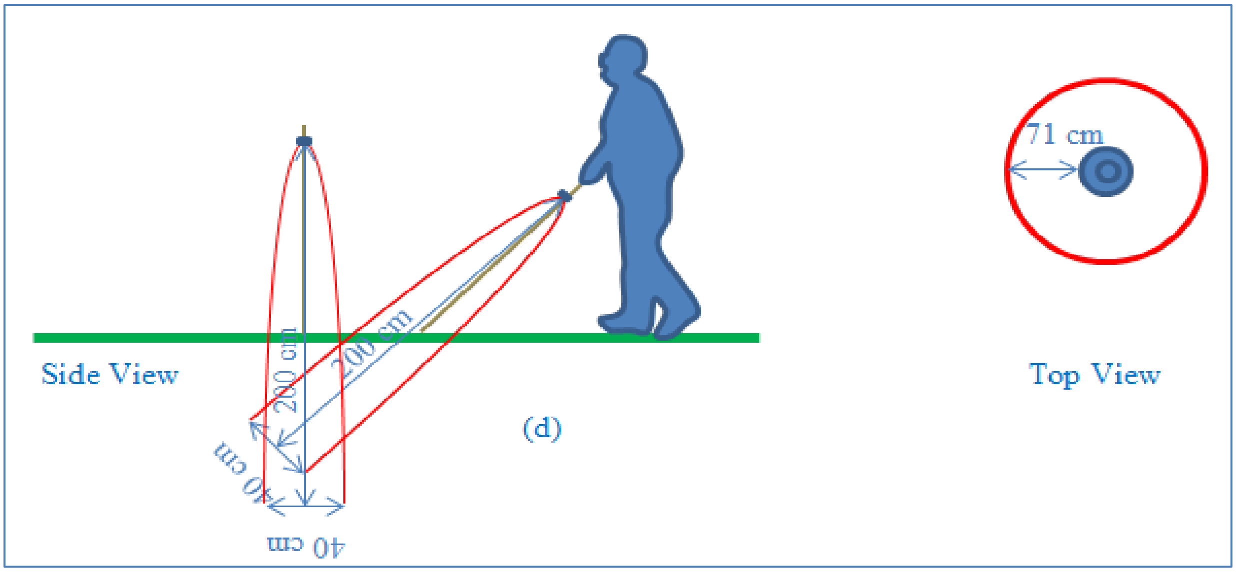


Figure 24: Sensor angle positioning on the stick: angles of (a) 90^0, (b) 60^0, (c) 30^0, (d) 0^0

Next, each of the arrangements in Figure 24 is assessed.

- Arrangement (a):
  - From side view: low objects cannot be detected by the sensor
  - From top view: it can detect a relatively wide range of surroundings
- Arrangement (b):
  - From side view: objects at the level of the user can be detected
  - From top view: a very wide range of surrounding objects can be detected
- Arrangement (c):
  - From side view: lower objects can be detected; however, for certain holding positions of the stick, it would detect the floor
  - From top view: a small range of surrounding objects can be detected
- Arrangement (d):
  - From side view: the floor would be detected instead of objects almost the whole time
  - From top view: a small range of surrounding objects can be detected

Based on the above arrangements, it was decided to use two main sensors with different angles in order to cover the most important and critical areas where the user might come across an obstacle and would require to avoid it. The selection of the angles of the two sensors is described in details in the next few subsections.

3.1.5.3.1 Sensor 1

Sensor Angle

The first sensor was selected to be according to arrangement (b) in Figure 24 for the reasons explained earlier in the assessment of each arrangement. In order to optimize the angle of sensor 1 relative to the stick for this arrangement, a mathematical model was created for the system. The system was solved for the angle that would obtain the maximum radial range as observed from the top view. The results of the mathematical modeling are illustrated in Figure 25.

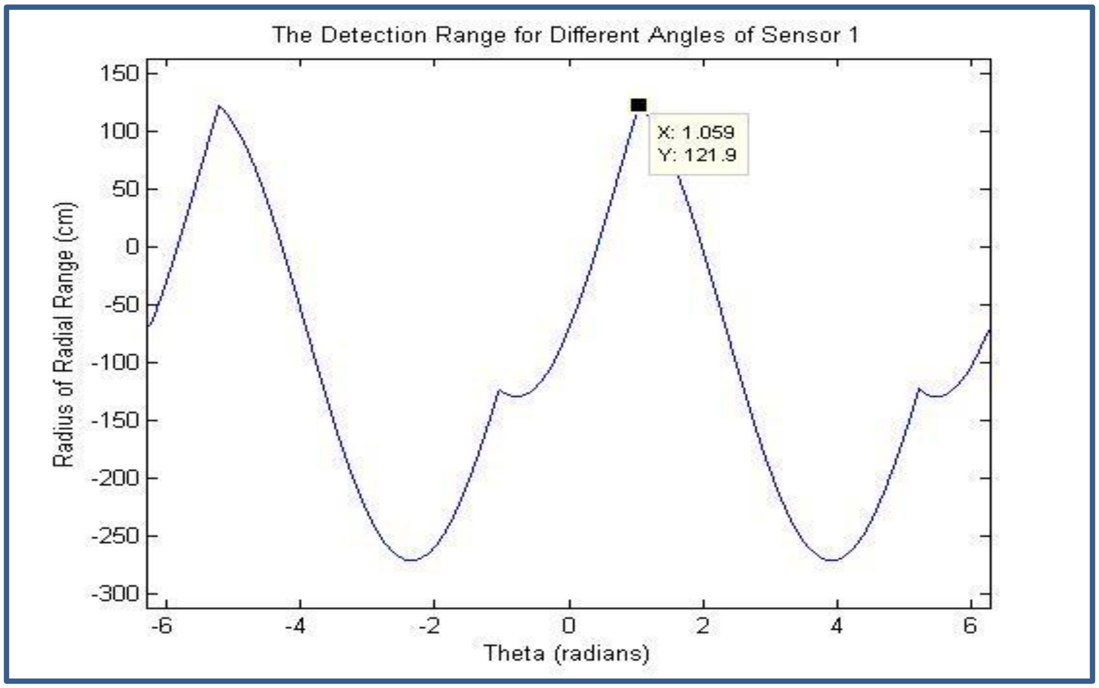


Figure 25. Results of mathematical modeling of detection system for sensor 1

Figure 25 gives a range of angles in radians and the corresponding range distances that represent the radius of the top view range. The angle corresponding to the maximum range that can be detected is 1.059 radians which is 60.6267^0. Therefore, the angle of sensor 1 relative to the stick was selected to be 60^0.

For detailed calculations and mathematical modeling of arrangement of sensor 1 and MATLAB code refer to Appendix E.

Sensor Range Limits

For this sensor, the vibration feedback ranges are defined the same as the ranges shown in Figure 20. It was assumed that the sensor distance measurement of objects is the same as the actual distance of the objects. Therefore the ranges would be as follows:

1. Range 1 limit: 110cm
2. Range 2 limit: 140cm
3. Range 3 limit: 170cm
4. Range 4 limit: 200cm

3.1.5.3.2 Sensor 2

Sensor Angle

For the selection of second sensor, it was required that the system detects low objects that may lead in tripping the user if not detected successfully. Therefore, a second sensor was needed to fulfill this requirement. For this purpose, arrangement (c) in Figure 24 was selected. Once again, the system was modeled mathematically in order to find a relationship between the angle of sensor 2 and the distance at which it can detect objects directly in front of the tip of the stick when secured on ground. The resulting relationship is illustrated in Figure 26.

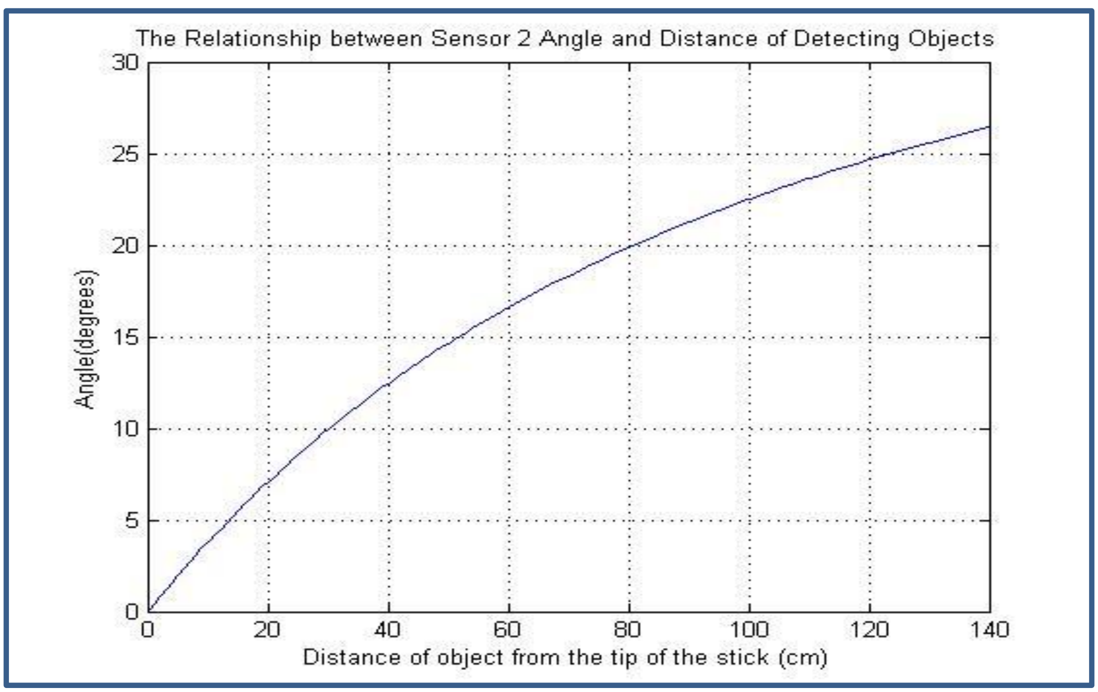


Figure 26. Results of mathematical modeling of detection system for sensor 2

Initially, it was thought that it is enough to detect objects up to 50cm far from the tip of the stick; therefore, the angle corresponding to 50cm in Figure 26 was selected which is 15^0. Upon further experimentation and testing, it was discovered that sensor 2 with 15^0 angle relative to the stick can detect beyond 50cm. In fact, from one of the experimentations using a 12×12×12cm cement cube, the maximum distance at which sensor 2 could detect the object from the tip of the stick was recorded to be 180cm. From further investigation, it was discovered that the reason behind the previous unexpected detection distance was the third dimensional range of the PING))) ultrasonic sensor that was not modeled in Figure 16 due to time and equipment limitations.

Sensor Range Limits

For this sensor, the vibration feedback ranges are different than the ones defined in Figure 20. Since the sensor has a very close angle relative to the stick, it is likely to detect the ground when the stick is held perpendicular to ground. In order to avoid this problem, the sensor was given a null starting range where it does not give any feedback for any objects detected within this range. Through experimentation, it was observed that the stick detects the floor at around 100cm while holding it perpendicular to ground.

Moreover, this time, the actual distances of objects are not the same as the measured ones using sensor 2 due to the positioning angle of the sensor. Therefore, this difference should be accounted for while defining the range limits for the second sensor such that the vibration motor gives meaningful feedback corresponding to what is indicated in Figure 20 and does not cause confusion for the user in comparison to sensor 1.

Using the same mathematical model for sensor 2, the relationship between the actual distances of objects and the measured distances using sensor 2 is depicted in Figure 27. This graph can be used to map the actual distances to sensor distances for more accurate feedback. The relationship illustrated in Figure 27 was verified using experimental data.

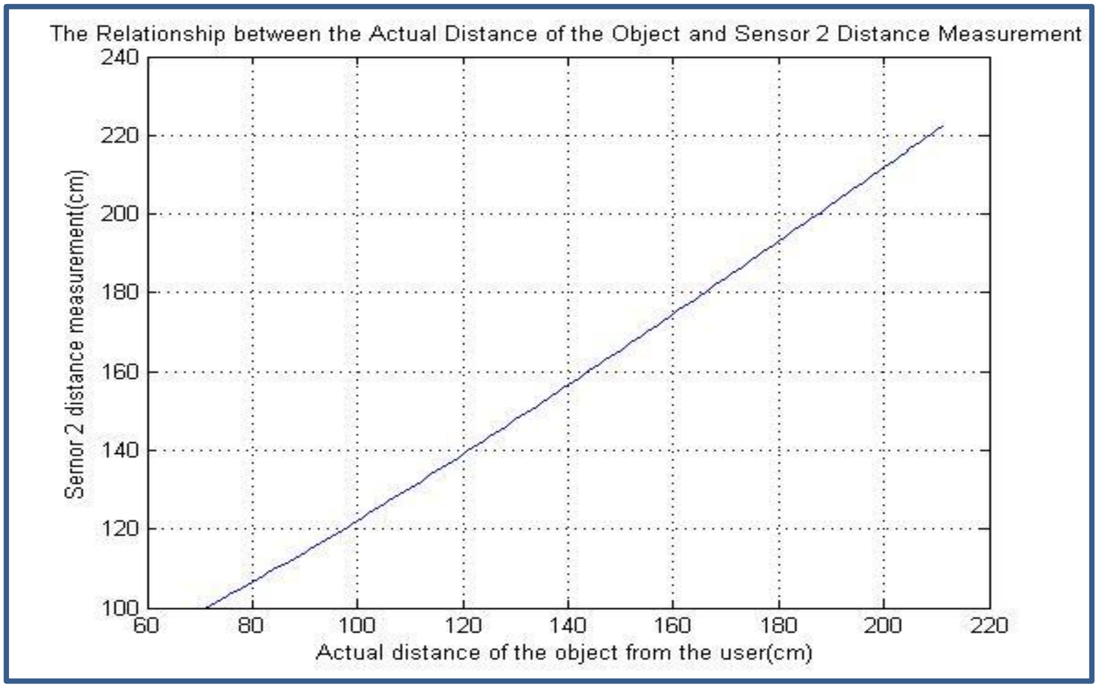


Figure 27. Mapping of actual object distances to measured distances using sensor 2

Using the mapping in Figure 27, the Final selected ranges are as follows:

1. Range 0 limit: 100cm
2. Range 1 limit: 130cm
3. Range 2 limit: 155cm
4. Range 3 limit: 180cm
5. Range 4 limit: 210cm

For detailed calculations and mathematical modeling of arrangement of sensor 2, MATLAB code, and experimental results refer to Appendix F.

3.1.6 Challenges

Throughout the design of the detection and alert system, several challenges were faced. Some of them are mentioned below:

1) Designing experiments for sensitivity analysis: Since there were many variables that needed to be considered, it was a challenge to cover all of them in an effective way. Thus, the method of OFAT was followed. Still, a bigger challenge was to collect objects

that had only one variable changing while the other ones were fixed. In order to solve this issue, considerable time was spent on building objects from scratch that satisfied the required conditions.

2) Sensor placement and positioning: The sensor's location was the most critical part of the design of detection and alert system. The main challenge was that the stick can basically have any position relative to ground depending on how the user holds it. Thus, a design was required to minimize errors such as sensing the floor and giving false feedback. The approach followed to solve this issue was to model different arrangements and to study and assess each one of them in order to come up with the best design. Also, the systems were mathematically modeled and solved for the angles that obtain the desired behavior.

In order to overcome the challenges, creative methods were followed that satisfied scientific reasoning and resulted in satisfactory outcomes.

3.1.7 Ethical Considerations

Similar to any other technological device, many ethical issues and concerns arise when thinking about the usage and implementation of the Self-Energized Smart Vision Stick in the real world. Some of the most important concerns are addressed in the next few paragraphs.

Some people might argue that dependency on technology for detecting surrounding obstacles may decrease visually-impaired people's use of their other senses such as hearing and touch sensing. This concern is valid, since throughout history the visually impaired individuals have demonstrated exceptional skills in using their other senses to overcome their lack of visual sense. However, the presented device is thought to assist the user in making better decisions and is not for him or her to entirely depend on it. It is solely dependent on the user and the way he or she wishes to use the device besides their other senses. According to IEEE Code of Ethics, the designers are required to make decisions consistent with the welfare of the public. Therefore, building a smart system using the current technology is acceptable, as it increases the welfare of visually impaired people by providing them an assisting tool that they can use in their daily lives.

Another concern in this topic would be that the detection system might mislead the user in situations where the traffic light is red and there are no cars in the proximity of the sensor. Knowing about the limitations of the system, the user should take responsibility in similar situations and ask for assistance from other people. The presented device is meant to assist the user to avoid existing obstacles and not identifying potential hazards that are hundred meters away. According to IEEE Code of Ethics, the designers are required to be honest and realistic in stating claims. In this case, the designers do not claim that the stick can replace the visually impaired people's visual sense and allow them to identify all types of hazards. The users should incorporate their other senses such as hearing to make decisions or get help from other surrounding passengers in similar situations.

Other ethical issues pertaining to the vision stick are discussed in the relevant sections.

3.2 Emergency System

3.2.1 System Architecture and Flowchart

The GPS/GPRS/GSM module (TEL0051 V3.0) is the choice of the emergency module as previously mentioned. The GPS/GPRS/GSM module is made up of a SIM 908 chip that has built-in 2G GSM and GPS capabilities. The purpose of the GSM module is to allow the visually impaired to send an SMS message to the emergency contact or authority for help. On the other hand, the purpose of the GPS capability is to allow the outdoor location, longitude and latitude, of the visually impaired to be fetched and sent via SMS for faster help. As it can be seen from the block diagram of the emergency system in Figure 28, the GPS/GPRS/GSM module is manually triggered by the user to pass through the Arduino microcontroller. The manual switch will trigger an interrupt in the microcontroller to halt all operations and start fetching the GPS coordinates then sending it via SMS to the help. The high level flowchart of the overall system is illustrated in Figure 29.

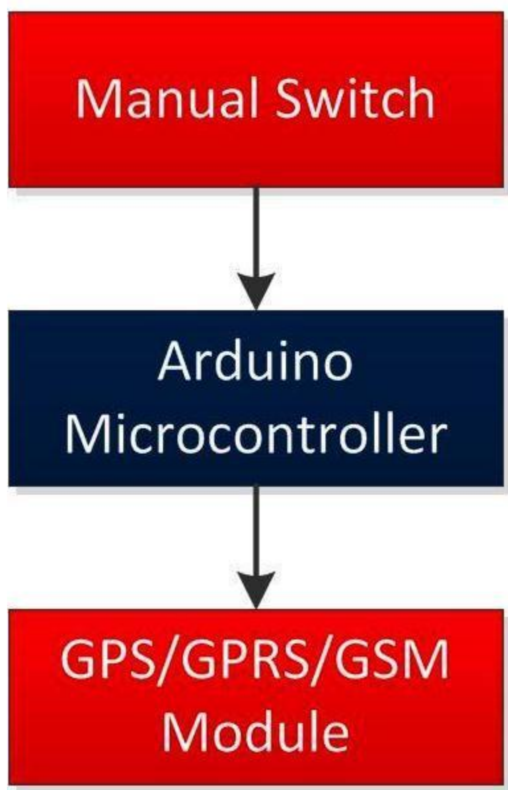


Figure 28: Block Diagram of the Emergency System

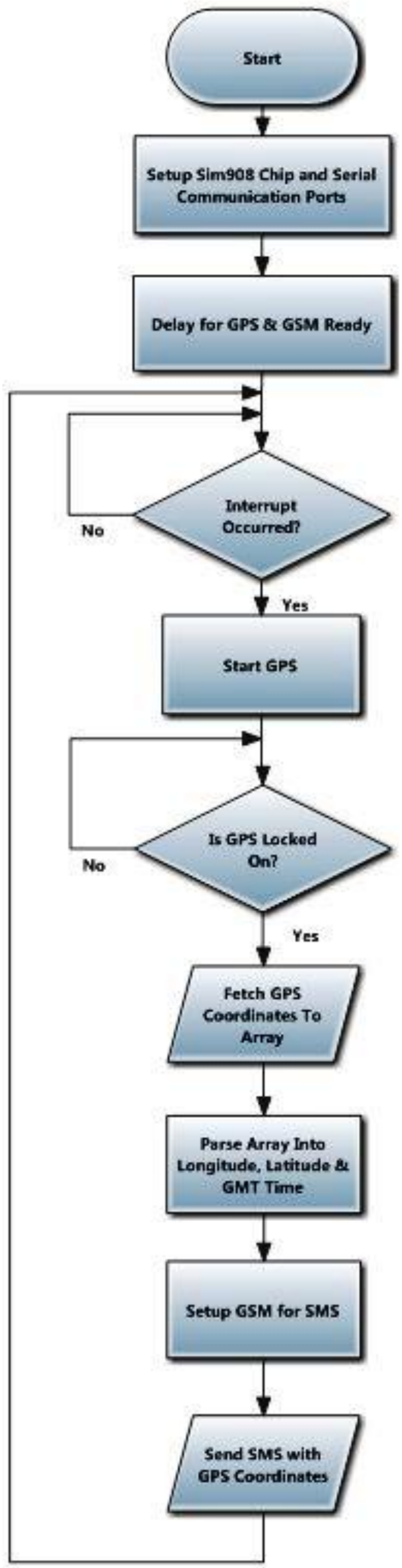


Figure 29: High Level Overall Flow Chart

3.2.2 System Background

3.2.2.1 GSM System

The Global System for Mobile communication, more commonly known as GSM, is a communication standard that is used by 80 percent of smartphones all around the world [**18**]. The United Arab Emirates uses 900 and 1800 MHz frequency bands for second generation GSM [**19**]. The GPS/GPRS/GSM module used for the emergency system supports up to the second generation GSM for sending SMS through the UAE telecommunication network. The third and fourth generation adds advanced internet connectivity that is not necessary for the emergency application. The GSM Network is made of a network of cells, where each cell is a radio tower, known as base station, which can transmit and receive signals to communicate with the GSM module. There are GSM controllers on board the base station which regulates the connecting and reconnecting of GSM module while traveling through different areas shown in Figure 30. By connecting to these towers, the GSM module is able to successfully make phone call, and send and receive SMS [**19**].

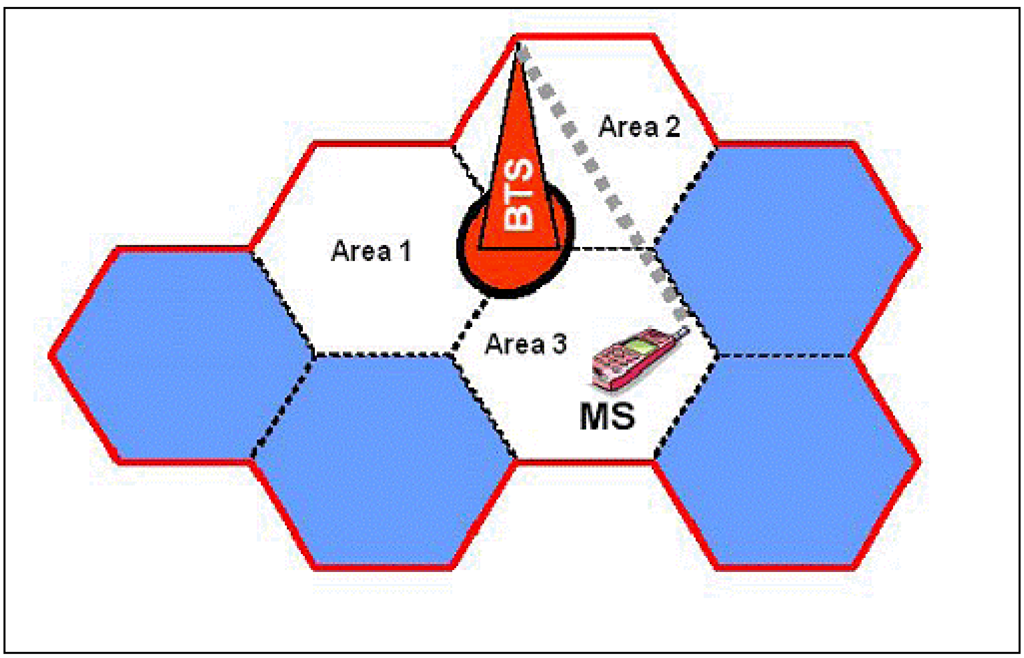


Figure 30: GSM Base Stations [20]

3.2.2.2 GPS System

The Global Position System (GPS) is a navigation system that is used by many from all around the world. It consists of a system of 30 satellites at 20,000km altitude surrounding earth. The networks of satellites are distributed in a way that a minimum of four satellites are available anywhere around the world. In order for the GPS module to find its current location, it needs to be connected to a minimum of three satellites. This allows for locating methodology known as trilateration. As shown in Figure 31, trilateration uses the intersection of a minimum of three satellites areas that pinpoints the current location. In addition, GPS satellites have in board atomic clock that helps it keep accurate timing [**21**]. The GPS has several output formats that can be found on the NMEA GPS format table.

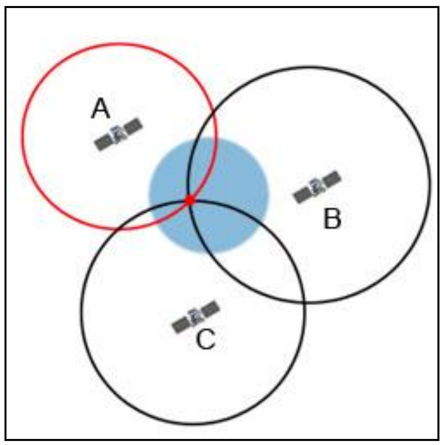


Figure 31: GPS Trilateration [21]

3.2.3 Controlling the GPS/GPRS/GSM Module

The GSM portion of the SIM 908 chip can be controlled using AT Commands. AT is an abbreviation for the word attention and start with the word AT [**22**]. These are a serial of commands used to control modem and where originally came from Hayes Commanded used to control Hayes modems. For the purposes of the emergency module, the AT Commands allows the PC or Arduino microcontroller to communicate with the SIM 908 chip. For example, the AT commands can be used to check if the chip is ready to received commands, send SMS, make calls and establish GPS connectivity and check for its status. Figure 32 shows an example of sending an SMS using AT Commands.

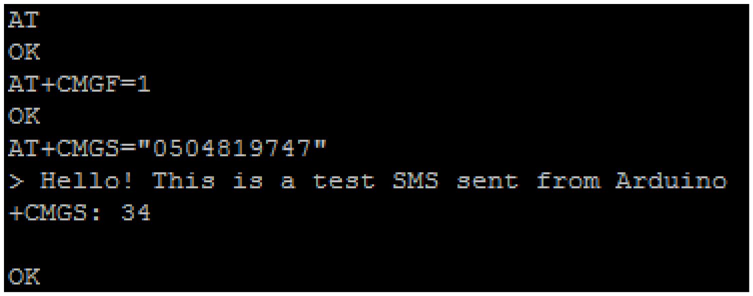


Figure 32: Sending SMS Using AT Commands

3.2.4 Interfacing the GPS/GPRS/GSM Module and its Challenges

Now that the background information about GSM and GPS has been established, it is time to learn how to interface the GPS/GPRS/GSM module with the Arduino. This is where the biggest challenge of this section of the project is presented. From previous experience with the Arduino microcontroller, it was known that there were some documentation issues. However, considerable experiences were gained since the first experience with Arduino, and it was decided that the overall benefits of the microcontroller outweighs the disadvantages. Nonetheless, this means that the issues need to be tackled. This section explains the steps taken in interfacing the GPS/GPRS/GSM module and the challenges that were faced while working with the emergency system as well as the approaches used to tackle the issues.

3.2.4.1 Interfacing GSM & GPS with USB

3.2.4.1.1 Learning the Connection of GPS/GPRS/GSM Module

The first step in interfacing the emergency module is to learn the connections and jumpers on board as illustrated on Figure 33. The GPS Module has two switches. The S1 switch allows the switching between Arduino Mode and USB Mode. Simply put, the Arduino Mode allows the SIM 908 chip to directly communicate with the Arduino microcontroller. On the other hand, the USB Mode allows the SIM 908 chip to semi-bypass the microcontroller and communicates directly with the PC using the USB port. Even at USB Mode, the SIM 908 still needs the microcontroller to prepare it in order to be able to communicate directly with the PC. The difference here is that the SIM 908 is bypassing the Arduino serial port and is directly connected to the PC. The S2 switch allows the switching between Programing and Communication Modes. The Programing Mode allows the Arduino to be program by releasing the emergency module from the controller. On the other hand, the Communication code allows the SIM908 to communicate with either the PC or Arduino based on the S1 selected mode. Finally, there is a jumper at the bottom right allows for the switching between GPS and GSM UART port. Although it is still early at interfacing stage, the first error with documentation has already been spotted. The labeling of S1 and S2 switch was revered in the original Figure 33. This was the beginning of a series of challenges that needed to be overcome.

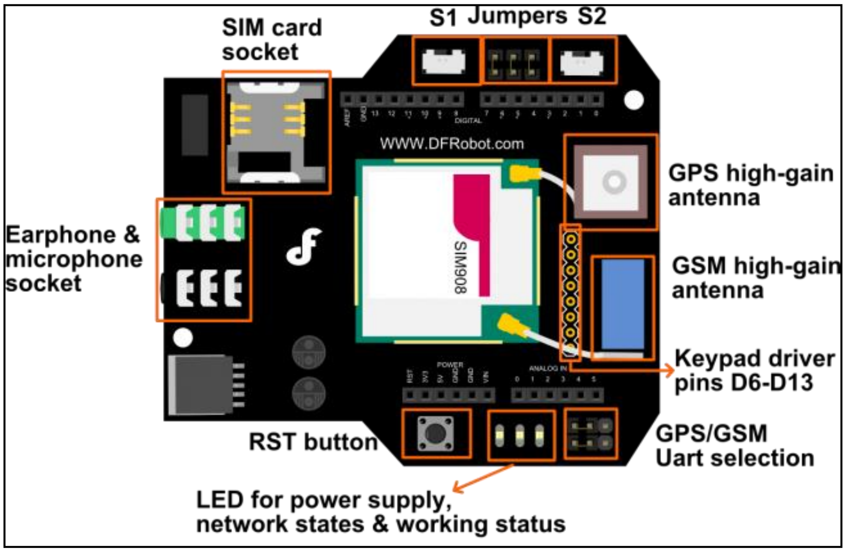


Figure 33: GPS/GPRS/GSM Module Connections [10]

3.2.4.1.2 The Challenge of Random Power Off in USB Mode

The first step in interfacing the emergency module is to make sure the chip works and that it has not been damaged while shipping. Hence, to eliminate the possibility of the error with the Arduino microcontroller code, the emergency module is tested in USB Mode. Theoretically, in order for the emergency module to work, the emergency module should be setup using the code in the Appendix C provided in the official documentation, S1 switch to USB Mode, the SIM Card inserted into socket shown in Figure 33, GSM/GPS jumper is sent to GSM, and enough time was given for the module to get ready. Then, once the emergency module is ready, a series of AT Commands can be sent to control the device via the Arduino serial monitor. Nonetheless, a problem struck from the first attempt to communicate with the device. The SIM 908 chip kept on randomly switching off at different time occasions of the code. At first, it was believed that the code provided was faulty as the chip seems to switch off after a couple of seconds. There was a correlation between the delays in the code with the amount of time that the chip will remain on before suddenly turning off. Though, after further experimentation, it was noticed that the correlation was random at best.

3.2.4.1.3 Research for the Solution

Despite the peculiar behavior, some consistent pattern was noticed. During the time that the chip was on, it was responsive to the AT commands sent via the serial monitor. However, it fails to successfully send and SMS or dial a test phone call. Therefore, research was done in an attempt to find similar occurring problem across the internet. Unfortunately, little was found that was relevant to solving the random switching off issue. In addition, other open source code was tested on the emergency module in an attempt get the device to work but each code online had its own set of problems with the module. This most likely is attributed to the fact that the emergency module at hand is a version 3, which is new. Most of the sample code available online where written for version 2 of the same module. The only version 3 sample code was the one provided in the official documentation that did not work.

The fact that the GSM AT-Commands did not work in the short period the chip was on lead to the conclusion that there was a problem with GSM part of the SIM 908 chip. Hence, the SIM Card was removed from the module and the documentation sample code was loaded. The chip was then able to successfully communicate with the PC via USB mode. Further testing was conducted and it was concluded that whenever the SIM Card was inserted, it prohibited the functioning of the SIM 908 chip. This was a serious concert and the SIM Card is a vital component of the emergency system. Initially, the reason for the SIM Card issue was thought to be the consequence of the SIM Card failing to connect to one of the cell phone towers. Hence, experts such as the lab engineer were consulted. The expert opinion is that the chip was somehow damaged during transport especially since most people on the web did not face the same problem. Moreover, a help request email was sent to the manufacturer of the emergency module but it yielded no result as it was posted an entry to the manufacturer's forum.

3.2.4.1.4 Breaking the Big Challenge into Smaller Challenges

At this point, a lot of time has been spent attempting to interface the module. At the edge of considering an alternative module, it was decided that a different strategy need to be taken to solve this issue. Hence, it was decided that the bigger problem of interfacing the whole emergency module can be broken down into section. Getting the GPS to work became the first goal. The choice GPS interfacing was made because it eliminated the need of using the problematic SIM Card. Thus, the GPS was interfaced via USB Mode by following the proper steps and sending the AT Commands shown in Figure 34. This yielded a successful result as the GPS managed to connected and obtain the correct GPS coordinates as seen on Figure 35. It is important to note that the GPS functionality was controlled from the GSM serial port while the output of the GPS can be obtained from the serial port. This switching of port was done by flipping the GSM/GPS jumper.

```
+CFUN: 1

+CPIN: READY

GPS Ready

Call Ready
AT+CGPSPWR=1

OK
AT+CGPSRST=1

OK
```

Figure 34: GPS USB Mode Input

```
$GPGGA,160101.787,,,,,0,0,,,M,,M,,*47

$GPGGA,160102.787,,,,,0,0,,,M,,M,,*44

$GPGGA,160103.782,2505.528795,N,05509.375247,E,1,3,2.90,126.806,M,-26.848,M,,*75

$GPGGA,160104.882,2505.525653,N,05509.376898,E,1,3,2.90,51.068,M,-26.848,M,,*41
```

Figure 35: GPS USB Mode Output

3.2.4.1.5 Solution to the Random Power Off

Once the USB GPS interfacing was completed successfully, it promoted more confidence that the chip was working fine and the challenge of interfacing it successfully is possible. Therefore, a more thorough research was conducted for the SIM 908 in general and not for purchased emergency module. One forum suggested that the problem with SIM 908 chip design is that when the GSM antenna is active it drops the voltage from 4.2 to 4.1V. This drop of 0.1V causes the chip to shut down. A capacitor was recommended to solve the issue. However, since the emergency module is prefabricated, this solution was not possible. Consequently, a different version of the Arduino board was used to test the chip and it resulted in the similar behavior. Nevertheless, when an external 9V power supply was used to power the arduino microcontroller, the emergency module worked seamlessly in USB mode. It successfully managed to send an SMS using the AT-Commands shown in Figure 36. The screenshot of phone receiving the message is illustrated on Figure 45.

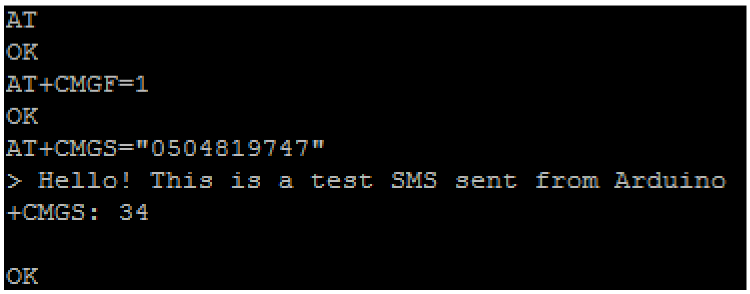


Figure 36: SMS USB Mode Input

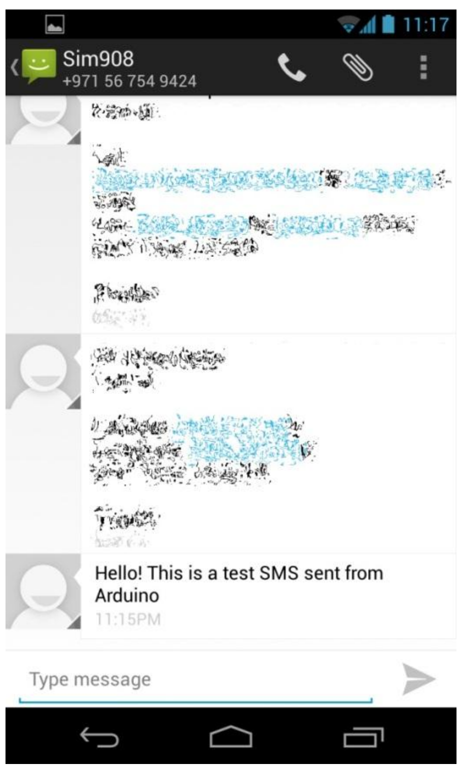


Figure 37: SMS USB Mode Output

3.2.4.2 Sending SMS using Arduino

The second step in interfacing the emergency module is to be able to successfully send SMS using the Arduino microcontroller. In order for Arduino to communicate with the SIM 908 chip, it needs to be Arduino Mode as supposed to USB mode. This is accomplished by switching the S1 switch to Arduino Mode. This returns the communication port to the Arduino microcontroller and it’s no longer bypassed. The difference between USB mode and Arduino mode is that in USB mode the AT-Commands are sent from the PC typed by the user. On the other hand, on Arduino mode, the AT-Commands are sent directly from the microcontroller and no user interference is needed. Along initial testing it was discovered that unlike in USB mode, when the SIM 908 chip is operating on Arduino mode, either the GSM or GPS communication port should be software enabled. This presented a small challenge to learn how control each communication port. The sample code provided on the documentation provided in the Appendix C worked without complications this time which simplified the processes of learning how to control the port.

3.2.4.2.1 Using Multiple Ports to Send SMS using Arduino

Because there are two communication ports, more than one serial port should be used. Surprisingly, when the port for the GSM from Arduino code was changed, it stopped working. At first, it was thought that perhaps the modified serial code was wrong as it the original code worked for the first serial port. Later, it was discovered that the manufacturers of the GPS/GPRS/GSM module have flipped the TX and RX pins while keeping it in the same location. Essentially, the ports are located on top of the original TX and RX pins but are internally flipped and not mentioned in the manual. Once that was discovered, the problem was rectified, and then a SMS was successfully sent from the second serial port without problems. One additional test was performed at this stage. A test phone call, shown in Figure 38, was made as this might be a future consideration as an additional safety feature.

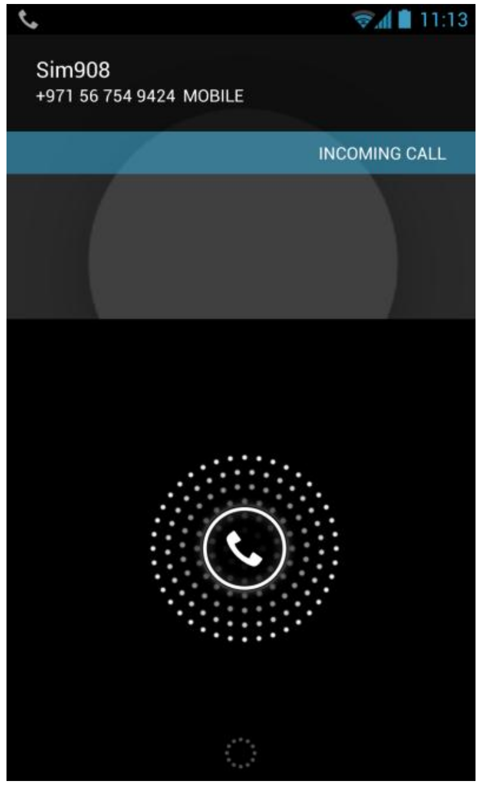


Figure 38: Arduino Calling

3.2.4.3 Attempting Interrupt with Arduino

It is important that the Arduino microcontroller response to interrupts as it will help lower the power consumption. Hence, a test was conducted to test if GSM can be triggered via a switch button. There are four triggers types for interrupt on the Arduino Mega microcontroller which are the change of value, low value, rising edge and falling edge. Unfortunately, the interrupts on the microcontroller was behaving erratically. To test the behavior, the microcontroller was connected to external power supply and USB stable while performing the interrupt trigger. The USB cable allowed the output of the number of times the interrupt handle was triggered to be outputted to the screen. The conclusion was that when a traditional switch was used, the interrupt got triggered multiple times. Sometimes it even triggered hundreds of times per second, especially if the connection was floating. With furtherer experimentation, it was decided that the switch need to be replaced with a push button for more stability. This allowed the rising edge and falling edge of the interrupt to detect and it worked as expected. Nonetheless, once the USB cable was disconnected from the Arduino and it was left to be solely powered by the 9V power supply, the interrupt failed. The next day, it was noticed that 9V power supply had suddenly died. This might have been a reason for the unpredictable behavior of the interrupt when used alone. Nevertheless, it was decided that more important aspect of the emergency system should be interfaced first and the trigger interfacing is delayed to later in the project.

3.2.4.4 Fetching GPS Coordinates with Arduino

3.2.4.4.1 GPS Not Responding to AT Commands

The third step is to learn how to fetch GPS coordinate with Arduino. Although this was initially thought of as a simple task, it turned out to be the biggest challenge of interfacing the Arduino microcontroller. Similar to interfacing with the GPS with USB mode, it was thought that the GPS can be controlled from the GSM serial port then the output is obtained from the GPS serial port. Unfortunately, the Arduino interfacing did not work in the same fashion. Even though the chip received the AT Commands to start GPS, nothing happens. Many days where spent attempting to tackle this problem especially around the area of software GSM/GPS communication port enabling but it yielded not result. To add to the mishap, there was no online code that showed how to interface the GPS with Arduino except for an example for version 2 of the GPS/GPRS/GSM module. The version 2 code was tested but the emergency module was stuck at a standstill.

3.2.4.4.2 Identifying the Problem

A few days into GPS Arduino interfacing research, the manufacturers of the emergency module posted an example of how to interface GPS with Arduino in the official documentation. The code regrettably did not work. It was trapped in the same location that the version 2 halted. The way the GPS interfacing worked was interesting as it has software enabled the GSM port to send AT-Commands to enable the GPS and then software switched to GPS port to allow for GPS output. The logic flow of the code seemed reasonable, yet the port did not work. Nonetheless, it was observed that when the board was reset, it outputted the correct GPS coordinates. This lead to the conclusion that the code somehow controlled the GPS successfully and but fails to fetch the information to be displayed. Among further testing, it was discovered that if once the TX pin was removed, the information will output successfully. Yet, if the TX pin was not used from the beginning, the GPS will not be able to fetch GPS coordinates. The professor was consult on this issue and he suggested that one such similar issue happens, voltage levels are usually the same. This led to the suspicion that the code was somehow reading and writing from the same serial pin at the same time. Therefore, the code was thoroughly investigated and debugged until the suspicion as indeed confirmed. The code is attempting to read and write at the same time putting the system on halt.

3.2.4.4.3 Solving the Problem

3.2.4.4.3.1 Controlling Data Flow

The part of the dealt with interfacing the GPS was taken apart from the whole documented code which included parsing the GPS data. The interfacing portion of the code was modified to read and write to two separate ports. This eliminated the problem and the GPS module can be solely controlled by the Arduino microcontroller. However, when the part of the code used to parse the GPS coordinates was introduced to the code, the GPS output came to a halt. Research was conducted on this matter and it was suggested that the port was overflow by data and the microcontroller fails to read it. Hence, the output of the GPS module was limited to the GPGGA GPS format output instead of outputting all 7 supported formats all at once. There was no particular reason for the choice of GPGGA format because all formats provided the data needed. However, GPGGA was chosen because the sample code used the particular format in parsing. Nevertheless, the code still did not work leading to the conclusion that there is something else that is wrong with the code.

3.2.4.4.3.2 An Alternative Approach

The SIM 908 manual was then examined to see if there are settings that can help in reading the GPS module's output. It was discovered that there is an AT Command that returned the GPS coordinates. This means that only a GSM serial port is needed in order to control and get GPS information from the device. Hence, a difference approach was taken to fetch the GPS coordinates. The AT Command was initially tested on the USB mode and positive result was obtained. However, in Arduino mode using the traditional serial port, the port does not have access to the response of the AT Command. The mystery is that when the serial read function is used, only the commands sent from the Arduino to the chip can be read. There was no record of the AT Command response that is necessary to using this method of fetching data. A lot of experimentation was conducted, but it yielded no result. Later, a different serial port was used in an attempt to obtain the AT Command response. An unexpected result occurred. The other serial port on the Arduino saved both the first couple of transmitted AT Commands and its response.

This led to the deduction that the Arduino mega has a shared buffer for both transmitting and receiving information. Because only the first couple of transmitted AT Commands and its response can be saved, it was suspected that there was a problem with the buffer not clearing once it is full. Hence, a serial flush command was attempted to remove all unnecessary information. Regrettably, as of Arduino 1.0 development environment, the serial flush command has been replaced with another one keeping the same syntax. Therefore, a different way of clearing the buffer was needed. After some investigation, a while loop was used to read all the data in the buffer to clear it. Once the buffer was cleared, the AT Command response was successfully obtained from Arduino leading to the successful way of obtaining the GPS coordinates. However, a problem occurred when trying to fetch the GPS coordinates. While using the Arduino to send AT Command to get a response, the GPS appeared not to be able to connect to the satellite as the coordinate response is always zero. Along further testing, it was discovered that the array used to store the GPS data was not resetting. Therefore, it was outputting the same first GPS response giving the illusion that it was not working. Once the issue is resolved, the GPS coordinates was successfully obtained as shown in Figure 39. Appendix C provides the final working code.

```
2,101724,0.000000,N,0.000000,E,0,0,99.989998,18
2,101727,0.000000,N,0.000000,E,0,0,99.989998,18
2,101730,0.000000,N,0.000000,E,0,0,99.989998,18
2,101733,2505.547624,N,5509.333442,E,0,3,4.2328
2,101736,2505.535976,N,5509.362357,E,1,3,4.2284
2,101740,2505.534611,N,5509.364954,E,1,3,4.2320
```

Figure 39: GPS Working Arduino

3.2.5 Interface the Emergency Push Button.

The first attempt at the interfacing the emergency button was unsuccessful because of the random execution of the interrupt. Hence, a counter was placed within the interrupt handler into to keep track of the number of times the interrupt was executed. The counter was monitored on the serial monitor and it was discovered that when the emergency button was pressed, the interrupt was executed eleven to twenty times at once. The reason for this execution is because the microcontroller is detecting falling edge to trigger the interrupt. Because of the mechanical noise from the push button, every press generated a random number of falling edges. A debouncing circuit found on [**23**] was used in order to generate a single falling edge per button press. As it can be seen on Figure 40, a 10uF capacitor with an 11kΩ resister was used to generate the graph shown in Figure 41. The circuit will output zero volts until the button is press. This button press will allow the capacitor to discharge creating a high voltage. Once the button is released, a smooth falling edge is created. Hence, the microcontroller will detect only a single falling edge allowing for proper execution of the emergency trigger.

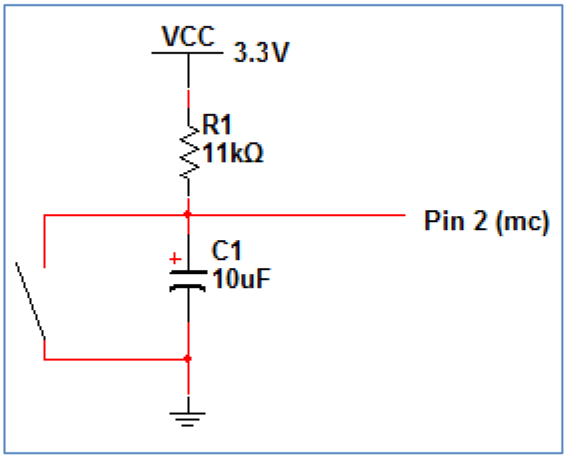


Figure 40: Debounce Circuit Switch

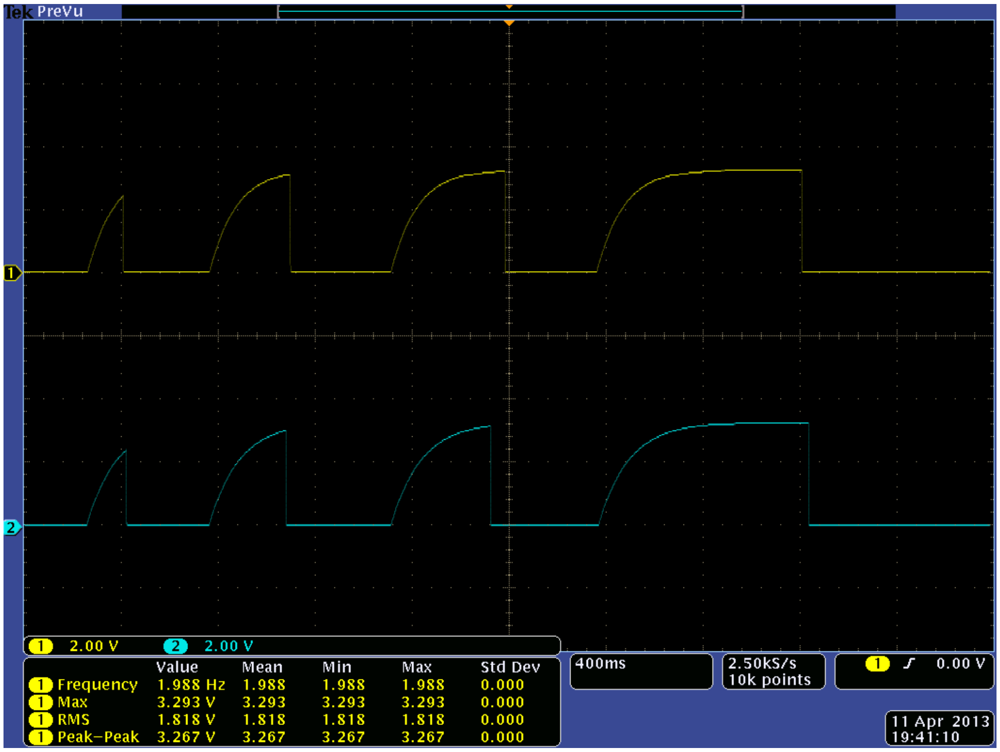


Figure 41: Oscilloscope Timing Waveforms of Testing the Debounce Switch

3.2.6 GSM & GPS Working Together with Arduino

The last step of interfacing the emergency module is the ability to fetch the GPS coordinates, and then successfully send an SMS with the coordinates for help. Because the GPS and GSM now work on a single GSM port and each component had previously worked separately, the process did not take much time. Moreover, because of the variations in the GPS connect timing, it is important that a GPS connect condition is added to the code. Hence, an AT command to check for GPS connect condition was added. Once the microcontroller detects that the GPS is connected, it will read the GPS coordinates. The GPS data is then parsed into an easy to read format before sending it as a SMS for better user experience. Additionally, a quick link to Google maps was added to the SMS so that users can access the visually impaired location easily. Figure 42 shows a sample SMS sent to the user with the help message, GPS coordinates, GMT time, and a quick link to Google Maps. In addition, Figure 43 shows the GPS location of the visually impaired when accessed from a smartphone. Lastly, Figure 44 shows the location of the visually impaired when access from a PC. Hence, by successfully fetching the GPS coordinate and sending the SMS the emergency system is now ready to be merged with the rest of the vision stick system.

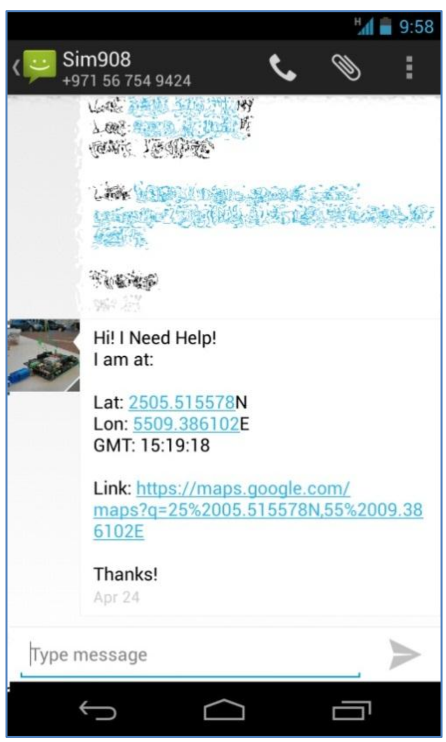


Figure 42: Mobile Phone Screenshot of an SMS for Help

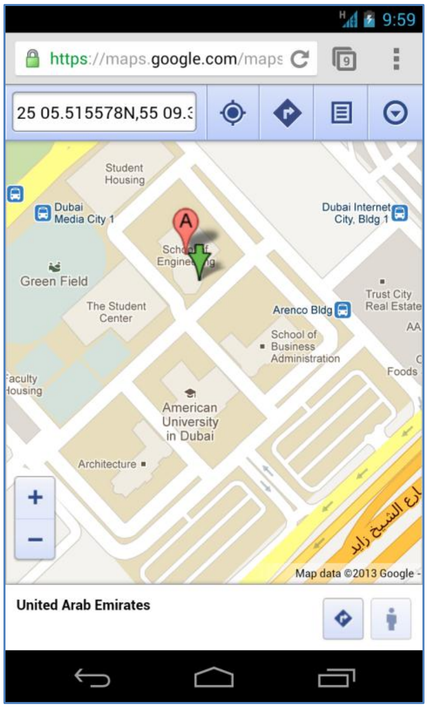


Figure 43: Mobile Phone Screenshot of the Google Map Access

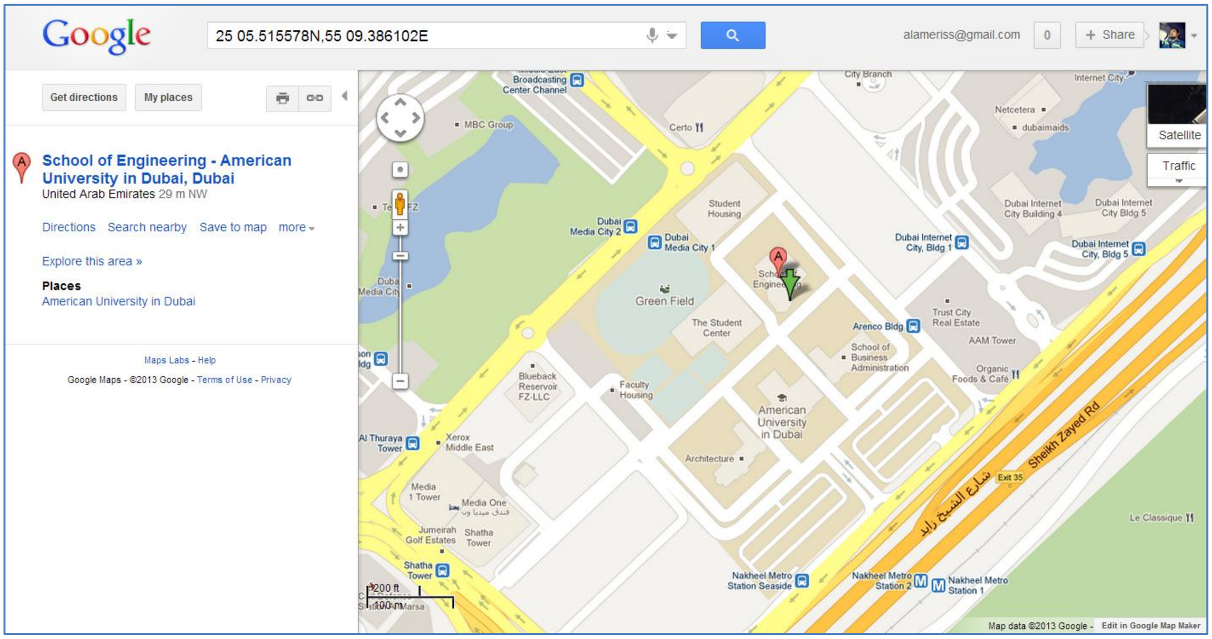


Figure 44: Desktop Browser Screenshot of the Google Map of Triggered Help Location

3.2.7 GPS Testing and Analysis

In order to ensure the best results for the visually impaired, the GPS was extensively tested to see how long it takes for the SMS to be sent. A series of 39 tests was performed on the GPS that was undertaken in different weather conditions, time of the day, and location. Out of a series of 39 tests, 67% of all SMS was sent under one minute. This ranges from sixty seconds to six seconds. In addition, 77% of the SMS was sent under two minutes and 87% of the SMS was sent under three minutes. Lastly, 97% of the SMS was sent under four minutes and the rest either sent at the maximum of five minute or failed to send an SMS. Therefore, the GPS module is functioning well and is reliable for an emergency system capable of sending an emergency SMS in under five minutes during most cases for the visually impaired.

3.2.8 Future Considerations

3.2.8.1 Limitation of Manual Trigger

The fact that the emergency module is manually trigger might present its own sets of consideration as the visually impaired might always be able to reach for help. For instance, if the visually impaired is paralyzed from an accident or medical emergency, they will not be able to signal for help. In addition, if the visually impaired loses or misplaces the vision stick, they can't signal for help. Additionally, the visually impaired might falsely trigger for help even after all prevention mechanism is in place. The best solution to tackle such problem is to inform the visually impaired about the limitations of the emergency system

3.2.8.2 Limitation of GPS

One important consideration is the limitations of GPS. Since working with GPS, it was observed that GPS does not work in indoor location. Also, because of the small antenna design, the GPS/GPRS/GSM module is sensitive to weather conditions such as wind. This affects the performance of the GPS. In addition, the telecommunication carrier might delay the transmission SMS in busy days such as public holidays. This presents an ethical issue as the visually impaired expects the vision stick's emergency feature to work flawlessly at all times. An argument can be made to counter the expectation that some safety measurement is better than one. Moreover, the visually impaired can be given informed of the imitations of the device

3.2.8.3 Indoor Emergency System

As previously mentioned, a major limitation of GPS is that does not work indoor. Since people spend a lot of times indoor, it is important that the emergency system work indoors. One possible future implementation of the project is to include a location detection system that works indoor such as WiFi location detection. This will allow the visually impaired to feel safe at all times as they will have the ability to signal for help at the comfort of an indoor settings.

3.2.8.4 Privacy Concern

Another consideration surrounding GPS is that it might invade the privacy of the visually impaired. With the right tools, the emergency module can be hacked and the visually impaired can be tracked. This present a major ethical issue as the privacy of an individual is a basic human right. That said, it can be argued that the emergency module adds a safety option to the visually impaired limiting the chance of them getting lost. Also, the potential privacy issue might not out way the benefit of help when in need. Moreover, the privacy issue could be solved by turning the module on only when needed.

3.3 Renewable Power Generation

Self-energizing the vision stick and powering it with a hybrid power supply would be possible through the vision stick's kinetic movements. Kinetic energy can be harnessed in the form of electrical energy through Faraday's Law of Induction shown in the equation below.

$$e = -N\frac{d\phi}{dt} \quad \text{(Eq. 2)}$$

Where,

- e is the electromotive force produced (V)
- N is the number of turns of the solenoid
- ϕ is the magnetic flux interacting between the permanent magnet and the solenoid (Wb)

As illustrated in Figure 45 below, the changing magnetic flux of the moving permanent magnet will induce a voltage in the solenoid, thereby acting as an electric generator. This will allow the user to generate and store the AC electricity in a DC form while using in remote areas away from the mains outlet. In this section, the renewable power generation design process is explained and analyzed to select a practicable prototype.

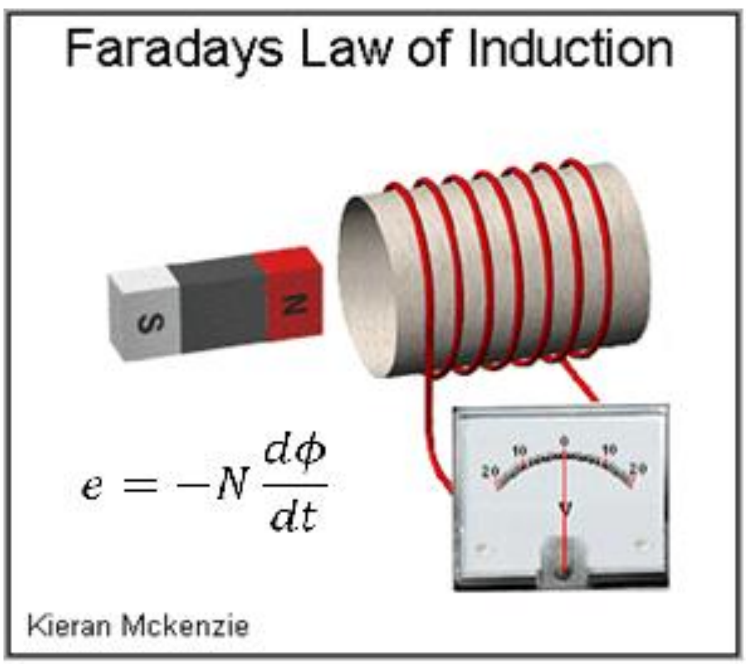


Figure 45: Induction of Voltage in the Solenoid through a Moving Permanenet Magnet [24]

3.3.1 Chosen Generation Method of the Concept Designs

A small-scale linear electric generator consists of an outer insulator which holds the inner black permanent magnet as shown in the left-hand 3D model of Figure 46 below. As the permanent magnet has a fixed magnetic field, it will cut the concentrated and centered copper solenoid on the outer insulator tube. By using sponges on both ends of the generator tube, the unwanted noise formed from the mechanical shaking of the internal permanent magnet is suppressed. Another way to obtain electrical energy from kinetic movements is by incorporating a wheel at the bottom of the vision stick shown in the right-hand 3D model of Figure 46. The mechanically-rotating magnetic field will induce a voltage in the copper solenoids above and two DC motors, which are mechanically connected to the wheel's axle, will produce electricity.

In a practical and common scenario, a blind user holds his or her white stick less than one foot distance away from the ground for scanning the surroundings. Using the wheel electric generator design would force the user to undesirably place the vision stick on a ground surface for power generation, leading to an unrealistic solution. The environment scanning process may be inhibited if a comfortably-rotating wheel is not designed, whereas the linear electric generator offers more flexibility in its fixed position on the vision stick. Therefore, the linear generation method was selected for harnessing electrical energy from the vision stick's movements.

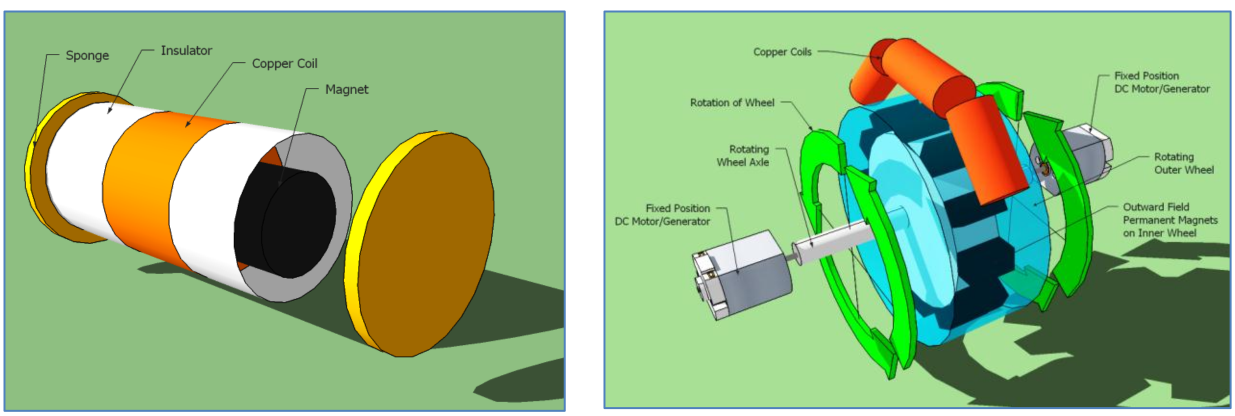


Figure 46: 3D Models of the Linear Electric Generator (left) and the Wheel Electric Generator (right)

3.3.2 Identification of Generator Design Parameters

Current linear generator designs are used for low-power applications, such as LED flashlights and nighttime lighting of security jackets. Through Faraday's Law, most linear generator manufacturers focus on creating the maximum possible number of turns using copper wires of small diameter, usually less than *0.1mm* in thickness. Even though the induced voltage is high as required such as *5V* peak, the generated power and current is not enough for this project's application and use. This section of the midterm report will focus on designing an optimized linear AC synchronous generator compared to a previous prototype design through a series of experiments and data analyses in the sub-sections below.

In order to systematically to create a generator design, the key design parameters must first be identified. In Faraday's Law of Induction, there are three main criteria which can be used to design a linear generator prototype. Each criterion is subdivided and elaborated to cover all the design parameters of the linear generator.

Magnet Material and Size Selection

New permanent magnet materials provide much higher magnetic field strengths than before, for example in higher ranges of more than one Tesla. As the magnetic field density B of the permanent magnet increases, the magnetic flux linked between the solenoid and magnet will further increase to induce more voltage in the solenoid.

Using the hysteresis curve shown in Figure 47, the relevant points on the red-colored B-H curve define a magnet's field strength. The residual field density B_r is the amount of magnetic induction when there is no magnetization force H applied upon magnetic saturation [**25**]. After material magnetization, the coercive force H_c defines how much of an opposing magnetic field is needed to demagnetize a magnet. In order to have high B_r and H_c in permanent magnets for resisting residual magnetism loss, the maximum product of B and H in the green square area of hysteresis curve's second quadrant is used to effectively compare different magnet materials. The maximum energy product BH_{max} is defined as the potential energy density in a magnetic material volume with the unit of kJ/m^3.

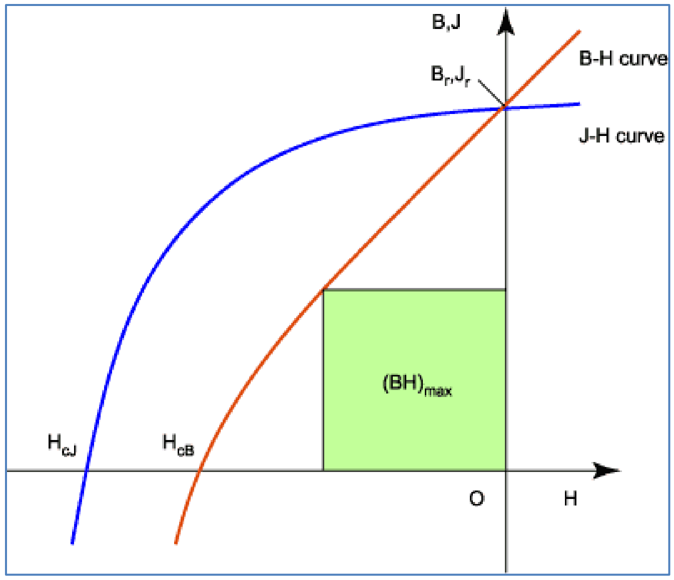


Figure 47: Demagnetization Quadrant of the Hysteresis Curve [26]

Although high magnet strength is required, the magnetization direction of permanent magnets also affects the amount of induced solenoid voltage due to the effective flux linkage. An example of different magnetization directions such as axial and diametric fields is on Figure 48.

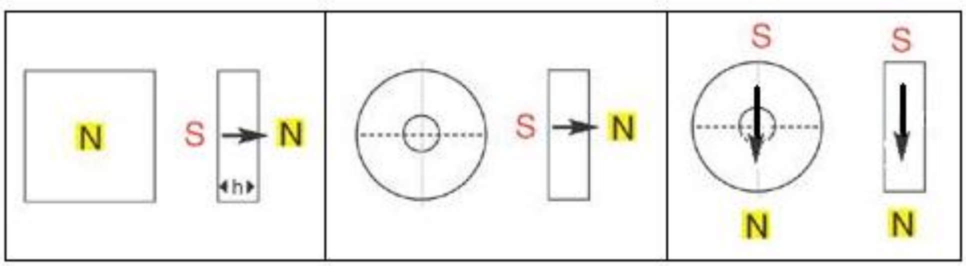


Figure 48: Directions of Magnetization Examples – Axial (left), Through Thickness (middle), Diametrically (right) [27]

Generator Design Structure

The air gap distance between the permanent magnet and solenoid has an inverse proportional relationship with the magnetic flux linkage. As shown in the equation below, the flux ϕ is proportional to the magnetic flux density B and the effective area A between the magnet and the solenoid. Although a small air gap is required for the magnet to move freely inside the generator tube, its distance must be minimized to stop the adverse weakening flux linkage effects. Also, the linear generator structure and material can undesirably attenuate the flux linkage of the permanent magnet. It is necessary to select thin and high magnetic susceptible insulation tubes for maximum flux linkage. In addition, the length of the generator tube leads to a higher magnet velocity which is directly related to the voltage induction characteristic curves. As Faraday's Law includes the derivative of the magnetic flux over time, the faster change in flux linkage would generate higher induced voltage. Through experimentation, the shaking frequency of the linear generator is between 8 to 15 Hz for an average human adult.

$$\phi \; \alpha \; BA \qquad \text{(Eq. 3)}$$

Solenoid Design

As long as the magnetic flux of the permanent magnet entirely cuts through the solenoid, the induced voltage linearly increases with higher number of solenoid turns. Even though high number of turns is desired for inducing more voltage, the electromechanical energy conversion also depends on the solenoid's impedance characteristic. The wire diameter has an inverse-square relation with the wire resistance, which accounts for the substantial drop or increase of the current produced. A high conductance wire must be used to have small resistive heat loss, for they are inversely proportional. Also, the solenoid structure and wire distribution affects the curve shape of the AC induced voltage. A trade-off between impulse shots and smoother sinusoidal voltage shapes must be considered.

$$Wire\ Resistance\ \alpha \frac{1}{(Wire\ Diameter)^2} \qquad \text{(Eq. 4)}$$

Once the wire diameter is chosen for high voltage and power output, the number of turns of the solenoid must be chosen such that the power generation is optimized. Even though the emf generated linearly increases for higher number of solenoid turns, the total coil resistance also linearly increases with the inductive reactance of the designed solenoid. A trade-off between high voltage and reasonable current must be considered as well for optimized power generation.

$$Total\ Resistance\ \alpha\ Number\ of\ Turns \qquad \text{(Eq. 5)}$$

3.3.3 Linear AC Synchronous Generator Design

Since all the design parameters have been classified under three main criteria, each one is elaborated in detail and the appropriate selection is justified through available data and experimental analyses.

3.3.3.1 Choice of Magnet Material and Shape

In order to have higher induced voltage, the permanent magnet strength must be maximized through the magnet material and size. First, four different common magnetic materials were compared as shown in Table 2. The Neodymium Iron Boron *NdFeB* material is shown to exhibit more maximum energy product BH_{max} and flux density than any other magnetic material. Even though the Neodymium magnet's coercive force for demagnetization and its physical density are high, the maximum working temperatures comparatively low in the range of about 100°C. As the vision stick is to be used for typical environments, the maximum working temperature will not be reached not the magnet is safe in this respect. A point to consider is that Neodymium magnets are known to be brittle and can shatter to pieces when it attracts with other magnets. As an ethical consideration, the magnet must be properly enclosed within the safe generator with appropriate cushioning effects able to sustain its operation up to a life time. Therefore, Neodymium magnets were chosen as the magnetic material to be used in the vision stick generator due to its high magnetics strength and ease of manufacturing various shapes and sizes.

Table 2: Comparison of Common Magnetic Material Properties [28]

Material	BHmax (kJ/m^3)	Flux Density (mT)	Max Working Temp. (°C)	Coercive Force (Hc)	Density (kg/m^3)
Ceramic	26	100	250	High	4980
Alnico	42	130	550	Low	7200
SmCo (2:17)	208	350	300	High	8400
NdFeB (N38H)	306	450	120	High	7470

Given that the choice of Neodymium magnetic material, a high magnet grade of N48 was chosen. Table 2 below shows how the Low Temperature Range of Sintered NdFeB Magnet Grades gradually increases from the lowest N35 to the highest grade N52. To start with testing different magnet shapes and sizes, the N48 grade was chosen due to its high availability of purchase and its relatively high magnetic strength of a maximum energy product 383.0 kJ/m^3 and a magnetic field density of 1.38T. Other versions of Neodymium magnets with relatively higher working temperatures, more than 100°C, were available, but were not chosen as the 80°C is a reasonable maximum limit for the generator tube temperature.

Table 3: Sintered NdFeB Magnet Grades for Low Temperature Ranges [27]

Grade	Br (T)	Hcb (kA/m)	BHmax (kJ/m^3)	Density (kg/m^3)	Max Working Temp. (°C)
N35	1.18	867.4	278.5	7400	80
N38	1.22	899.2	302.4	7400	80
N40	1.25	923.1	318.3	7500	80
N42	1.28	923.1	334.2	7500	80
N45	1.32	875.4	358.1	7600	80
N48	1.38	835.6	382.0	7700	80
N50	1.40	795.8	397.9	7800	80
N52	1.44	835.6	413.8	7800	80

Once the magnetic grade was systematically chosen, five different Neodymium N48 grade magnets were selected and ordered. Their shapes and sizes, such as Ring, Rod, Sphere, Button and Cylinder magnets, were relatively chosen to be close to a 2cm diameter range of the generator tube.

Upon receiving the Neodymium magnets after a one week delay, a sample 12cm in length generator tube was constructed with 2cm of condensed wire wrapping in the generator's center. The generator structure was kept constant while each magnet shape was tested in the range of 10 to 15 Hz shaking frequency and for different number of magnets. Figure 14 below illustrates the experimental data points of the induced voltage versus the number of magnets used. The best magnet configuration is the ring magnet due to its bigger size and axial magnetization direction which cuts the solenoid very well. Figure 50 below displays the different Neodymium magnet shapes used, where the triple Ring magnet configuration is highlighted to be the best magnet for testing and experimentation in the vision stick project. More information about the physical layout of the generator can be referred to the *Generator Design Structure* subsection below.

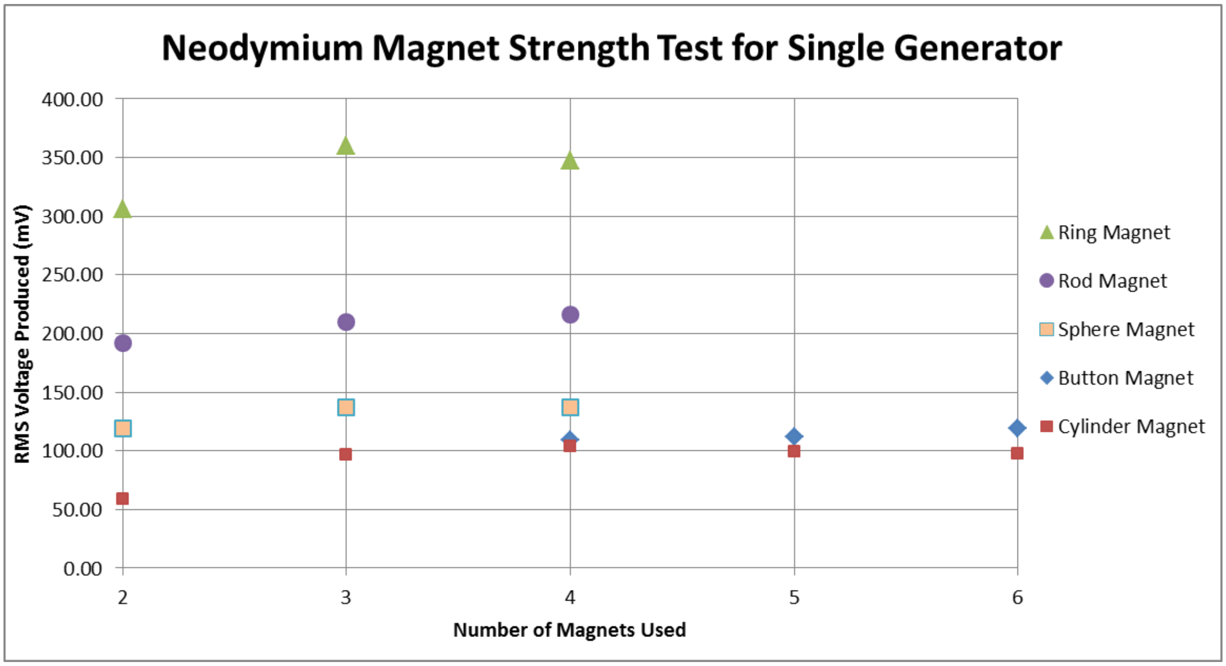


Figure 49: Neodymium Magnet Shape Test for Single 12cm Long Generator with 0.50mm Solenoid Wire Thickness within 2cm of Centered Space.

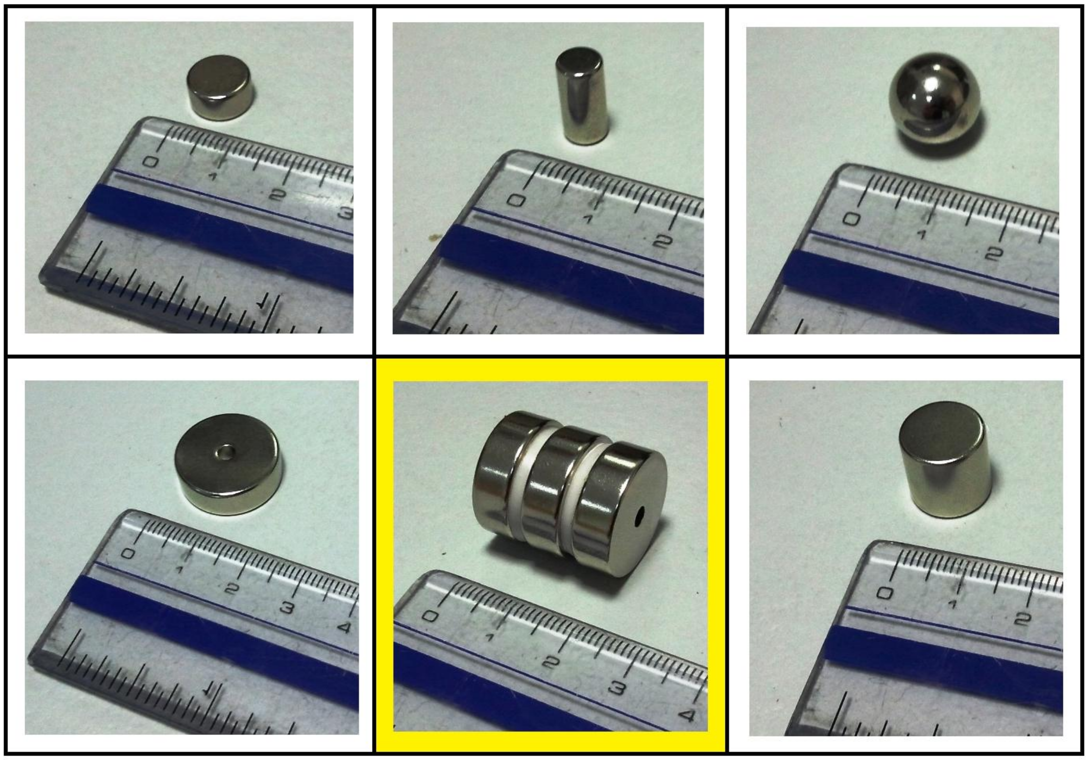


Figure 50: NdFeB Rare Earth Magnets in Different Shapes: Axial Button (Upper Left), Diametric Cylinder (Upper Middle), Axial Sphere (Upper Right), Single Axial Ring (Lower Left), Three Axial Rings with Stoppers (Lower Middle), Axial Rod (Lower Right)

3.3.3.2 Generator Design Structure

In order to have maximum transfer of magnetic field strength between the Neodymium permanent magnet and the solenoid, a correct choice of generator tube material was chosen. Previous shaking flashlight linear generators used thick insulation tubes which attenuated the magnetic field linking with the centered solenoid. In order to fix this noticed problem, the insulation paper currently used to cover copper coils in electric motors and generators was chosen. Based on its widespread use, this white-colored insulation paper is able to withstand high temperatures and electrical currents while motors and generators are running at high load. Also, the attenuation of the stator rotating magnetic field can be almost neglected due to the high magnetic susceptibility of the insulation paper material. Hence, the insulation paper with a small thickness of 0.5mm was chosen to construct and design the cylindrical generator tubes.

The top and side views of the cylindrical generator tube are shown in Figure 51 below. It is 12cm long and contains a 2cm space used for wrapping the solenoid wires. The 12cm length ensures that the triple Ring magnets are able to get head start acceleration from one end to another. Keeping this 2cm space constant ensures that the geometric limitation of the maximum number of turns is considered during the generator design. The top view shows a 2.1cm diameter which is fully able to hold the triple Ring magnet configuration within the generator tube.

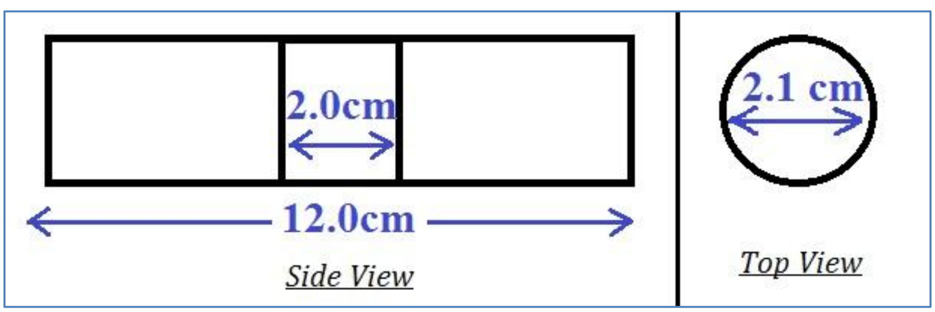


Figure 51: Blueprint Drawings of the Generator's Cylindrical Tube Design for Side and Top Views

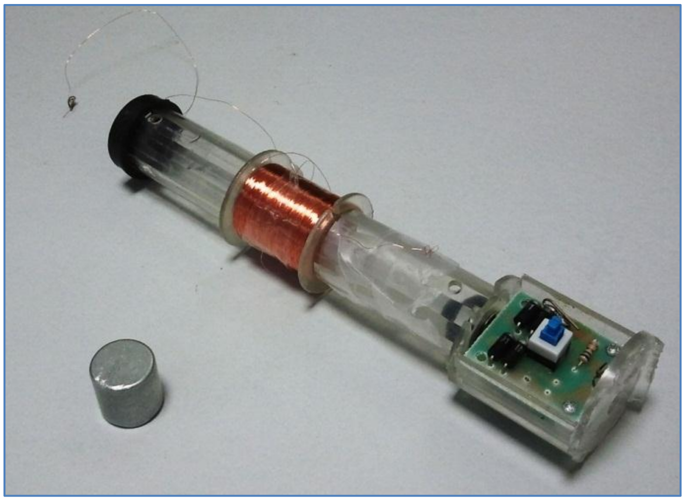


Figure 52: Prototype 1 of Linear AC Synchronous Generator

3.3.3.3 Solenoid Design and Experimentation

Since the generator tube structure and the magnet material and shape have been fixed and chosen, the correct choice of the solenoid design is crucial. Copper wires were used as the solenoid's wire material due to its high conductance of $5.96x10^{7}$ S/m for low generator resistive heat loss. As it was previously mentioned, current linear generator manufacturers focus only on selecting small diameter wires to maximize the number of turns, while negatively affecting the current output of the generator. Hence, a series of experiments have been conducted to find the relation between the peak power and high voltage induced with respect to both the wire diameter and the solenoid number of turns.

3.3.3.3.1 Sensitivity Analysis

Similar to the ultrasonic sensor tests, a sensitivity analysis was performed for the linear generator design. This analysis helped in eliminating the unneeded solution for each design parameters on way of enhancing the generator power output. The affecting variables include wire diameter, solenoid number of turns, and magnet material. The method of One-Factor-At-a-Time (OFAT) was used to test the effect of each of the above-mentioned variables by keeping the rest of the variables unchanged in the three tests explained below.

3.3.3.3.2 Test 1: Changing the Wire Diameter for Weaker Magnet 1

In Test 1 experiment, the fixed dimension and shape of the 12.0cm long generator tube with 2.1cm diameter was used to find the different relations with the copper wire thickness. There were 15 different generator test cases, ranging from 0.10mm to 0.85mm thickness with approximately 0.05mm step increments in diameter size. Slight deviations for some of the wire thicknesses, such as 0.28mm and 0.67mm, were due to the unavailability of exact 0.05mm step increments in local shops. For each wire thickness, the 2cm centered generator outer space was covered until an entire row was filled with minimal overlaps. This fixed size parameter is related to the geometric limitation of packing numerous wire turns onto the generator. Also, Test 1 uses the Magnet 1 from the shaking flashlight linear generator to demonstrate the comparison with the new Neodymium magnets. The electrical characteristics are shown and explained below with the aid of experimental graphs.

Using the resistance formula shown below, the wire resistance is related to the square inverse of the wire diameter. Figure 53 shows the calculated and measured curves more clearly. From about 0.25mm to the right of the horizontal axis, the resistance per turn starts to have a smoother slope and stays within the *20mΩ/turn* range. The previous generator design used wires thinner than 0.10mm resulting in a very high wire resistance.

$$Resistance = \frac{length}{(conductivity \cdot area\ of\ cross\ section)}\ \alpha \frac{1}{diameter^2} \quad \text{(Eq. 5)}$$

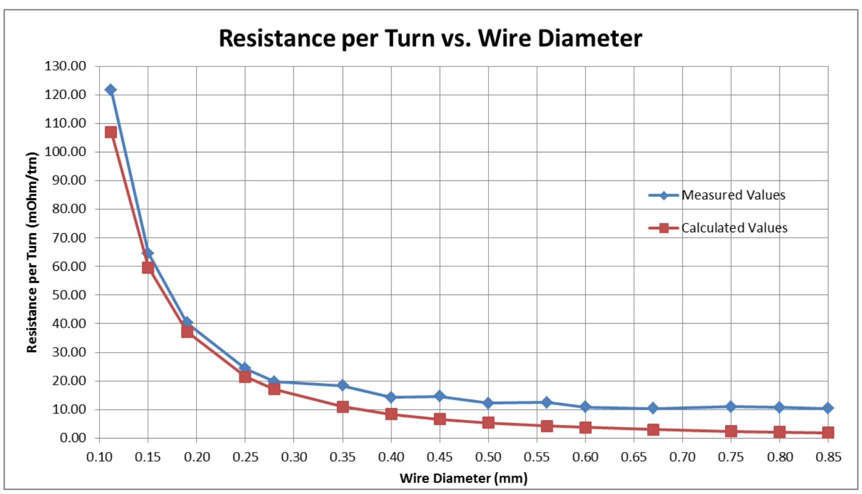


Figure 53: Resistance per Turn Relation with Wire Diameter for Measured and Calculated Values

In a similar way, the number of turns that can be packed for one row of solenoid is inversely proportional to the wire diameter. Figure 54 shows the calculated and measured curves more clearly. From about 0.45mm to the left of the horizontal axis, the number of turns which is directly related to the induced solenoid voltage starts to sharply increase.

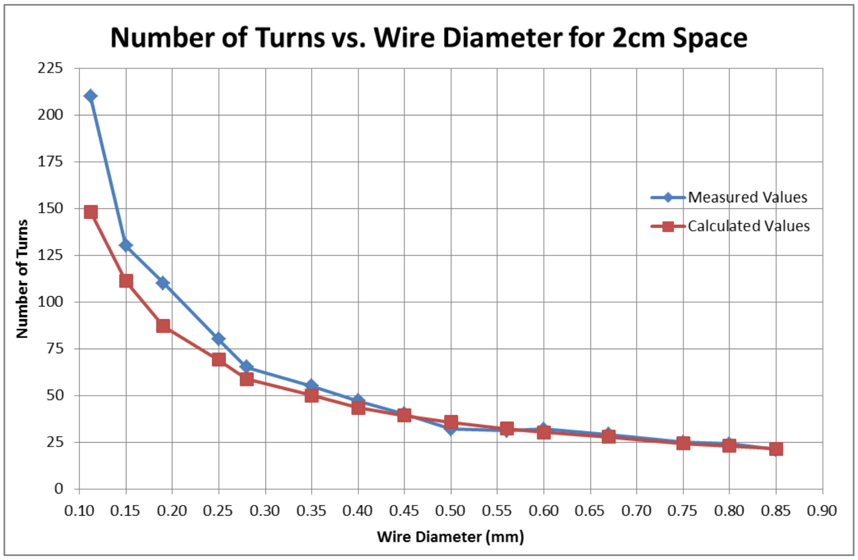


Figure 54: Number of Turns in 2cm Space Relation with Wire Diameter for Measured and Calculated Values

Using Figure 53 and Figure 54, it was observed that for one level of packing wires into 2cm of space, there exists a complex relation between increasing the number of turns while trying to limit the generator internal resistance to be low.

In order to measure the open –circuit voltage and short-circuit current of the linear generator, the experiment was standardized as follows. As the shaking frequency of the generator is directly related to the induced voltage, four different frequency ranges were defined: low frequencies from 0 to 5 Hz, medium-low frequencies from 6 to 10 Hz, medium-high frequencies from 11 to 15 Hz, and high frequencies from 16 to 20 Hz. An average human can easily shake his or her hand to power the linear generator in the medium-high frequency range. In the following graphs, the deviation of certain data points from regression lines is attributed to the manual uneven shake of the linear generator through human testing, the spread of each frequency range, and the non-uniformities in each hand-made generator design.

For each of the 15 wire thicknesses, the root-mean square (RMS) open-circuit voltage was measured, and the voltage density, which is the ratio between the RMS voltage and the number of turns, was computed to present a measure of how the voltage production varies from one wire diameter to another. This will eliminate the biasing effect of higher voltages due to higher number of turns in thinner wires. Figure 55 below illustrates the scatter graph data points with linear regression of each frequency range for the voltage density versus the wire diameter. It can be observed that the voltage density has a slightly decreasing linear change with respect to the increase in wire diameter. Thinner wires have a higher voltage density due to the greater number of turns packed within the centered 2cm space. For the medium-high frequency range, the average voltage density for the 15 test generators is about ***4.50mV/turn***.

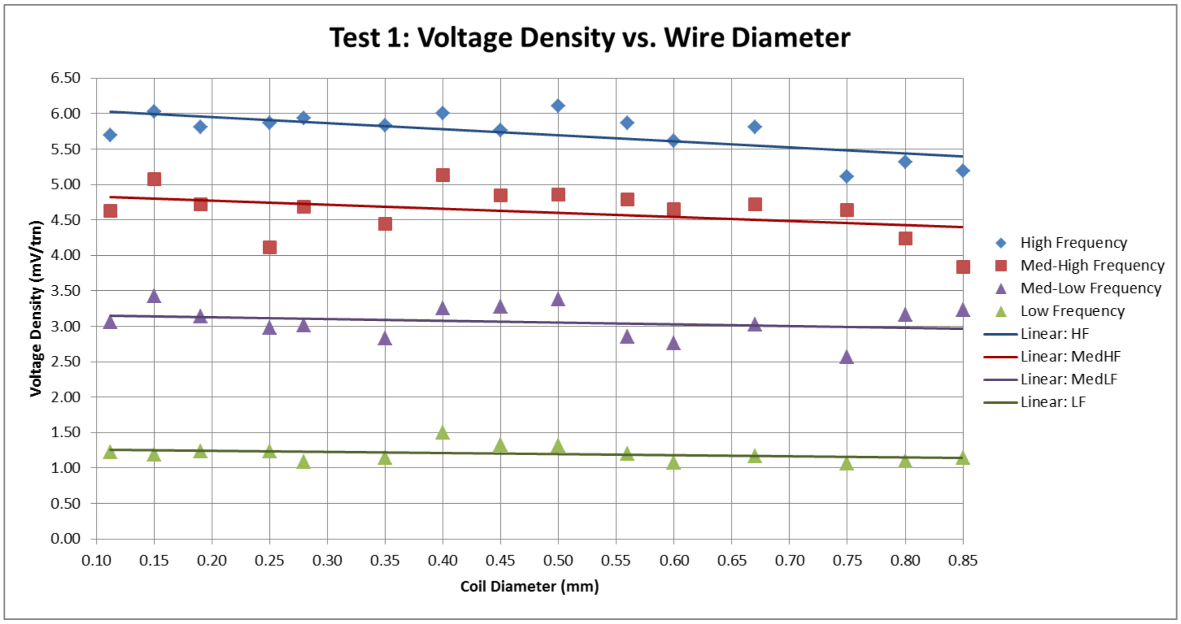


Figure 55: Test 1 - Voltage Density versus Wire Diameter for Four Frequency Ranges

Also, the peak AC voltage was measured to obtain the RMS ratio by dividing it with the RMS voltage. The RMS ratio shows how much area is covered by the induced voltage over one period. Since the mechanical shaking frequency is equal to the electrical voltage frequency, the linear AC generator has a synchronized frequency, giving rise to the synchronous generator name. For sinusoidal signals, the RMS ratio is about 1.4. For the four frequency ranges and the 15 test generators, it was found that the RMS ratio was approximately 3.0. Since the solenoid is packed within 2cm of space and the triple ring magnets is about 2.5cm in length, the voltage versus time curve has an impulse nature for a short period with zero values for rest of the time period. Figure 56 below shows this explained behavior. Each periodic sharp rise and fall of voltage has a small absolute area over one period arising to a higher **RMS ratio of approximately 3.0** for Test 1.

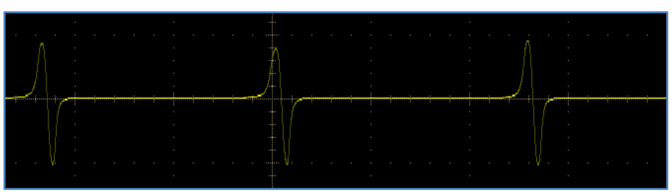


Figure 56: Sample 2 Hz Induced Voltage for 0.50mm Wire Diameter Generator

Similarly, the RMS short-circuit current for each of the 15 wire thicknesses was measured, and the current density presents the relative change in current production from each wire diameter. The current produced is the ratio of the induced voltage and the generator impedance. Even though the impedance incorporates both the wire resistance and reactance, the lagging reactance may be ignored for wires smaller than the mid-range diameter due to the significantly higher resistance value. Figure 57 below shows the scatter graph data points with second order polynomial regression of each frequency range for the current density versus the wire diameter. The regression lines fit well to the curve, since the R^2 value is above 0.85. It can be observed that the current density linearly increase up to about 0.55mm wire diameter before it starts to saturate for thicker wires. Even though the generated voltage density is approximately constant ignoring the slight deviations, the reactance due to higher coil inductance significantly increases the solenoid impedance. For the medium-high frequency range, the average saturated current density for the 15 test generators is about ***5.00mA/turn***.

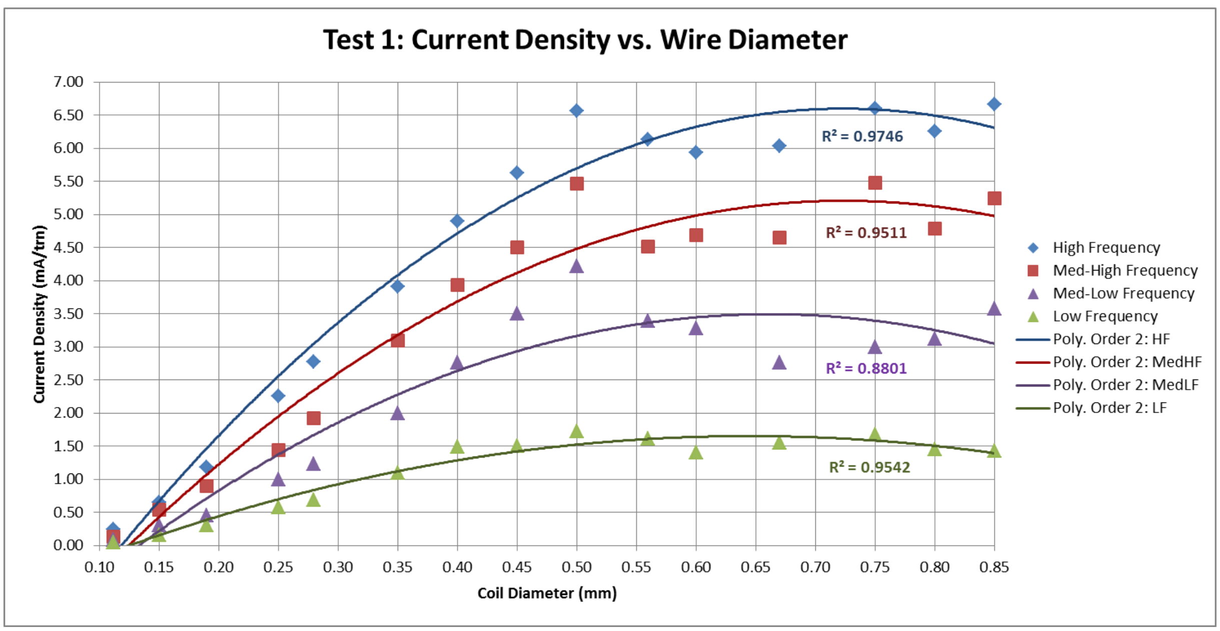


Figure 57: Test 1 - Current Density versus Wire Diameter for Four Frequency Ranges

In order to evaluate the better solenoid performance, the power density, which has the unit *mW/turn*, was computed as a figure of merit. For the four frequency ranges and the same 15 test generators, the observed characteristic curves were obtained as shown in Figure 58. Between 0.25mm and 0.60mm wire diameter, the maximum power density data points were experimentally computed. The peak power density for the medium-high frequency range is about ***0.90mW/turn***.

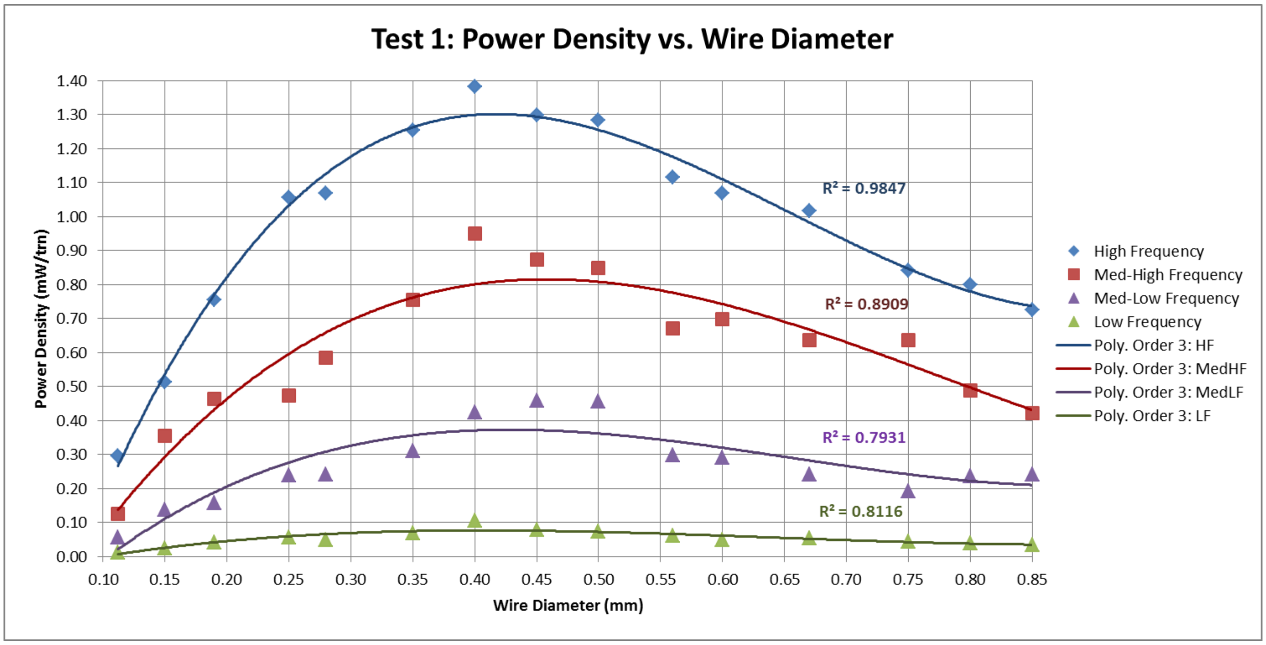


Figure 58: Test 1 - Power Density versus Wire Diameter for Four Frequency Ranges

Therefore, the results obtained from Test 1 for 15 different wire thicknesses while fixing the generator dimension and shape along with using the Magnet 1 can be used to advance to a similar test experiment using the new Neodymium triple ring magnets.

3.3.3.3.3 Test 2: Changing the Wire Diameter for the New Triple Ring Permanent Magnet 2

In Test 2 experiment, the fixed dimension and shape of the 12.0cm long generator tube with 2.1cm diameter were also used to find the different relations with the copper wire thickness. Again, there were 15 different generator test cases, ranging from 0.10mm to 0.85mm thickness with approximately 0.05mm step increments in diameter size. Also, Test 2 uses the new Neodymium triple ring magnets, Magnet 2, and the electrical characteristics are shown and explained below with the aid of experimental graphs.

For each of the 15 wire thicknesses, RMS open-circuit voltage was measured, and the voltage density was computed to show the variation from one wire diameter to another. Figure 59 below illustrates the scatter graph data points with linear regression of each frequency range for the voltage density versus the wire diameter. It can be observed that the voltage density has a slightly decreasing linear change with respect to the increase in wire diameter. Thinner wires have a higher voltage density due to the greater number of turns packed within the centered 2cm space. For the medium-high frequency range, the average voltage density for the 15 test generators is about ***8.00mV/turn***. Also, the **RMS ratio** was calculated to be **approximately 2.4** for Test 2. This is due to the triple ring magnets having a longer length than the Magnet 1causing a bigger area covered in the induced voltage versus time curve.

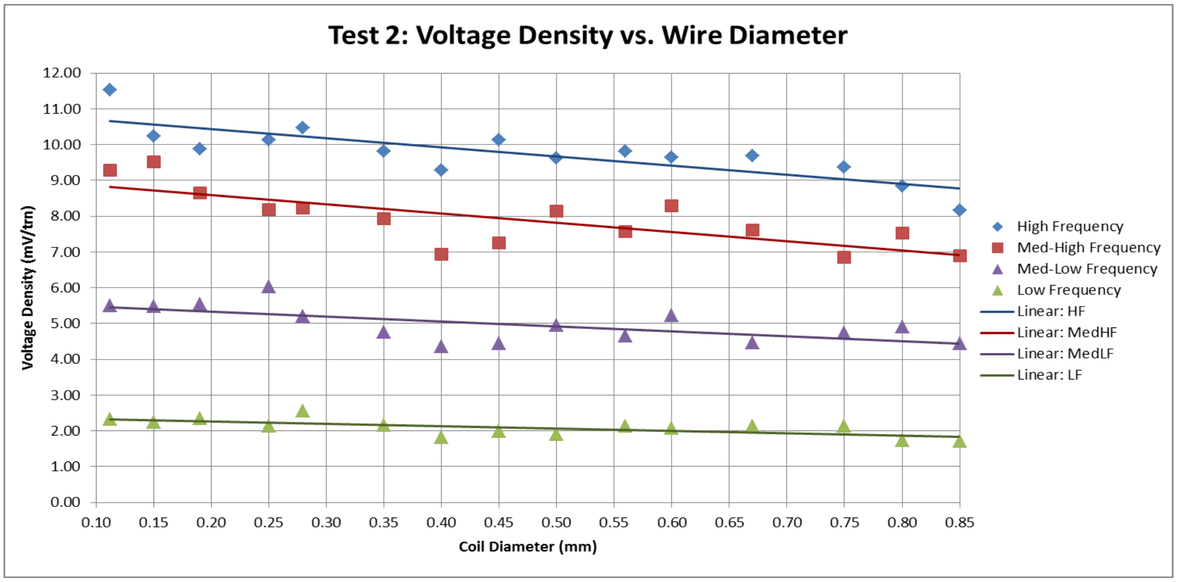


Figure 59: Test 2 - Voltage Density versus Wire Diameter for Four Frequency Ranges

Similarly, the RMS short-circuit current for each of the 15 wire thicknesses was measured, and the current density presents the relative change in current production from each wire diameter. Figure 60 below shows the scatter graph data points with linear regression of each frequency range for the current density versus the wire diameter. The regression lines fit well to the curve, since the R^2 value is above 0.97. It can be observed that the current density linearly increase up to about 0.55mm wire diameter before it starts to saturate for thicker wires. Even though the generated voltage density is approximately constant ignoring the slight deviations, the reactance due to higher coil inductance significantly increases the solenoid impedance. For the medium-high frequency range, the average saturated current density for the 15 test generators is about ***8.00mA/turn***.

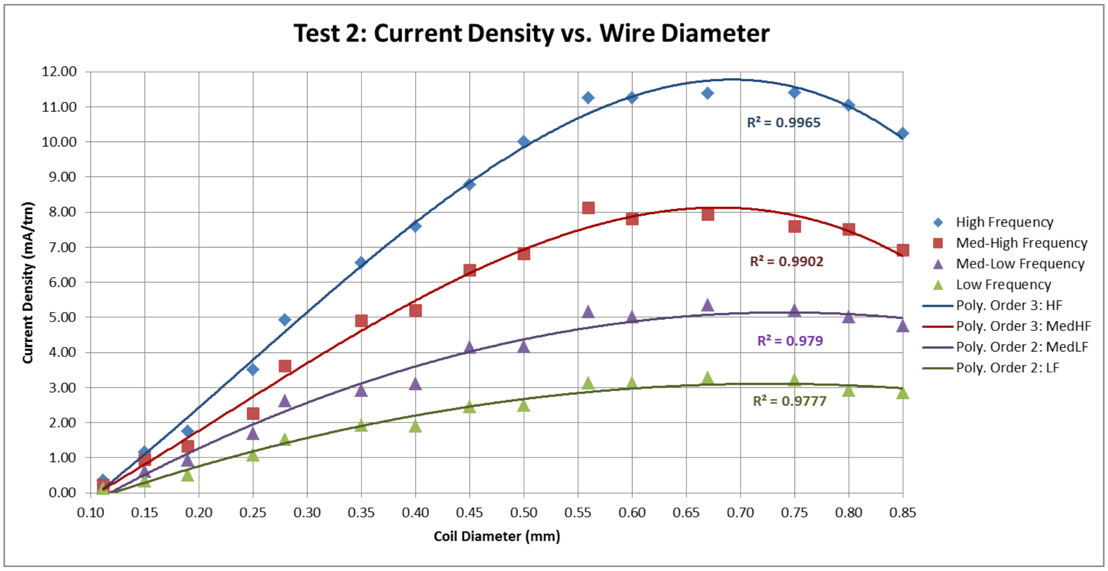


Figure 60: Test 2 - Current Density versus Wire Diameter for Four Frequency Ranges

In order to compare the better solenoid performance and the magnet strength of both Test 1 and Test 2, the power density was computed. For the four frequency ranges and the same 15 test generators, the observed characteristic curves were obtained as shown in Figure 61. Between 0.28mm and 0.60mm wire diameter, the maximum power density data points were experimentally computed. The peak power density for the medium-high frequency range is about ***2.00mW/turn***, which is more than double the power density for the Magnet 1in Test 1. Hence, Test 2 experimentally proved the greater strength of the Neodymium permanent magnet.

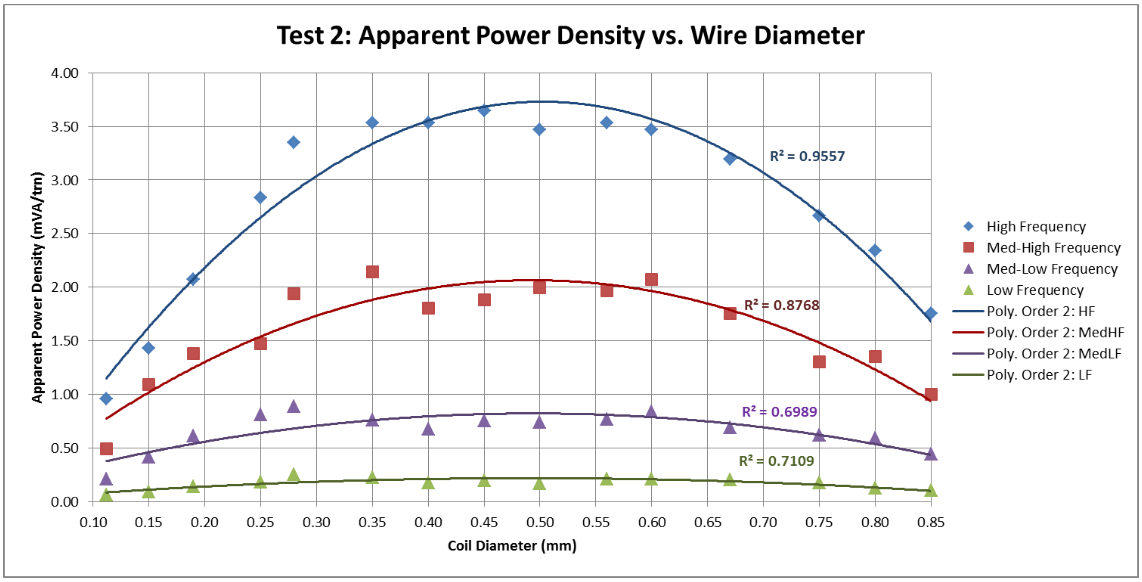


Figure 61: Test 2 - Power Density versus Wire Diameter for Four Frequency Ranges

3.3.3.3.4 Test 3: Changing the Number of Turn Levels for High Power Density Wires

After the Neodymium magnets have been experimentally proved to be much stronger than the Magnet 1 and the maximum power density peaks were observed, Test 3 initially focused on three wire thicknesses of 0.28mm, 0.35mm, and 0.40mm diameter. Referring to the characteristic curves shown Figure 61, the chosen wire diameters for the maximum power densities were chosen toward the left side of the bell curve's peak to increase the induced voltage needed to a required *5V*. Let the maximum number of turns packed into the 2cm space be defined as Level 1. Then, the next levels would simply be integer multiple of Level 1 number of turns in the same way of staking wires on top of each other. Hence, Test 3 analyzes the relation between increasing the number of turns to an optimum peak before undesirable low power and current effect arise due to increasing wire impedance.

For the 0.28mm wire thickness, the voltage produced versus the wire turn level, where Level 1 had 65 turns, has the graph shown in Figure 62. As in Faraday's Law, the induced voltage is linearly dependent on the number of turns of the solenoid for all four frequency ranges. However, the voltage produced will saturate for very high number of turns where the permanent magnet's flux is not able to cut the outer levels of the solenoid wires. For Level 15, the RMS voltage produced is less than ***7.00V***.

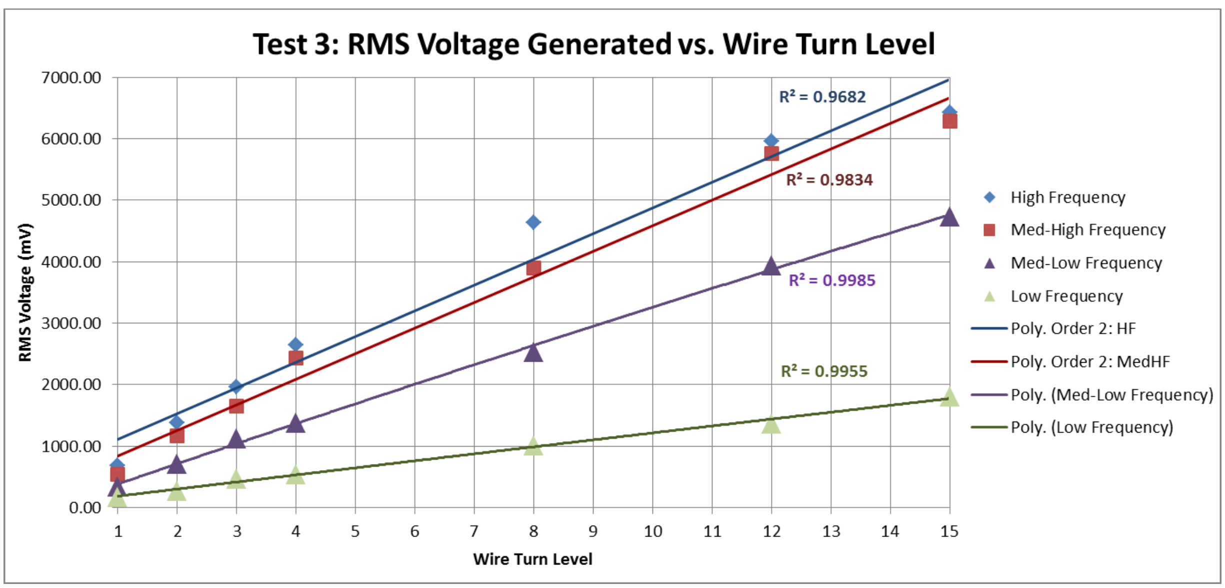


Figure 62: Test 3 – Voltage Produced versus Wire Turn Level for Four Frequency Ranges (Each Level is 65 turns)

For the same 0.28mm wire thickness, the current produced versus the wire turn level has the graph shown in Figure 63. It was observed that the current curves are bell-shaped due to the adverse and unwanted effects more wire resistance and reactance. Also, the high levels of the solenoid are not cut by the magnet's flux in the same way the lower levels are. For Level 15, the current produced is around ***250.00mA***.

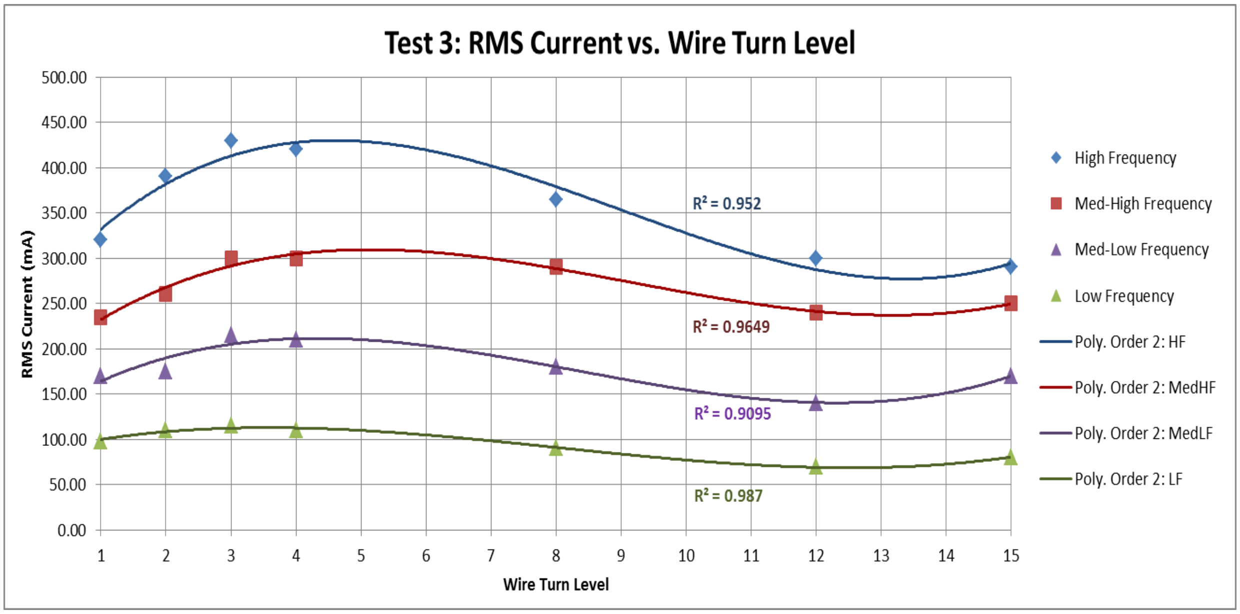


Figure 63: Test 3 – Current Produced versus Wire Turn Level for Four Frequency Ranges (Each Level is 65 turns)

As seen in Figure 64 below, the power generated in *mW* shows saturation curves for the four frequency ranges. The medium-high frequency curve initially increases fast, but later settles down to a peak of about ***1.60W*** for Level 15. Even though there were only six data points, the second-order power polynomial regression curves fit very well to the scatter data points and the regression equation can be accurately used to determine the required number of turns needed for optimum power with respect to the voltage and current curves.

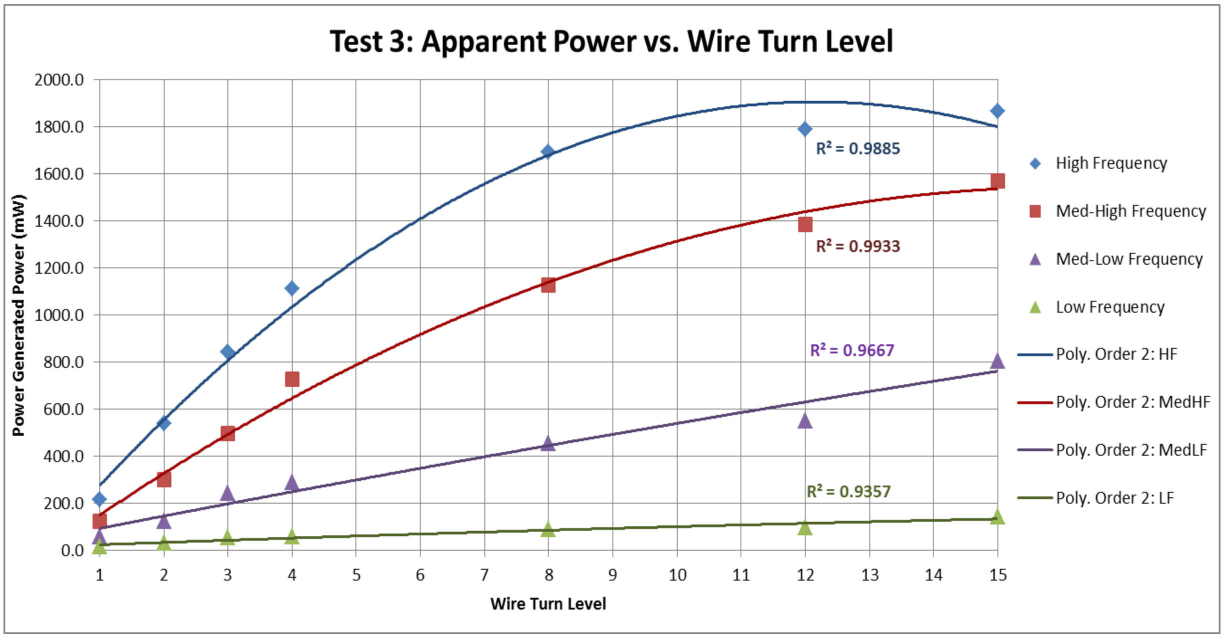


Figure 64: Test 3 – Power Generated versus Wire Turn Level for Four Frequency Ranges (Each Level is 65 turns)

Experiments were also performed on 0.35mm and 0.40mm, and they both had almost similar characteristics, but with different peak data points. The 0.28mm wire was also more preferable, for its solenoid is more capable of packing more number of turns within the same space for producing a higher emf. Their graphs are displayed in Appendix D below. The main results of Test 2 for medium-high frequency range and Level 4 are summarized in Table 4 below.

Table 4: Electrical Characteristic Data Points for Level 4, Medium-High Frequency Range of Three Coil Diameters

Coil Diameter	RMS Voltage (V)	RMS Current (mA)	Power (mW)
0.28mm	2.43	300.00	729.30
0.35mm	2.00	370.00	738.90
0.40mm	1.60	490.00	781.60

3.3.3.4 Current Selection of Optimized Generator Design

Based on the previous test experiments, the 0.28mm wire thickness with Wire Turn Level 15 was chosen as the current selection of the optimized generator design. As explained in Concept Design 1 in the sub-section above, Figure 65 shows the white generator tube with a 2cm packed solenoid with 0.28mm wires for about 975 turns. The triple ring magnets and the two sponges at either end of the generator tube are shown as well. Comparing with the medium-high frequency

140mW power produced in the previous Prototype 1 generator with Magnet 1, the new linear AC synchronous generator with 0.28mm wire thickness, Prototype 2, is capable of generating more than **11 times more power**. Through the conducted experiments, the desired 5V induced voltage was reached, but with a better 250mA no-load current.

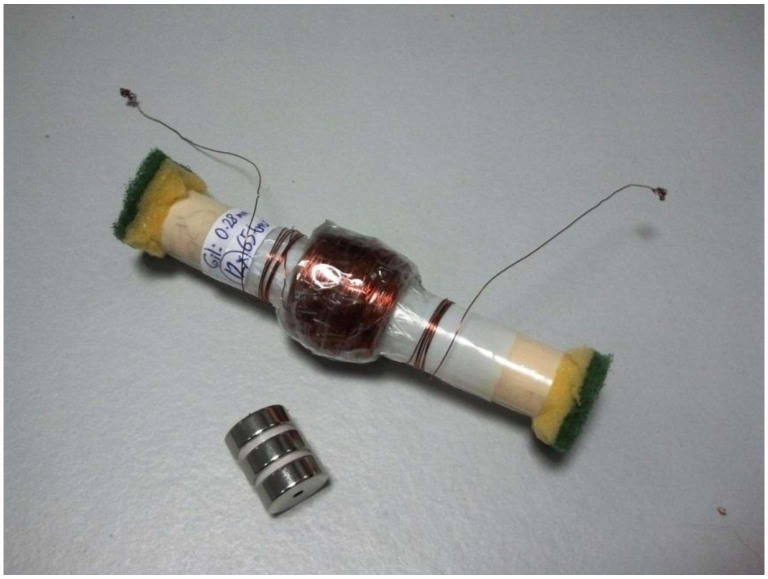


Figure 65: Prototype 2 - Linear AC Synchronous Generator with 0.28mm Diameter Solenoid with Triple Ring Magnets

Since Neodymium permanent magnets are brittle and weak to mechanical stresses, the linear electric generator was mechanically protected by covering the generator shown in Figure 65 entirely with around 2cm of plastic foam. As shown in Figure 66, the plastic foam will damp common mechanical shocks and inhibit the permanent magnet's magnetic field within the generator to protect the surrounding electronic components against electromagnetic interference.

Figure 66: Prototype 2 Protected with Plastic Foam

3.3.4 Challenges and Future Considerations

Throughout the design of the renewable power generation, several challenges were faced:

1) Designing experiments for sensitivity analysis: Since there were many control variables that needed to be considered, it was a challenge to cover all of them in an effective way. Designing a better generator might also need more testing and experimentation. Thus, the method of OFAT was followed.

2) Getting delayed by one week: The required Neodymium magnets unexpectedly arrived one week late and this caused a substantial delay in the experimentation and analysis phase. Due to this problem, numerous consecutive nights were spent to cover for the previously waiting time.

In the future, the power generation of the electric generator can be further improved by using stronger N52 grade Neodymium magnets with maximum magnetic flux linkage between the solenoid and the permanent magnet. This can be accomplished via specifically designed magnetization directions for the permanent magnets and guiding the magnetic flux through designed iron cores in a squirrel cage structure around the copper solenoid. Also, more experimental data are needed to be performed for the three tests with a machine shaking at different frequencies as opposed to the human hand.

3.3.5 Ethical Issues

While designing the linear AC synchronous generator, some ethical issues were considered. First, the magnetic field of the generator resulting from the strong permanent magnets may harm both the health of the user and the expected life of the used electrical components. Current scientific research shows that strong magnetic fields may cause adverse effect on the user's well-being. However, other scientific researches argue that magnetic fields are not as severe in causing life-threatening illnesses such as cancer. On the plus side, renewable energy generation enables the user to ben more self-aware of sustainable living. Electrical components may be negatively affected causing inaccuracies in measurements. The high cost of Neodymium permanent magnets may overwhelm the overall cost of the vision stick. According to the IEEE Code of Ethics, Code 7.8.1 requires that engineers hold paramount to the welfare and health of the public. Adverse effects of magnetic fields must be minimized through appropriate containing material design. Code 7.8.3 requires that engineers be honest in stating claims about the product. Therefore, the issues pertaining magnetic field generating devices must be properly disclosed to interested product customers.

Requiring renewable energy generators may cause more burdens to the user due to its major weight issue. As the generators contribute toward the major part of the vision stick's weight, the user is forced to carry the heavy stick for using other features. Optimizing the generator's size and weight can minimize the heaving weight effect. It is questionable whether the generators are actually needed for users or not. For some instances, the user may not want to carry extra weight owing to the generators. Properly positioning the stick can reduce the overall pressure of the user's hand while in operation. Optimization costs of the generator weight may be unneeded for certain users. Code 7.8.3 requires hat engineers must be honest in stating claims about their product. The weight issue must be properly disclosed to customers. Code 7.8.8 requires that disability and age of others must be considered. The weight of the vision stick may be a major problem for disabled people not capable of carrying considerable weights. A solution would be to minimize the possible weight of the stick during design. Code 7.8.7 requires that honest criticism of technical work must be seeked and accepted. Before designing the optimized generators, the overall picture of the vision stick's weight must be considered for criticism. Code 7.8.5 requires that engineers must improve upon current technologies and its consequences. The engineer must ensure that the energy generators are optimized according to current technologies.

Requiring renewable energy generation may force the user to have his or her energy to be harvested. Harnessing energy through motion helps reduce electrical charging costs and reliance to the electrical grid. It is also environmentally-friendly as it motivates sustainable living. User may not generate enough energy to power the vision stick due to his or her physical disability. User might not want to generate energy from the vision stick as an alternative power sources are available. Code 7.8.1 requires engineers must be concerned in making decisions with the health and welfare of the public. Therefore, the user must be disclosed with the energy generation issues prior to product purchase. Code 7.8.6 requires that engineers must fully disclose the limitations to their engineering design. The user must be fully notified of the amount of energy generated in an understandable way. Code 7.8.2 requires that conflict of interest must be disclosed to relevant parties. Environmentalists and users must be notified of the benefits and consequences of energy generation with the vision stick.

3.3.6 Power Charging Circuit

Since the normal human is capable of shaking an object at a mechanical frequency of about 10Hz, the mechanical shaking time constant is 100ms. The power charging circuit, which consists of a bridge rectifier and a smoothing capacitor, is shown in Figure 67. The linear generator produces an AC voltage which is rectified before the smoothing capacitors follow the peaks with slight ripples for the DC charging battery supply. The two 5V input ports of the 2000mAh batteries are connected in parallel to charge both at the same time. As the electrical time constant must be greater than the mechanical time constant and the generator resistance is about 23Ω, the chosen capacitance values must be greater than 4.4mF. Hence, two 4.7mF capacitors were connected in parallel to obtain a 9.4mF capacitance.

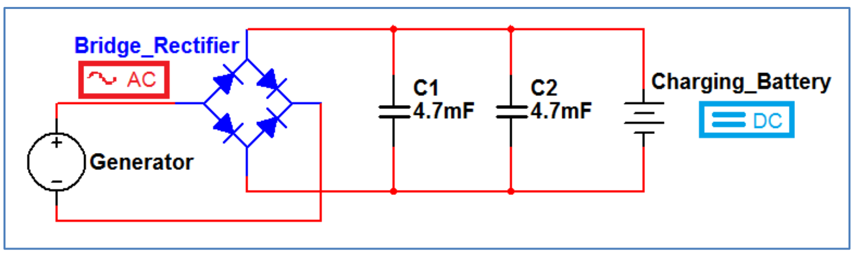


Figure 67: Power Charging Circuit of the Battery Supply

Figure 68 below shows the charging voltage created by the linear generator shaking at about a 10Hz frequency. The periodic ramps are created by the discharging the capacitor voltage into the battery which is at a minimum designed value of around ***3mV/ms***. Using smaller capacitors would increase this discharge rate to more than ***12mV/ms*** which is not desired.

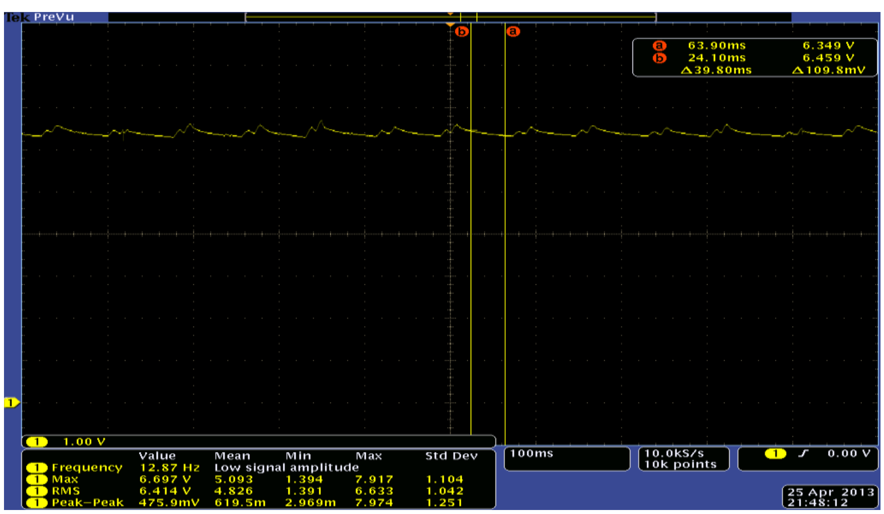


Figure 68: Oscilloscope Waveform of the Charging Voltage at a Single Battery Input Port

3.4 Extra Features

In addition to the three main features of the Self-Energized Smart Vision Stick, some extra features were incorporated that would add more value to the system and facilitate the use of the device. Each of the extra features is further explained in the next subsections.

3.4.1 Location the Vision Stick

Since the vision stick can be an integral important part of the visually-impaired person's life, appropriate measure should be taken in order to limit the chance of it being lost. An extra feature is added to the vision stick for signaling an alert for its location. Since the emergency module has GSM capability, it is leveraged to signal the alert. The way the stick location system works is by calling the SIM card number on the stick. Once the GSM module received the phone call, it will ring the connected speaker allowing the visually impaired to locate their stick in close proximity. One future improvement of this feature is perhaps to allow the emergency module to receive SMS asking for a location. Once the SMS is received, it could send and SMS of its location to the sender of the SMS. However, the privacy concern of the visually impaired should be taken into consideration if this feature were to be implemented.

3.4.2 Low Battery Indication

Since the vision stick runs on a power bank, it will eventually reach a low battery state. Unfortunately, the visually impaired does not have the ability to see a low battery LED indicator. Therefore, low battery should be detected and introduced to the visually impaired in a way they can understand. Hence, the low battery LED indicator was read using the photo resister circuitry shown in Figure 69. This method of detection was possible because the chosen power banks blink when they have low battery. The photo resister detects a low battery whenever the low battery LED indicator is off. This in essence generates a table that is illustrated on Table 5. As it can be seen from the table, when either battery indicator is off, the photo resister will output a high state. This will tell the microcontroller that there is low battery. The microcontroller will then use a buzzer beeping twice to indicate low battery. This will ensure that the visually impaired knows if the vision sticks needs recharging. Thus, preventing the vision stick from suddenly not work working because it ran out of charge.

Table 5: Truth Table of the NAND Logic for Detecting Low Battery Condition

Battery 1	Battery 2	Output
Low Charge	Low Charge	1
Low Charge	Normal Charge	1
Normal Charge	Low Charge	1
Normal Charge	Normal Charge	0

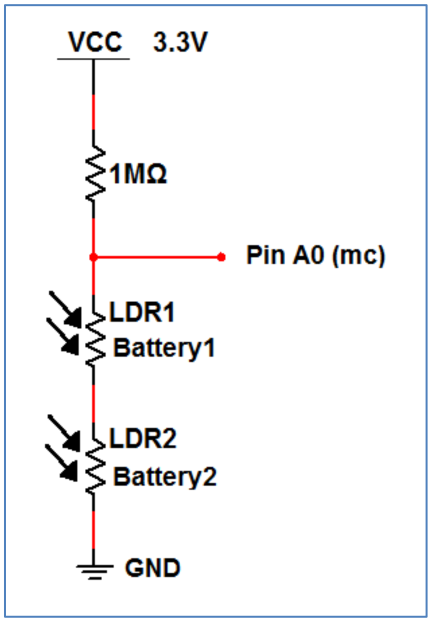


Figure 69: Circuit Schematic of the NAND Logic for Detecting Low Battery Condition

3.4.3 Automatic LED Switching

Because the visually impaired has less information to use during their commute, it means that they are at more danger than the visually capable, especially during night time. In order to increase the safety of the visually impaired, a series of nine LEDS shown in Figure 70 are placed along the stick. This will improved the visually impaired visibility to the visually capable increasing their safety. Since the visually impaired differential from light and dark areas, and to save power on the vision stick, a photo resister circuitry in Figure 70 is added to detect low light. Only when low light is detected will the stick turn on the nine LEDS. A software Schmitt trigger was implemented in order to prevent the LED from triggering. This means that the level for turning on LED is much higher than the level to turn off LED creating a seamless automated LED switching.

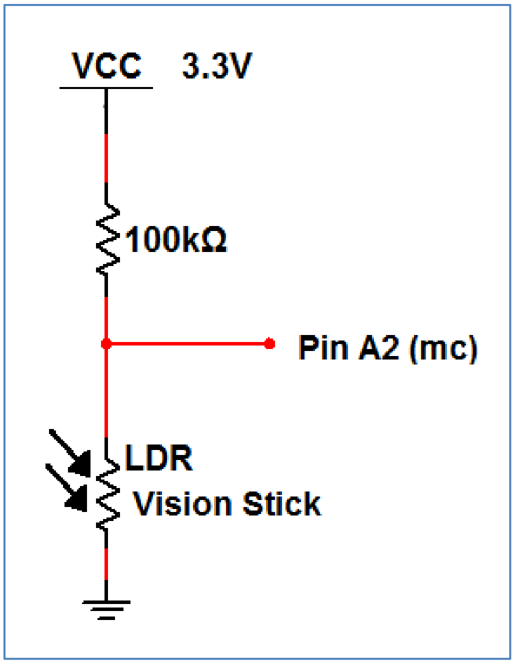


Figure 70: Circuit Schematic of the Automatic LED Switching Logic (left) and Implementation on the Prototype (right)€

3.4.4 Folding the Stick

The vision stick will accompany the visually impaired virtually everywhere. Therefore, it is important for the stick to be as portable as possible. An added feature to the vision stick is the ability to be folded as shown in Figure 71. This is will allow for more portability and it will allow the stick to accompany the visually impaired to more places. Therefore, when choosing the base of the vision stick, the ability to be folded was one of the key criteria.

Figure 71: Folding the Vision Stick for Portability

3.4.5 Two Modes of Charging

The vision stick is not only capable of being self-energized using the embedded linear generator for emergency situations, but also the battery supplies can be recharged using the mains outlet of the power utility. In this way, the fully-charged 2000mAh battery may be used for a full day before its remaining charge depletes.

4 FINAL DESIGN AND PROTOTYPE

4.1 Final Prototype

The final prototype of the Self-Energized Smart Vision Stick is illustrated in Figure 72. Each of the components are numbered and described further in the coming subsections.

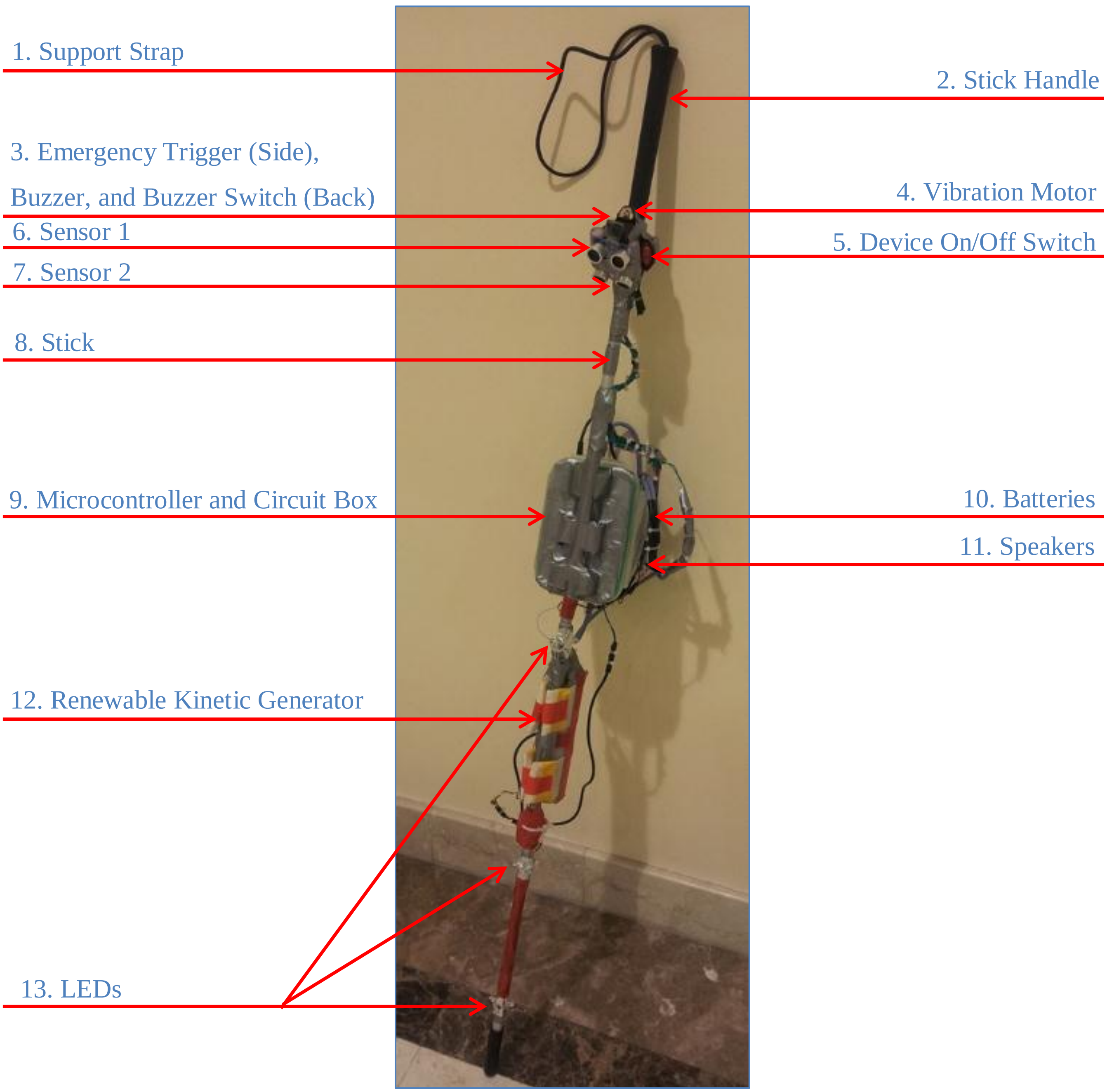


Figure 72: Final Prototype of the Self-Energized Smart Vision Stick

4.1.1 Stick Structure

The normal foldable metallic blind stick was used as the general structure for the stick which is component number 8 in Figure 72. The overall length of the stick is 120 cm. It has a support strap and a plastic handle referred to as components 1 and 2 respectively in Figure 72.

4.1.2 Emergency Trigger Switch

The emergency trigger switch is used to initiate emergency messages in case the user in lost or needs help. The location of the switch is indicated by number 3 in Figure 72. A closer view of the switch is shown in Figure 73.

Figure 73: Closer View of Emergency Trigger Switch

4.1.3 Low Battery Buzzer

A buzzer was added to the system that indicates whether the batteries have low charge or not. Also, the buzzer gives feedback for triggering emergency switch and for indicating that an emergency message has been sent. In addition, the buzzer is accompanied by a switch that gives the user the option of turning off the switch if desired. The location of the switch is indicated by number 3 in Figure 72 which is directly behind the sensors on the opposite side of the stick.

4.1.4 Speaker for Locating the Stick

As part of the extra features of the system, two speakers were added for audio feedback when the stick is called. The location of the speakers is indicated by number 11 in Figure 72. A closer view of one of the speakers is shown in Figure 74.

Figure 74: Closer View of the Speaker for Locating the Stick

4.1.5 Vibration Feedback

The location of the vibration motor is indicated by number 4 in Figure 72. Selecting the location of the vibration motor was very important since it plays a very important role in giving obstacle feedback to the user. A closer view of the location of the vibration motor with reference to the handle of the stick is shown in Figure 75.

Figure 75: Closer view of the Vibration Motor as Part of the Stick

4.1.6 Detection Sensors

The two sensors used in the system are referred to as numbers 6 and 7 respectively in Figure 72. A closer view of the sensors is shown in Figure 76, where sensor 1 has an angle of 60^0 relative to the stick while sensor 2 has an angle of 15^0 relative to the stick.

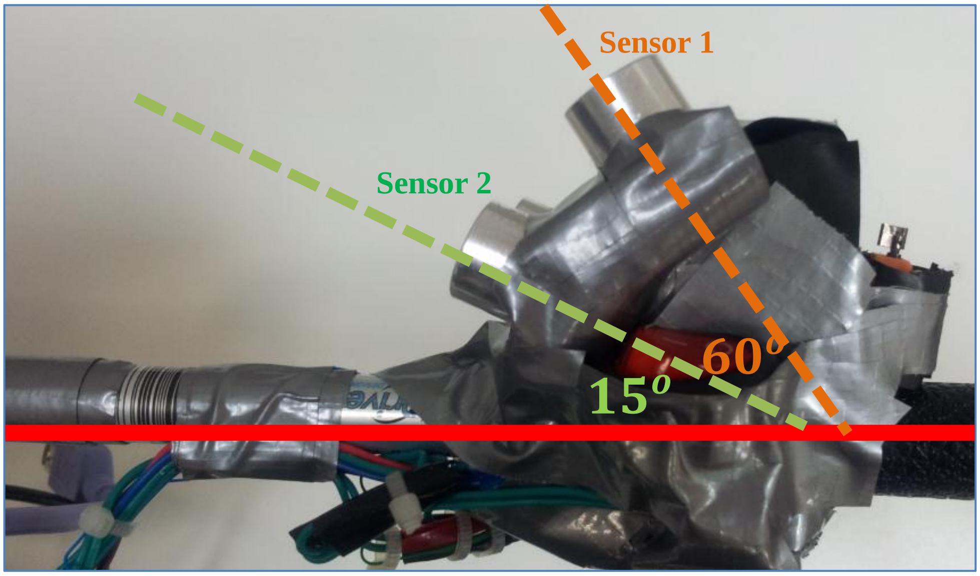


Figure 76: Closer view of the two Ultrasonic Sensors in the System and their Angle Relative to the Stick

4.1.7 Power Switch and Batteries

The power switch in the system is referred to as number 5 in Figure 72. It serves as a switch for the entire system and controls its operation. A closer view of the switch is shown in Figure 77.

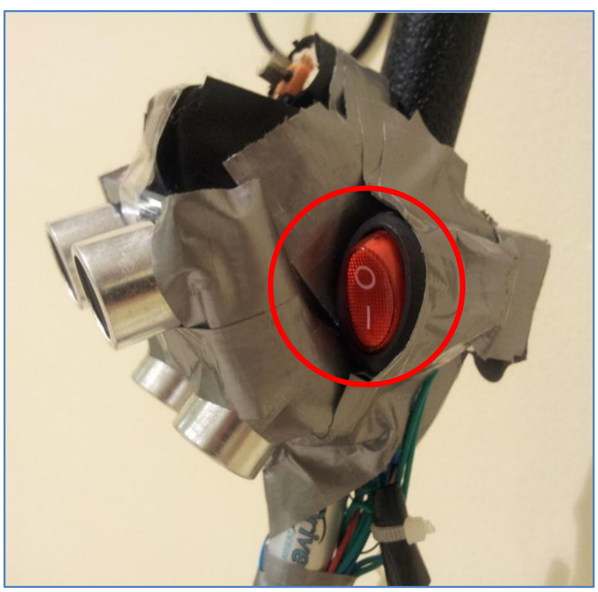


Figure 77: Closer View of the System Power Switch

The batteries in the system are referred to as number 10 in Figure 72. A closer view of the batteries, and the discharging and charging cables is shown in Figure 78.

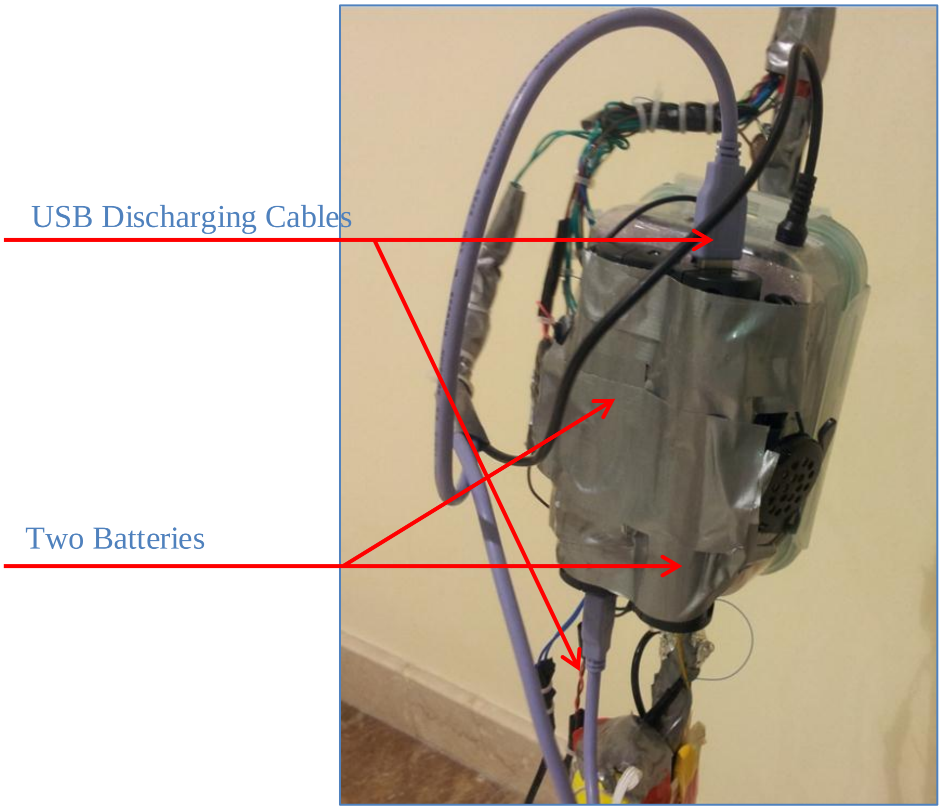


Figure 78: Closer View of the Batteries in the System

4.1.8 Renewable Kinetic Generator

The designed renewable kinetic generator is referred to as number 12 in Figure 72. A closer view of the generator is shown in Figure 79.

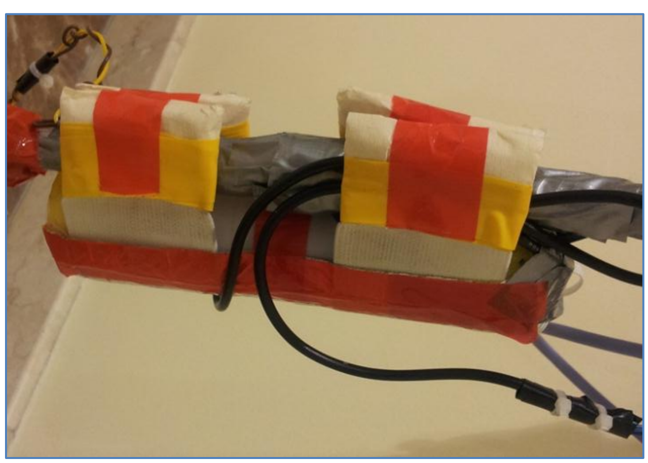


Figure 79: Closer View of the Designed Renewable Kinetic Generator Installed on the Stick

The batteries can be charged by removing the generator from the stick and shaking it for a certain period of time. The separation of the generator from the stick is illustrated in Figure 80.

Figure 80: View of the Kinetic Generator Ready for Shaking and Charging the Batteries

4.1.9 LEDs

The LEDs that automatically turn on in dark areas are referred to as number 13 in Figure 72. A closer view of the LEDs is shown in Figure 81.

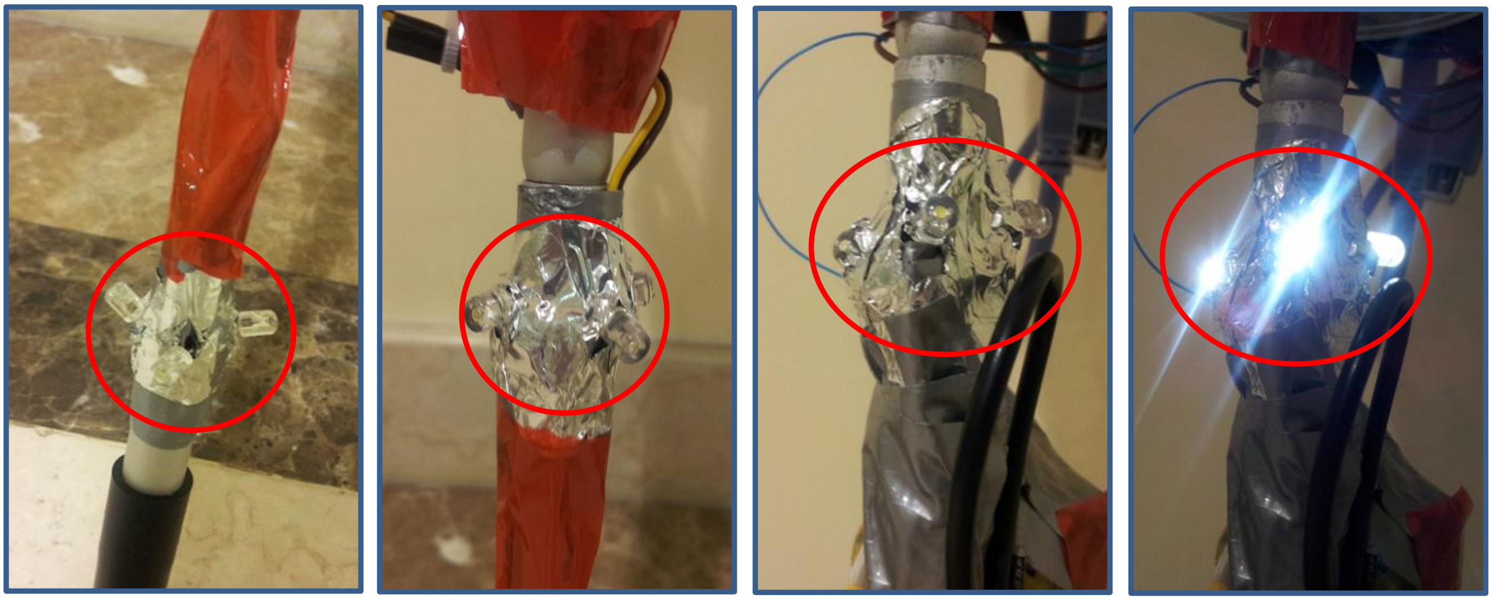


Figure 81: Closer view of the Three LED Locations on the Stick

4.1.10 Microcontroller and Circuit Box

The microcontroller and circuit box are referred to as number 9 in Figure 72. A closer view of the exterior of the box is shown in Figure 82.

Figure 82: Close View of the Exterior of the Microcontroller and Circuit Box

On the upper part, the box was carved such that it is easy to communicate with the microcontroller through different cables. Figure 83 illustrates the holes made into the box for the different purposes.

Figure 83: Close View of Holes Made into the Microcontroller and Circuit Box for Different Cables

Finally, Figure 84 shows the microcontroller and the GPS/GPRS/GSM modules inside the box.

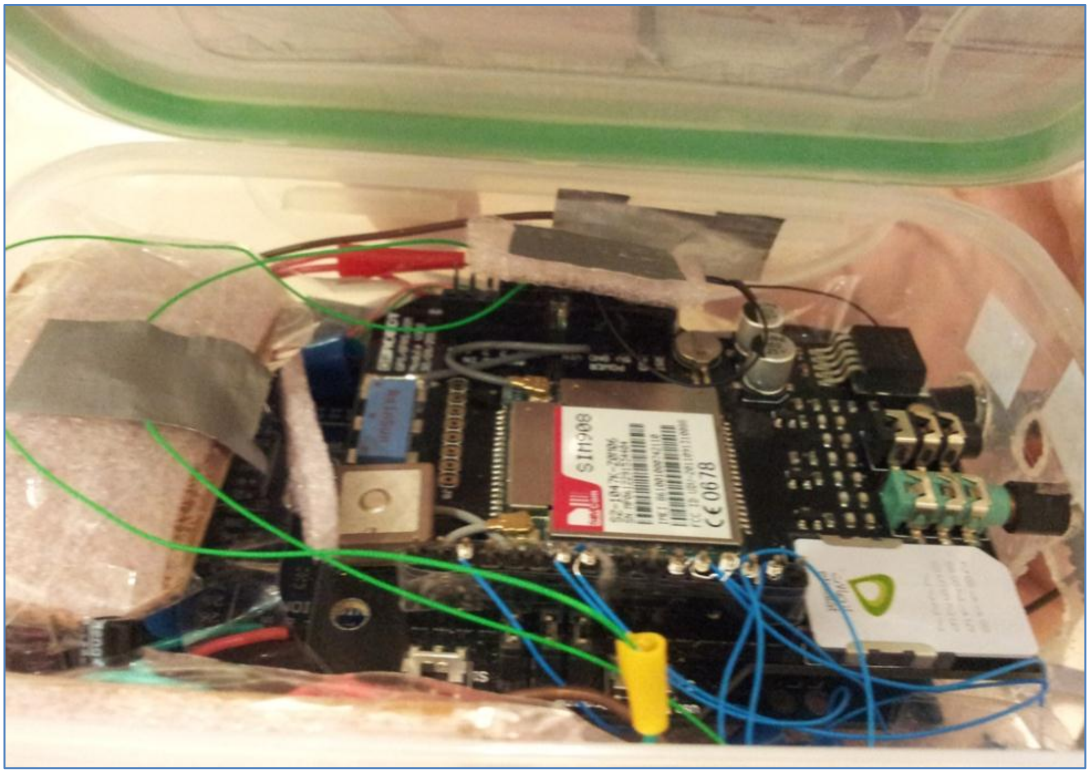


Figure 84: The Microcontroller, the Different Modules, and the System Circuits inside the Box

In Table 6 below, the digital and analog pin connections used for connecting the different electronics components are shown.

Table 6: Pin Connection from Electronic Components to the Arduino Microcontroller

Type	**Electronic Component**	**Pin Connection to MC**
Input	Ultrasonic Sensor 1 (Upper)	Digital Pin 7
Input	Ultrasonic Sensor 2 (Lower)	Digital Pin 6
Output	Vibration Motor	Digital Pin 10
Input	Battery LDRs	Analog Pin 0
Output	Buzzer	Digital Pin 11
Input	Light/Dark LDRs	Analog Pin 2
Output	Stick LEDs	Digital Pin 12
Input	Emergency Trigger Switch	Digital Pin 2

4.2 Combined Code of the Detection and Alert System with the Emergency System

One of the main challenges faced during the implementation of the project was to combine the code for detection and alert system with the code for the emergency system that used to operate independently at earlier stages of the design. The flow chart in Figure 85 illustrates the logic and the implemented algorithms in the entire Self-Energized Smart Vision Stick system. The emergency code requires the processors to be constant checking for GPS connections before sending and SMS. This means that throughout the process of fetching GPS coordinates the user will not be able to use the vision stick. In addition, the detection and alert uses the delay function to control the vibration. Any tempering with the delay will give the visually impaired a false or a not comprehendible feedback making the vision stick useless. Therefore, for the vision stick to be successful, it needs to overcome the limitation.

The solution to this problem is to break the emergency system part into separate smaller functions can perform different task. As illustrated on Figure 85, flag where used to determine which function to execute. For instance, when the emergency button is clicked, the emergency button handler will execute. Within the handler, the start GPS flag will be set then the program will return to the main function of detecting and altering. Once it reached the emergency section, it will check to see that the start GPS flag is raised and it will start the GPS. At the end of start GPS flag, the check GPS status flag will be raised and the program will return to the main function of detecting an alerting. The same process will repeat until the GPS is connected, GPS coordinates are read, and SMS sent. One important fact is that each function takes 350ms to execute. This 350ms is intentionally placed in order to perform the vibration feedback.

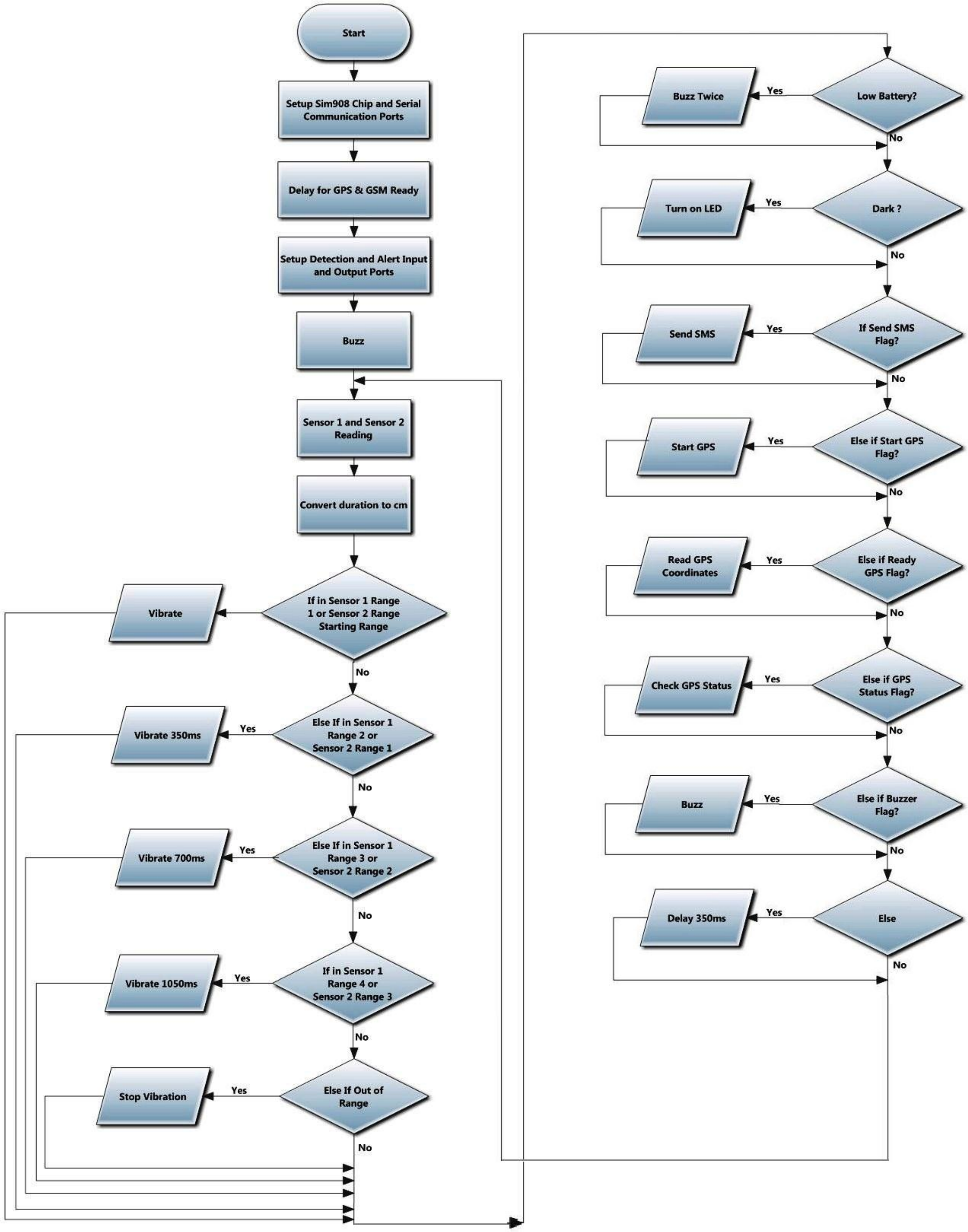


Figure 85: Complete Detection and Alert System with Emergency System Program Flowchart

Since tradition delay function is not feasible for vibration feedback when combining the code with emergency code, an alternative way of executing vibration feedback should be implemented. As it can be seen on Figure 85, the detection and alert part of the system is checking to see which vibration feedback to implement depending on the distance from the vision stick. The vibration feedback is implemented by introducing a counter value. The counter will set the vibration motor to high and then go through a loop that takes a cycle time 350ms. The 350ms can either be one of the emergency functions or if the emergency is not executed, the else condition will add a 350ms delay. This will ensure that it will always take 350ms to execute one loop of the program. This means that in order to have 750ms, the counter needs to be incremented twice. Hence, the counter can be used to control the vibration feedback and obtained the desired delay. The final code of the complete emergency system working with the detection and alert is provided in Appendix B. Here, the code shows the details of successfully implementing the algorithm. Also, it is important to note that the battery indicates as well as the LED automatic switching has been implemented using the same methodology.

5 PROTOTYPE PERFORMANCE

5.1 Power Consumption and Generation

Considering all the different combinations of the components operating as shown in Table 7 at a supplied voltage of 10V, the minimum power consumption is around 2.1W and the maximum power consumption is estimated to be about 4.4W. By using a hybrid power supply of two battery banks of 2000mAh charge rating, the smart stick is able to supply this power rating for a longer time alongside the renewable power generation. Each battery bank has an output voltage of 5V, and the two output ports are connected in series to supply the Arduino microcontroller with 10V. The input ports are connected for charging via the mains outlet or the linear generator.

Table 7: Estimated Power Consumption of the Vision Stick

Safety LEDs	Stick Finder (Calling)	Object Detection & Alert	
		No Object	Near Object
OFF	OFF	210 mA	270 mA
OFF	ON	240 – 320 mA	300 – 380 mA
ON	OFF	270 mA	330 mA
ON	ON	330 – 380 mA	380 – 440 mA

While retrieving the GPS location and sending the emergency SMS, the average current consumption is around 260mA. The average time taken to send one emergency SMS since the moment the emergency trigger button was pressed is around 2 minutes leading to a needed electric charge of 8.67mAh. On full battery charge of 2000mAh, the system is capable of sending 230 emergency SMSs or operating only the object detection and alert for about 8 hours. By shaking the designed linear generator for a maximum of 15 minutes and a minimum of 10 minutes, the battery supply will be able to store enough charge for one emergency SMS. This vital feature is crucial during emergency situations when the vision stick is nearly out of charge. However, the key limitation of the battery supply poses a problem for the charging behavior of the linear generator. The battery supply does not allow both the charging and discharging ports to be used at the same time.

Both Prototype 1 and Prototype 2 of the linear AC synchronous generator have been compared below in Table 8. It can be seen that Prototype 2 generated more than **eleven times** more power than Prototype 2. Also, the power mass density of Prototype 2 is more than **four times** more than

Prototype 1. This shows the significant improvement and current challenge that was overcome in generating multiple times the first prototype.

Table 8: Power Generation Comparison of the Two Prototypes

Prototype	Mass (g)	Power Generated (mW)	Power Mass Density (mW/g)
1	56	140	2.5
2	150	1600	10.7

5.2 Vision Stick Usability

Upon designing the vision stick, different people tested the stick and were able to learn using the system within the first few minutes. Even though they were suing the vision stick for the first time, the small learning curve of the detection and alert system allowed them to be trained fast. It can be deduced that the use of vibration motors simplifies the learning process for detecting objects at the ground and waist levels. However, a visually-impaired volunteer is still needed to practically use the stick and to provide feedback for improving the prototype stick's usability and for adding features that are currently not implemented. The automatic LED switching works well in dark conditions and helps peoples at distances to identify the vision stick's user. Not to forget, the vision stick is a universally-portable device that can be used by any person physically capable of carrying it around at any time. This feature identifies the project's unique challenge into packaging a prototype as compact as possible.

As in every engineering prototype, a few system limitations exist. For example, the vision stick is not capable of detecting objects lower than the ground level such as a hole or stairs going down. Also, the mass distribution of the vision stick is not well-balanced and can tire the user if used for long periods. Future improvements of the vision stick must improve upon the overall *1kg* mass of the stick which may be able to pose wrist pains for the user.

-

6 PROJECT DESIGN PARAMETERS

In this section, different design parameters of the Self-Energized Smart Vision Stick such as the project cost and mass obtained are shown in the following subsections.

6.1 Cost and Mass

For every part of the project, the different components needed were found and listed along with their prototype cost and mass in Table 9 below. It was found that the total approximated mass of the current prototype stick is about *1kg*.

Table 9: Final Mass of the Self-Energized Smart Vision Stick Prototype

Required Components	Unit Mass	Total Mass
PING Ultra Sonic Sensor	2 x 10.0g	20.0g
Vibration Motors	1 x 5.0g	5.0g
Arduino Mega Microcontroller	1 x 35.0g	35.0g
GPS/GPRS/GSM V3.0 Module	1 x 37.0g	37.0g
Linear Electric Generator	1 x 200.0g	200.0g
Buttons and Switches	3 x 5.0g	15.0g
Portable Rechargeable Batteries	2 x 90.0g	180.0g
Blind Cane	1 x 250.0g	250.0g
Plastic Food Container	1 x 50.0g	50.0g
Miscellaneous	1 x 250.0g	250.0g
	Total Prototype Mass $\approx \mathbf{1.042}\ \boldsymbol{kgs}$	

In Table 10 on the next page, the total project development costs such as current purchases and shipment costs is shown. Also, the total purchase cost was approximated to be about *AED 3000*, and the total approximated prototype cost for this project was calculated to be about *AED 1400* which is less than the proposed $500 cost. Many components were purchased for the vision stick's research and design that were eventually not used in the prototype. Also, the labor cost is calculated as part of the development costs. If 3 employees work over 14 weeks at a work rate of 15 hours per week and a pay rate of $20 per hour, the total labor cost would be:

Total Labor Cost = $12,600 ≈ AED 47,500

Table 10: Updated Project Development Costs

Current Purchases	Quantity	Unit Price (AED)	Total Price (AED)	Quantity Used in Prototype
iPhone 4G S Vibration Motor	1	10.00	10.00	-
iPhone 4G Vibration Motor	5	6.00	30.00	-
VTRMIX Vibration Motor	10	4.00	40.00	1
iPhone 4GS Vibration Motor	5	6.00	30.00	-
Motion Sensor	1	30.00	30.00	-
Ultrasonic Module HC-SR04 Sensor	1	118.00	118.00	-
Ultrasonic Transducers SQ-40 R/T	2	10.00	20.00	-
2 Port Wires	5	2.00	10.00	-
Arduino MEGA 2560 MC	1	250.00	250.00	1
Piezo Touch Sensor	1	15.00	15.00	-
Insulation Paper 0.5mm (Mtr)	4	4.00	16.00	1
Insulation Paper 1.2mm (Mtr)	4	8.00	32.00	1
Zener Diodes	5	2.00	10.00	-
1 Watt Resistors	12	0.50	6.00	-
Compression Springs	3	16.50	49.50	-
Spring Kit	1	50.00	50.00	-
Earphones	1	6.50	6.50	1
Red Colored Tape	1	3.50	3.50	1
Duct Tape	1	7.50	7.50	1
Folding Blind Cane	1	119.00	119.00	1
Battery Holders	2	4.50	9.00	1
Bicycle Dynamo	2	20.00	40.00	-
Capacitors (3300uF & 4700uF)	7	-	20.00	2
LDRs	3	14.00	42.00	3
Buzzers	4	5.00	20.00	1
Portable Battery Supplies	2	90.00	180.00	2
Bearings (small)	10	2.00	20.00	-
Bearings (big)	5	4.00	20.00	-

Steel Balls (pack)	1	10.00	10.00	-
Parallax Ultrasonic Sensors	4	110.36	441.44	2
GSM/GPS Module v2.0	1	365.32	365.32	1
UPS Shipping	1	202.60	202.60	1
Apex Magnet Order	1	502.87	502.87	1
USPS Shipping	1	229.59	229.59	1
			Total Purchase Cost (AED)	**Prototype Cost (AED)**
			≈ 3000.00	**≈ 1400.00**

Total Development Cost = Total Labor Cost + Total Purchase Cost ≈ AED 51,000.00

6.2 Prototype Breakeven Analysis and Economics

Breakeven Analysis

A simplistic breakeven analysis can be used to obtain the required number of vision sticks needed to be sold in mass production for a machine option versus a handcraft option. The calculations are shown below:

Option 1: Machine AED 20,000.00 annual pay + AED 20.00 per product

Option 2: By hand AED 90.00 per product

Number of Products Needed to Break Even = 285.7 units

Investment Cost

The mass production cost can be subdivided into the following by choosing n=500 units:

- Cost to develop ≈ AED 51,000
- Costs of marketing and distribution are neglected
- Cost to mass manufacture in Year 0 = Machine Cost + Material Cost =

  AED 20,000 + (AED 1,400)n ≈ AED 720,000

Hence, the **total project's investment cost is approximately AED 771,000**.

Cash Flow Diagram

By choosing 500 units to manufacture in Year 0 for selling over a 5 year period at an inflation rate of 2% and initial investment cost of AED 771,000, where a constant 100 units are sold per year, the cash flow diagram is represented Figure 86. The future-to-present cash conversions are shown in the bulleted list below.

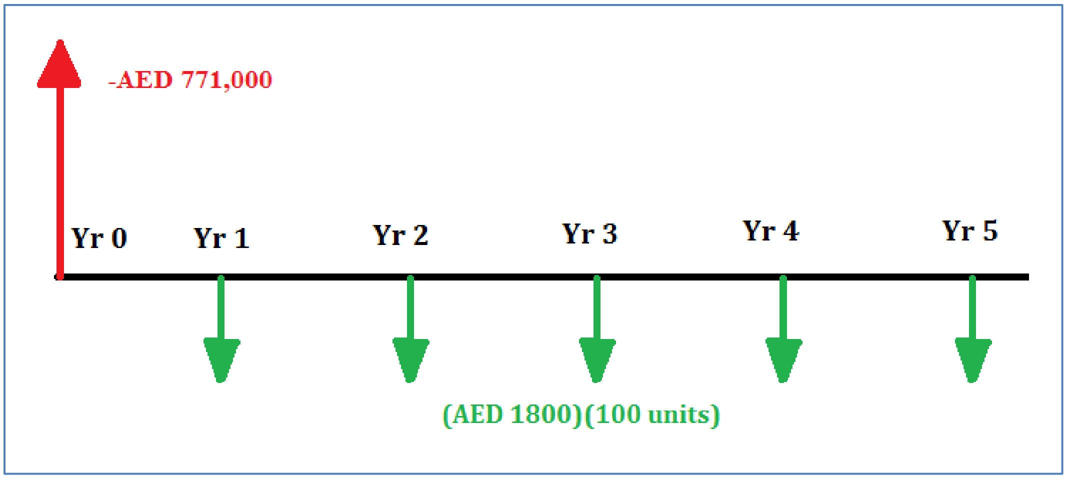


Figure 86: Cash Flow Diagram over a 5 Year Project Investment

- Year 1: (100units)(AED 1800)/(1.02) = AED 176,471
- Year 2: (100units)(AED 1800)/$(1.02)^2$ = AED 173,011
- Year 3: (100units)(AED 1800)/$(1.02)^3$ = AED 169,618
- Year 4: (100units)(AED 1800)/$(1.02)^4$ = AED 166,293
- Year 5: (100units)(AED 1800)/$(1.02)^5$ = AED 163,032

Net Present Value of Project Investment = AED 848,425 – AED 771,000 = +AED 77,425

Maintenance Cost

Since the engineering prototype is not well-package and mass produced, it requires more frequent maintenance than the usual electronic devices. Considering that the electric generator case and internal permanent magnet can last for many decades to its protected structure and the electronic components are not subjected to abnormal weather conditions, such as sandstorms and heavy rain, the portable battery banks must be replaced every two years along with all the wiring connections. In total, a maintenance cost of around ***AED 300*** is necessary every two to three years is necessary for the prototype's proper functionality.

7 PROJECT PLANNING

In Figure 87 below, the final project Gantt chart is shown with the given tasks on the left column. The dark blue bars represent the completed tasks where the group members have successfully overcome project problems such as component shipment delays. The project's team members were successful in overcoming the different milestones and challenges throughout the 15 week timeline to finally deliver the working proposed prototype with extra features.

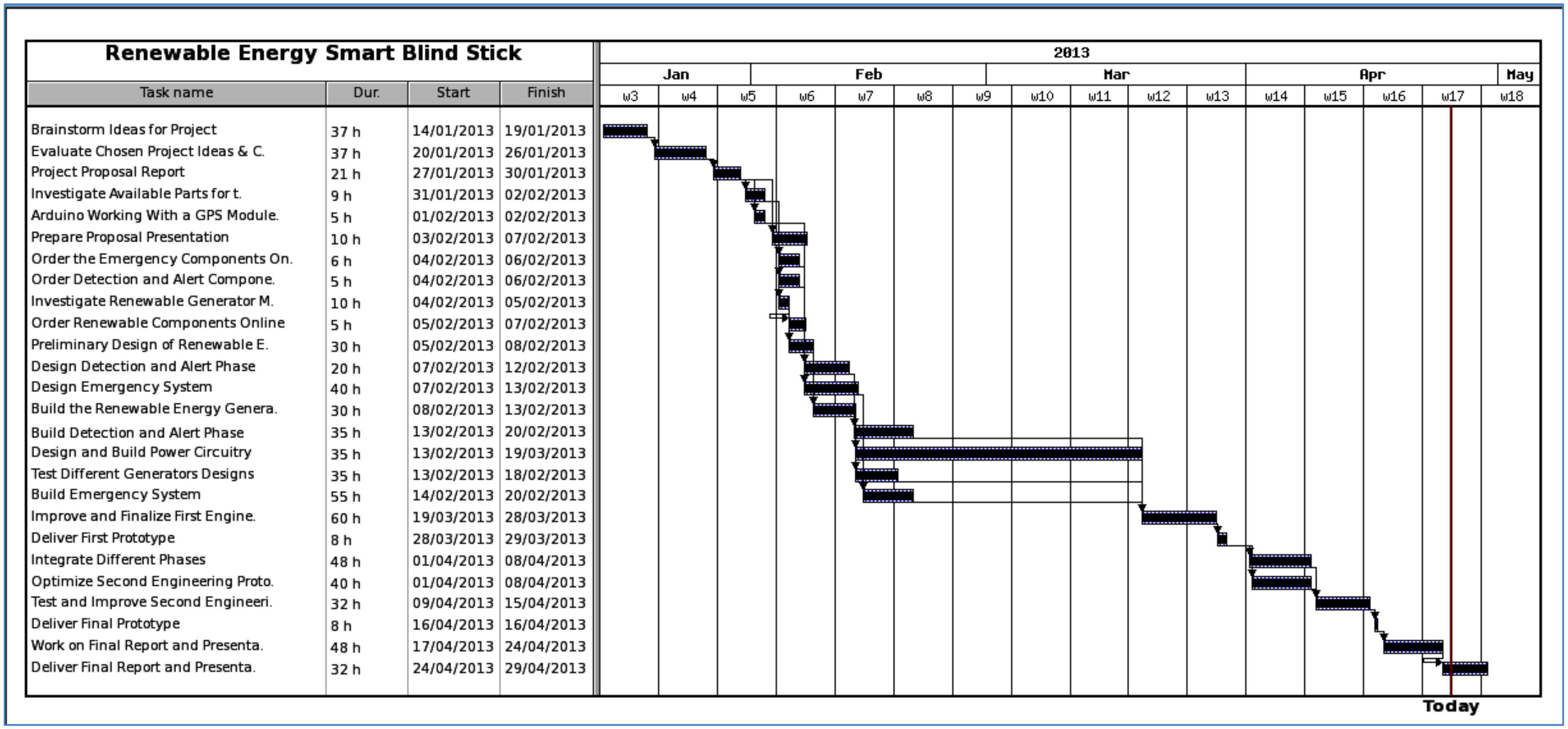


Figure 87: Completed Project Gantt Chart

Figure 88 below shows the project task list for the Self-Energized Smart Vision Stick. The green rows indicate that the tasks have been completed or over the assigned dates. In spite of certain delays throughout the semester, the project team members were able to work harder in certain periods to overcome and meet the certain deadlines. By using the project planning tool, the team members were able to follow an orderly and logical pattern toward reaching the final project goal.

	Pin	New Log	Work	P	Task Name	Task Creator	Assigned Users	Start Date	Duration	Finish Date
		Log	100%		Brainstorm Ideas for Project	saif	mohammad (100%) (+2)	14/01/2013 12:00 pm	37 hours	19/01/2013 05:00 pm
		Log	100%		Evaluate Chosen Project Ideas & Choose Final Idea	saif	mohammad (100%) (+2)	20/01/2013 12:00 pm	37 hours	26/01/2013 05:00 pm
		Log	100%		Project Proposal Report	saif	mohammad (100%) (+2)	27/01/2013 12:00 pm	21 hours	30/01/2013 05:00 pm
		Log	100%		Investigate Available Parts for the Project in the UAE Market	saif	mohammad (100%)	31/01/2013 08:15 am	9 hours	02/02/2013 04:15 pm
		Log	100%		Arduino Working With a GPS Module obtained from Hashem	saif	saif (100%)	01/02/2013 12:00 pm	5 hours	02/02/2013 04:00 pm
		Log	100%		Prepare Proposal Presentation	saif	mohammad (100%) (+2)	03/02/2013 03:00 pm	10 hours	07/02/2013 05:00 pm
		Log	100%		Order the Emergency Components Online	saif	mohammad (100%) (+2)	04/02/2013 08:00 am	6 hours	06/02/2013 05:00 pm
		Log	100%		Order Detection and Alert Components Online	saif	mohammad (100%) (+2)	04/02/2013 08:00 am	5 hours	06/02/2013 05:00 pm
		Log	100%		Investigate Renewable Generator Materials Needed	saif	mohammad (100%) (+2)	04/02/2013 08:00 am	10 hours	05/02/2013 01:00 pm
		Log	100%		Preliminary Design of Renewable Energy Generator	saif	mohammad (70%) (+2)	05/02/2013 01:00 pm	30 hours	08/02/2013 12:00 pm
		Log	100%		Order Renewable Components Online	mohammad	mohammad (100%) (+2)	05/02/2013 01:00 pm	5 hours	07/02/2013 02:00 pm
		Log	100%		Design Detection and Alert Phase	saif	sana (80%) (+2)	07/02/2013 08:00 am	20 hours	12/02/2013 05:00 pm
		Log	100%		Design Emergency System	saif	saif (80%) (+2)	07/02/2013 08:00 am	40 hours	13/02/2013 05:00 pm
		Log	100%		Build the Renewable Energy Generator	mohammad	mohammad (80%) (+2)	08/02/2013 12:00 pm	30 hours	13/02/2013 01:00 pm
		Log	100%		Build Detection and Alert Phase	mohammad	mohammad (100%) (+2)	13/02/2013 08:00 am	35 hours	20/02/2013 09:00 am
		Log	100%		Design and Build Power Circuitry	saif	mohammad (80%) (+2)	13/02/2013 01:00 pm	35 hours	19/03/2013 01:00 pm
		Log	100%		Test Different Generators Designs	mohammad	mohammad (80%) (+2)	13/02/2013 01:00 pm	35 hours	18/02/2013 01:00 pm
		Log	100%		Build Emergency System	mohammad	saif (100%)	14/02/2013 08:00 am	55 hours	20/02/2013 09:00 am
		Log	100%		Improve and Finalize First Engineering Prototype	saif	mohammad (100%) (+2)	19/03/2013 01:00 pm	60 hours	28/03/2013 12:00 pm
		Log	100%		Deliver First Prototype	saif	mohammad (100%) (+2)	28/03/2013 03:00 pm	8 hours	29/03/2013 05:00 pm
		Log	100%		Integrate Different Phases	mohammad	mohammad (100%) (+2)	01/04/2013 08:00 am	48 hours	08/04/2013 05:00 pm
		Log	100%		Optimize Second Engineering Prototype	mohammad	mohammad (100%) (+2)	01/04/2013 04:00 pm	40 hours	08/04/2013 05:00 pm
		Log	100%		Test and Improve Second Engineering Prototype	mohammad	mohammad (100%) (+2)	09/04/2013 08:00 am	32 hours	15/04/2013 05:00 pm
		Log	100%		Deliver Final Prototype	mohammad	mohammad (100%) (+2)	16/04/2013 08:00 am	8 hours	16/04/2013 04:00 pm
		Log	100%		Work on Final Report and Presentation	mohammad	mohammad (100%) (+2)	17/04/2013 10:00 am	48 hours	24/04/2013 09:00 am
		Log	100%		Deliver Final Report and Presentation	mohammad	mohammad (100%) (+2)	24/04/2013 09:00 am	32 hours	29/04/2013 05:00 pm

Figure 88: Completed Project Task List

8 CONCLUSION

The design process, detailed implementation methodologies, project planning, and progress of the Self Energized Renewable Smart Vision Stick senior design project was presented. The vision stick project focuses on detecting surrounding obstacles and alerting the visually impaired of their proximities. The two designed placements of the ultrasonic sensors detect objects at the ground and waist levels up to a maximum of 2m. The emergency features allows for the visually impaired to manually trigger for help by sending a message to the relevant emergency contact with the GPS coordinates of the visually impaired. As of now, the GPS/GPRS/GSM module can successfully send an SMS with the GPS coordinate with an accuracy of about +/- 10m from the true location. The renewable energy generation focuses on converting the kinetic energy into stored electrical energy that powers the vision stick. Thus far, performance test was conducted to choose the best super magnet, number of turns and coil design. More than 1.5Watts of electric power was obtained during the experimentations and different tests which is 11 times stronger than the compared industrial prototype. The extra features added improve the overall usability of the smart stick, such as automatic LED switching for safety lights during nighttime use.

The final engineering prototype was delivered in Week 15 which met all the proposed features in addition to the extra features discussed. Compared to previous senior designs presented in the Department of ECE at AUD, this project uniquely stands out for being universally-portable for any user capable of physically carrying the vision stick. Many challenges and deadlines were faced on the course of the project such as patiently waiting for components shipping delays, learning to interface with new hardware, combining the separate project codes and coming up with new optimized generator design. Therefore, the completion of this senior design project within 15 weeks is an accomplishment for all team members and supporting members.

For future development, the object detection and alert must be enhanced to account for more details which were currently ignored such as moving objects on the stick's sides and falling stairs. The packaging team must ensure that the final product is lighter than the current 1kg prototype and has an ergonomic design. Also, an indoor emergency feature must be integrated to ensure call for help at all times, and smartphone integration can further widen the features of the Self-Energized Smart Vision Stick.

9 BIBLIOGRAPHY

[1] (2012, June) World Health Organization. [Online]. http://www.who.int/mediacentre/factsheets/fs282/en/

[2] Mary Catherine O'Connor. (2009, September) Michigan Students to Develop RFID-enabled Robotic Guide Dog. [Online]. http://www.rfidjournal.com/article/view/5214/1

[3] Mohd Helmy Abd Wahab et al., "Smart Cane: Assistive Cane for Visually-impaired People," *IJCSI International Journal of Computer Science Issues*, vol. 8, no. 4, pp. 21-27, 2011. [Online]. http://arxiv.org/ftp/arxiv/papers/1110/1110.5156.pdf

[4] MoriBus. (2010, December) Safety First Series - Gloves - Rubber - Short Cuff. [Online]. http://sketchup.google.com/3dwarehouse/details?mid=25c22eb4a826f622e4773d7a183337d9&prevstart=0

[5] Dj:Tj. (2007, March) black T-shirt. [Online]. http://sketchup.google.com/3dwarehouse/details?mid=6547433f606945dbd9d6eb448e778c01&prevstart=0

[6] (2012, January) Bit-Tech. [Online]. http://images.bit-tech.net/content_images/2013/01/bit-tech-raspberry-pi-case-competition/raspberry-pi-model-b-512mb-1280x1024.jpg

[7] (2012) Nice Gear. [Online]. http://nicegear.co.nz/obj/images/arduino_mega.jpg

[8] (2012) Robot Shop. [Online]. http://www.robotshop.com/Images/xbig/en/parallax-ping-ultrasonic-sensor-B.jpg

[9] Mobile Spares. [Online]. http://www.mobilephone-spares.com/images/P/Nokia-7610-7610B-Vibrator-Motor-Original.jpg

[10] DF Robot Wiki. (2013) GPS/GPRS/GSM Module V3.0 (SKU:TEL0051). [Online]. http://www.dfrobot.com/wiki/index.php/GPS/GPRS/GSM_Module_V3.0_(SKU:TEL0051)

[11] Parallax. [Online]. http://www.parallax.com/Portals/0/Downloads/docs/prod/acc/28015-PING-Sensor-Product-Guide-v2.0.pdf

[12] Namiki. Vibration Motors. [Online]. http://www.namiki.net/product/vibration/motor/tech.html

[13] Understanding ERM Vibration Motor Characteristics. [Online]. http://www.precisionmicrodrives.com/application-notes-technical-guides/application-bulletins/ab-004-understanding-erm-characteristics-for-vibration-applications

[14] Wikimedia. Red LED. [Online]. http://commons.wikimedia.org/wiki/File:Red_led_x5.jpg

[15] UltraCane. How to choose the correct length UltraCane. [Online]. http://www.ultracane.com/ultracane_size

[16] Lone Some Mercury. [Online]. http://www.lonesomemercury.com/wp-content/uploads/2011/09/water-benefits-to-human-body.jpg

[17] Statistic Brain. Human Body Statistics. [Online]. http://www.statisticbrain.com/human-body-statistics/

[18] EHow. How Does GSM Phone Work? [Online]. http://www.ehow.com/how-does_5041190_gsm-phone-work.html

[19] GSM Freq Band. [Online]. http://www.worldtimezone.com/gsm.html

[20] Skobzar. GSM Cell Tower. [Online]. http://www.skobzar.co.uk/sk/gsm-cell-tower-info/

[21] Physics.org. How Does GPS Work? [Online]. http://www.physics.org/article-questions.asp?id=55

[22] What is AT Command? [Online]. http://www.engineersgarage.com/definitions/what-is-at-command

[23] Jeremy Blum. (2011, March) JeremyBlum. [Online]. http://www.jeremyblum.com/2011/03/07/arduino-tutorial-10-interrupts-and-hardware-debouncing/

[24] Way 2 Science. Faraday's Law Animation. [Online]. http://www.way2science.com/wp-content/uploads/2012/03/faradyanim.gif

[25] Apex Magnets. Glossary. [Online]. http://apexmagnets.com/index.php?main_page=page&id=3&zenid=2f8725d3e96ccacb6e24e36cda68ac1a

[26] Shinetsu. Rare Earth Basics. [Online]. http://www.shinetsu-rare-earth-magnet.jp/e/design/

[27] Magnet Sales. Magnets. [Online]. http://www.magnetsales.co.uk

[28] Stephen P Beeby and Terence O'Donnell, "Electromagnetic Energy Harvesting," in *Energy Harvesting Tecnologies*, Shashank Priya and Daniel J Imman, Eds.: Springer.

10 APPENDIX

10.1 Appendix A

10.1.1 Color Test

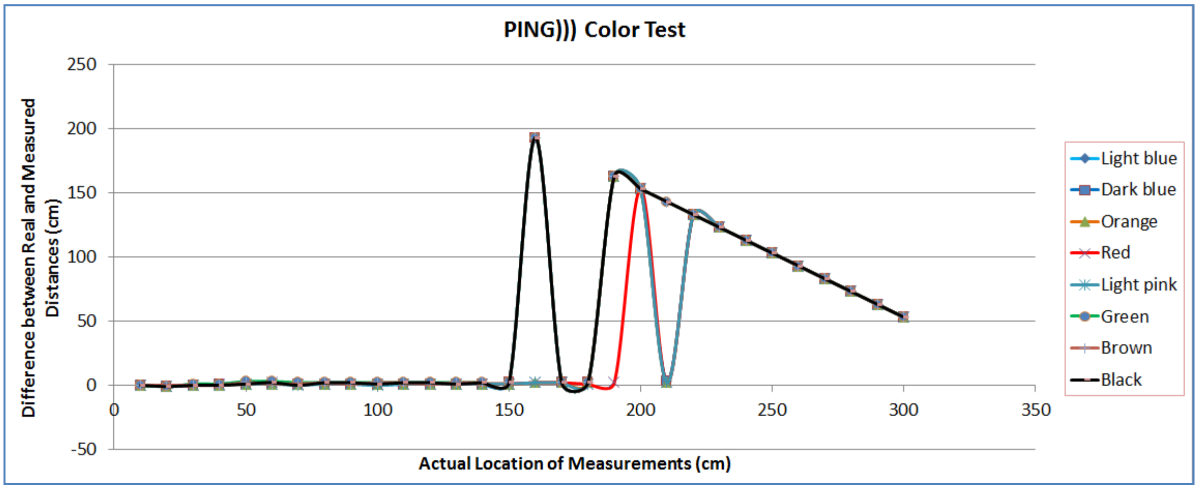


Figure 89: PING))) Sensor Color Test Results

Table 11: Data Values for Color Test

Color	Maximum Distance (cm)
Light blue	180
Dark blue	180
Orange	180
Red	190
Light pink	180
Green	180
Brown	180
Black	180

10.1.2 Material Test

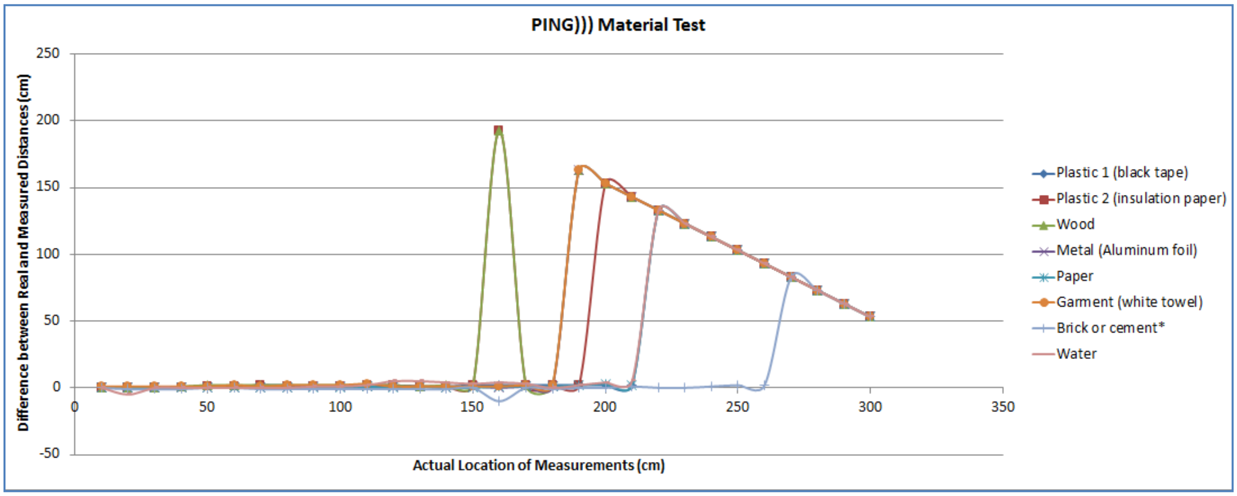


Figure 90: PING))) Sensor Material Test Results

Table 12: Data Values for Material Test

Material	Maximum Distance (cm)
Plastic 1 (black tape)	210
Plastic 2 (insulation paper)	190
Wood	180
Metal (aluminum foil)	180
Paper	210
Garment (white towel)	180
Brick or cement*	260
Water	210

10.1.3 Common Objects Test

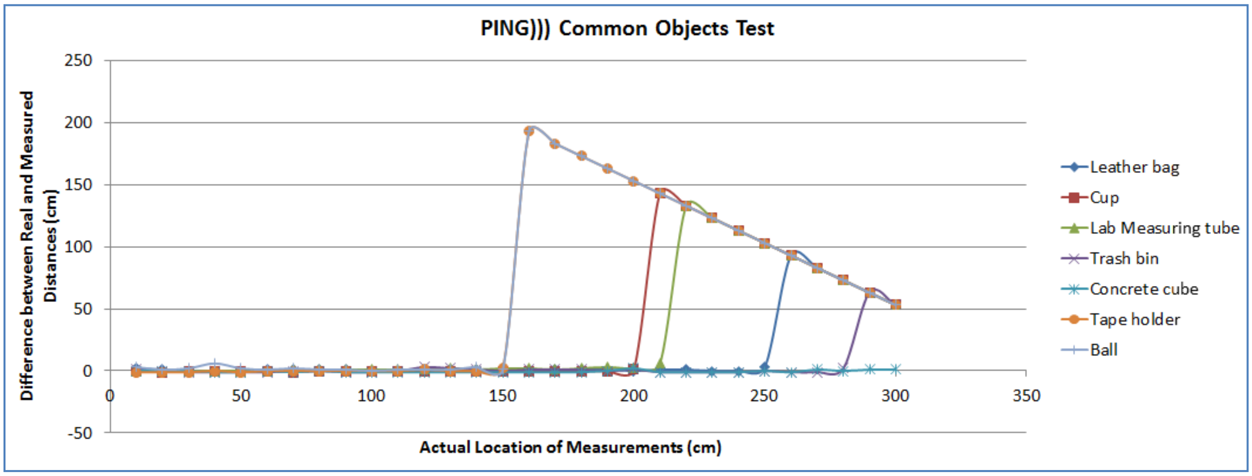


Figure 91: PING))) Sensor Common Objects Test Results

Table 13: Data Values for Common Objects Test

Shape	Maximum Distance (cm)	Dimensions
Leather bag	250	33 × 34 cm
Cup	200	H = 14 cm, 1 = 3.75 cm
Lab Measuring tube	210	H = 43 cm, r = 3.5 cm
Trash bin	280	H = 29 cm , r = 11 cm
Concrete cube	300	16 × 16 × 16 cm
Tape holder	150	15 × 5 × 5 cm
Ball	150	r = 12.5 cm

10.1.4 Vibration Motor Test

The graph in Figure 92 illustrates the measured current-voltage characteristic for each vibration motor and the different intensity levels.

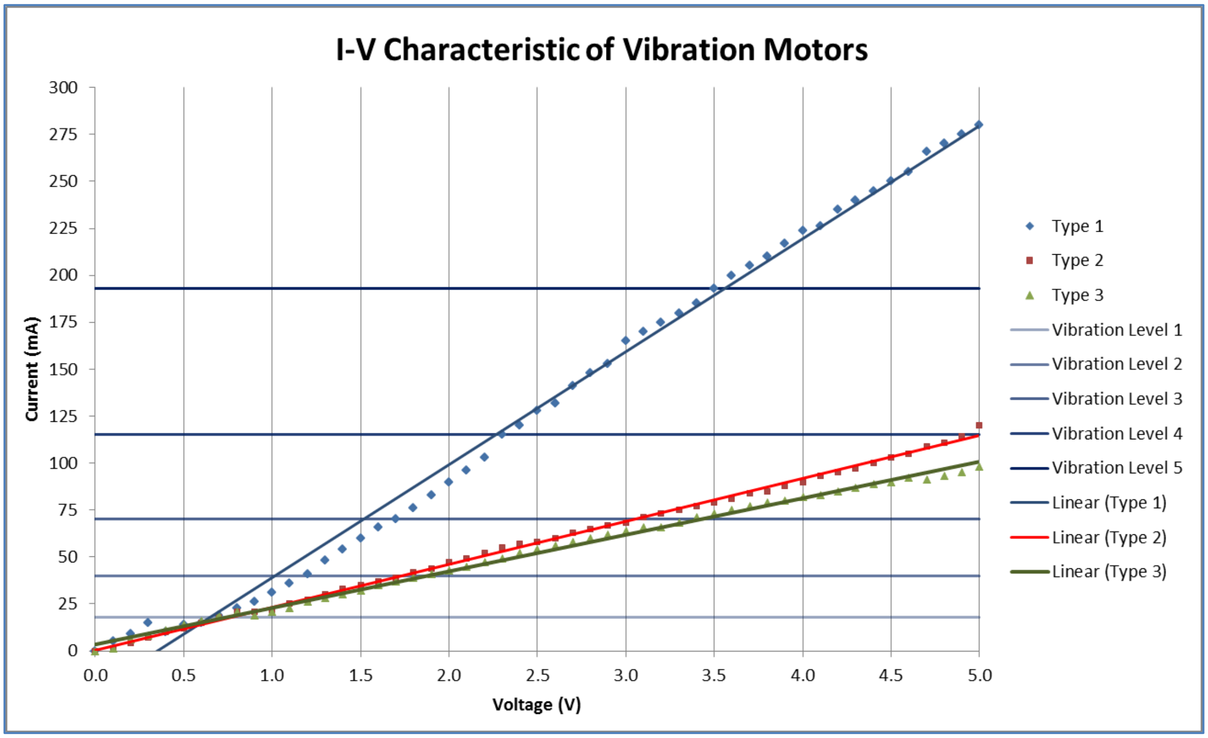


Figure 92: Graph of I-V Characteristics for Different Vibration Motors

As it can be observed in Figure 92, five vibration intensity levels were identified where level 1 gives the least vibration intensity and level 5 gives the most vibration intensity. From the measurement results, it can be observed that Vibration Motor Type 2and Vibration Motor Type 3 give very close intensity levels and have approximate I-V characteristics. However, on the other hand, Vibration Motor Type 1 has more noticeable vibration intensity at the expense of more current consumption. Finally, Vibration Motor Type 3 was chosen since it has the least power consumption, which is an important parameter in the system, and has a noticeable vibration level that is for giving feedback to the user.

10.2 Appendix B

Fully commented code for the combined Detection and Alert System and Emergency System using Arduino Mega 2560 Microcontroller:

```
/*
  EECE498 Senior Design Project - Spring 2013
  - Course advisor: Dr. Majid Poshtan
  - Authors: Saif Al Ameri, Sana Ziaei, and Mohammad Hossain Mohammadi
  The PING))) Sensor code was created 3 Nov 2008 by David A. Mellis modified 30 Aug 2011
  by Tom Igoe
  - Description:
  This program was designed for the Self-Energized Smart Vision Stick System.
  It contains 2 main parts; detection and alert, and emergency.
  The program also consists of some extra features implemented in the design.
  The extra features are: receiving calls and giving audio feedback,
  checking the charge of the battery and giving audio feedback, turning on LEDs in dark areas
  */

//********************************************* START of CODE
**********************************************************
//--------------------------------------------Global Variables --------------------------------
-------------------------

//**Emergency System Variables**

int counter = 0; //Interrupt Counter
int SMSFlag =0; //SendSMS Function Flag
int GPSStartFlag = 0; //Start GPS Function Flag
int GPSReadFlag = 0;//GPSRead Function Flag
int GPSStatusFlag = 0;//Read Status Function Flag
int BuzzerFlag = 0; //Buzzer Function Flag
int counterGPS = 0; //GPS Counter before Resetting
int comma_count =0; //Number of Comma Counter for Parsing GPS Coordinates
char lat[12] ; //Latitude
char lon[12] ; //Longitude
char glat[12] ; //Latitude for Google Maps
char glon[12] ; //Longitude for Google Maps
char Dlat; //Directiom of Latitude
char Dlon; //Direction of Longitude
char UTC[7]; //GMT Time before spliting it with collen
char GMT[9]; //GMT Time after spliting it with collen
char var[160]; //Temp for GPS Coordinates
char commandbuffer[1000]; //AT Responce Array.
char statusbuffer[1000]; //GPS Status Array
int counterArray=0;      //Counter for Parsing GPS Coordinates
byte gsmDriverPin[3] = {3,4,5}; //The default digital driver pins for the GSM and GPS mode
void SendSMS();  //Send SMS Function Declaration


//**Automatic LED Lighting Variables**

int LEDValue = 0; // Variable that holds analog values from photo sensor input
long count_LED(0); // Counter for LED timing
const int Photo_LED = A2;  // Photo sensor input for LEDs
const int LED = 12; // LEDs output pin


//**Low Battery Indicator Variables**
```

```
const int Battery = 11; // Buzzer output pin for low battery indication
const int Photo_Battery = A0; // Photo sensor input for low battery indication
int BatteryValue = 0; // Variable that holds analog values from photo sensor input
int BatteryCountFlag = 0;  // Battery counter
long count_battery(0);  // Counter for battery timing


//**Detection and Alert System Variables**

const int pingPin = 7; // PING))) sensor 1 output and input pin number
const int pingPin2 = 6; // PING))) sensor 2 output and input pin number

const int vibration = 10; // Vibration motor output pin number

// The follwoing variables define the 4 distinctive ranges of obstacle feedback for sensor 1
int max_range1 = 110;  // First range maximum is 110cm
int max_range2 = 140; // Second range maximum is 140cm
int max_range3 = 170; // Third range maximum is 170cm
int max_range4 = 200; // Fourth range maximum is 200cm

// The follwoing variables define the 4 distinctive ranges of obstacle feedback for sensor 2
int max_range20 = 105; //Starting range is 105cm which represents the tip of the stick
int max_range21 = 140; //First range maximum is 140cm
int max_range22 = 170; //Second range maximum is 170cm
int max_range23 = 200; //Third range maximum is 200cm
int max_range24 = 230; // Fourth range maximum is 230cm

long duration, duration2; // Sensors 1 and 2 time readings
long cm2, cm; // Sensors 1 and 2 distance readings in cm
long count_s1r2(0), count_s1r3(0), count_s1r4(0), count_s2r2(0), count_s2r3(0); // Counters
for sensor range delays


//------------------------------------------- System Set Up-----------------------------------
----------------------

void setup()
{
  //Enabling Interrupt
  attachInterrupt(0, Button, FALLING);

  //Enabling Debuging LED
  pinMode(13,OUTPUT);
  digitalWrite(13,HIGH);

  //Initializing the driver pins for GSM function
  for(int i = 0 ; i < 3; i++)
  {
    pinMode(gsmDriverPin[i],OUTPUT);
  }

  //Setting up GPS and GSM, setup code provided by official documentation
  //http://www.dfrobot.com/wiki/index.php/GPS/GPRS/GSM_Module_V3.0_(SKU:TEL0051)
  digitalWrite(5,HIGH);//Output GSM Timing
  delay(1500);
  digitalWrite(5,LOW);
  digitalWrite(3,LOW);//Enable the GSM mode
  digitalWrite(4,HIGH);//Disable the GPS mode
  delay(2000);
  Serial1.begin(9600); //set the baud rate
```

```
  delay(5000);//Waiting for Call ready
  delay(5000);
  delay(5000);
  Serial.begin(9600);

  //Setting up 9 LED, Vibration Motor, and Battery Indicators pins as ouput
  pinMode(LED,OUTPUT);
  pinMode(vibration, OUTPUT);
  pinMode(Battery, OUTPUT);

   //Buzz to know stick is ready.
   Buzzer();
}


//------------------------------------------- System Loop-------------------------------------
--------------------

void loop()
{

  /* Detection and Alert System

   This part of the code reads 2 PING))) ultrasonic rangefinder and returns the
   distance to the closest object in range. To do this, it sends a pulse
   to the sensor to initiate a reading, then listens for a pulse
   to return.  The length of the returning pulse is proportional to
   the distance of the object from the sensor.

   After finding the distance, it compares it to predefined ranges and
   give feedback to the user accordingly through vibration mototrs

  */

  // The PING))) is triggered by a HIGH pulse of 2 or more microseconds.
  // Give a short LOW pulse beforehand to ensure a clean HIGH pulse:
  pinMode(pingPin, OUTPUT);
  digitalWrite(pingPin, LOW);
  delayMicroseconds(2);
  digitalWrite(pingPin, HIGH);
  delayMicroseconds(5);
  digitalWrite(pingPin, LOW);

  // The same pin is used to read the signal from the PING))): a HIGH
  // pulse whose duration is the time (in microseconds) from the sending
  // of the ping to the reception of its echo off of an object.
  pinMode(pingPin, INPUT);
  duration = pulseIn(pingPin, HIGH);

  // Convert the time into a distance
  cm = microsecondsToCentimeters(duration);

  // The same is done for sensor 2
  pinMode(pingPin2, OUTPUT);
  digitalWrite(pingPin2, LOW);
  delayMicroseconds(2);
  digitalWrite(pingPin2, HIGH);
  delayMicroseconds(5);
  digitalWrite(pingPin2, LOW);
  pinMode(pingPin2, INPUT);
  duration2 = pulseIn(pingPin2, HIGH);
```

```
  cm2 = microsecondsToCentimeters(duration2);

  // Print the results to serial screen for numerical interpretation
  // This step was required for carrying out the tests for PING))) sensor
  Serial.print("Sensor1: ");
  Serial.print(cm);
  Serial.print("cm, Sensor2: ");
  Serial.print(cm2);
  Serial.print("cm");
  Serial.println();

 //***Sensor 1 Vibration Feedback***
  if ((cm<=max_range1)||((cm2>max_range20)&&(cm2<=max_range21)))
  {
    count_s1r2 = 0;
    count_s1r3 = 0;
    count_s1r4 = 0;

    digitalWrite(vibration, HIGH);
  }
  else if ((cm<=max_range2)||((cm2>max_range20)&&(cm2<=max_range22)))
  {
    count_s1r3 = 0;
    count_s1r4 = 0;

    if((count_s1r2==0))
    {
       digitalWrite(vibration, HIGH);
    }
    else if(count_s1r2==1)
    {
       digitalWrite(vibration, LOW);
    }
    else if((count_s1r2==2))
    {
      count_s1r2 = 0;
      digitalWrite(vibration, HIGH);
    }

    count_s1r2++;

  }
  else if ((cm<=max_range3)||((cm2>max_range20)&&(cm2<=max_range23)))
  {
    count_s1r2 = 0;
    count_s1r4 = 0;

    if((count_s1r3==0))
    {
       digitalWrite(vibration, HIGH);
    }
    else if(count_s1r3==1)
    {
       digitalWrite(vibration, LOW);
    }
    else if((count_s1r3==3))
    {
      count_s1r3 = 0;
      digitalWrite(vibration, HIGH);
    }
```

```
    count_s1r3++;
  }
  else if ((cm<=max_range4)||((cm2>max_range20)&&(cm2<=max_range24)))
  {
    count_s1r2 = 0;
    count_s1r3 = 0;

    if((count_s1r4==0))
    {
       digitalWrite(vibration, HIGH);
    }
    else if(count_s1r4==1)
    {
       digitalWrite(vibration, LOW);
    }
    else if(count_s1r4==5)
    {
      count_s1r4 = 0;
      digitalWrite(vibration, HIGH);
    }

    count_s1r4++;
  }
  else // case: outside of range
  {
    count_s1r2 = 0;
    count_s1r3 = 0;
    count_s1r4 = 0;

    digitalWrite(vibration, LOW);
  }


 //***Low Battery Indication Feedback***

    if (count_battery == 0)
    {
      BatteryValue = analogRead(Photo_Battery);
      BatteryValue = map(BatteryValue, 0, 1023, 0, 100);
    }

    if(BatteryValue < 15)
    {
      if((count_battery==0)||(count_battery == 2))
      {
        digitalWrite(Battery,HIGH); //Low Battery
      }
      else
      {
        digitalWrite(Battery,LOW); //Good
      }

      count_battery++;
    }

    if(count_battery == 850) // 5*60/0.35 = 857
    {
      count_battery = 0;
    }

 //***LED Feedback System***
```

```
    if (count_LED == 0)
    {
      LEDValue = analogRead(Photo_LED);
      LEDValue = map(LEDValue, 0, 1023, 0, 100);
    }

    if(LEDValue >=50)
    {
      digitalWrite(LED,HIGH); //Low illumination
    }
    else if (LEDValue < 30)
    {
       digitalWrite(LED,LOW);
    }

    count_LED++;

    if(count_LED == 3) // 1/0.35 =  .... checks every ~1 seconds
    {
      count_LED = 0;
    }

 //***Emergency System***
 //Checking flags to know which function to start
    digitalWrite(13,LOW);
    if(SMSFlag == 1)
    {
      SendSMS();
    }
    else if (GPSStartFlag == 1)
    {
      StartGPS();
    }
    else if(GPSReadFlag == 1)
    {
      GPSRead();
     }
    else if (GPSStatusFlag == 1)
    {
      GPSStatus();
    }
    else if (BuzzerFlag == 1)
    {
      Buzzer();
    }
    else
    {
        delay(350);
    }
}

//------------------------------------------- Defined Functions -----------------------------
---------------------------

//Button Interrupt Handler
void Button()
{
  digitalWrite(13,HIGH);
  detachInterrupt(0);
  //Checking if interrupt executed.
  counter++;
```

```
  Serial.println(counter);
  Serial.print("\n");

  GPSStartFlag = 1;

}

//Sending SMS Function
void SendSMS()
{

  int i =0;
  int j =0;
  comma_count =0;

  //Paring GPS Coordniates
   while(comma_count < 6)
   {
     if(commandbuffer[i] != ',')
     {
       if(comma_count == 1)
       {
         UTC[counterArray] = commandbuffer[i];
         counterArray++;
       }
       else if(comma_count == 2)
       {
         lat[counterArray] = commandbuffer[i];
         counterArray++;
       }
       else if(comma_count == 3)
       {
         Dlat = commandbuffer[i];
       }
       else if(comma_count == 4)
       {
         lon[counterArray] = commandbuffer[i];
         counterArray++;
       }
       else if(comma_count == 5)
       {
         Dlon = commandbuffer[i];
       }
     }
     else
     {
       comma_count++;
       counterArray = 0;
     }

     i++;
  }

  counterArray = 0;

  //Adding Collen to GMT Time
  for(i=0; i<6; i++)
  {
    if((i == 2) || (i == 4))
    {
```

```
      GMT[counterArray] = ':';
      counterArray++;
    }

    GMT[counterArray] = UTC[i];
    counterArray++;
  }
    counterArray = 0;
   //Using GSM PINS!
     i =0;
     j=2;


  //Saving Mobile Google Map Coordinates
   while(lat[j] != '\0')
   {
     glat[i++] =lat[j++];
    }

     i =0;
     j=2;

   while(lon[j] != '\0')
   {
     glon[i++] =lon[j++];
    }

   //Sending the SMS
   Serial1.println("AT+CMGF=1");
   delay(250);
   Serial1.println("AT+CMGS=\"0504819747\"");//Change the receiver phone number
   delay(250);
   //Serial1.println((char*)commandbuffer);
   Serial1.println("Hi! I Need Help!\nI am at:\n");
   Serial1.print("Lat: ");
   Serial1.print((char*)lat);
   Serial1.println(Dlat);
   Serial1.print("Lon: ");
   Serial1.print((char*)lon);
   Serial1.println(Dlon);
   Serial1.print("GMT: ");
   Serial1.println((char*)GMT);
   Serial1.print("\nLink: https://maps.google.com/maps?q=");
   Serial1.print(lat[0]);
   Serial1.print(lat[1]);
   Serial1.print("%20");
   Serial1.print((char*)glat);
   Serial1.print(Dlat);
   Serial1.print(",");
   Serial1.print(lon[0]);
   Serial1.print(lon[1]);
   Serial1.print("%20");
   Serial1.print((char*)glon);
   Serial1.println(Dlon);
   Serial1.print("\nThanks!");
   Serial1.write(26);

   //Ending SendSMS Function and Buzz to indicate Emergency SMS Sent.
   SMSFlag = 0;
   BuzzerFlag =1;
   attachInterrupt(0, Button, FALLING);
```

```
}

//Starting GPS Function
void StartGPS()
{
   //Start GPS
   digitalWrite(Battery, HIGH);
   Serial1.println("AT+CGPSPWR=1");//Power on GPS
   delay(250);
   Serial1.println("AT+CGPSRST=1");//Restart GPS to Autonomous Mode
   delay(250);
   digitalWrite(Battery, LOW);

   //Starting GPS Status Function & Ending Start GPS Function
   GPSStartFlag = 0;
   GPSStatusFlag = 1;
}

//Reading GPS Coordinates Function
void GPSRead()
{
   int i =0;
   Serial1.println("AT+CGPSINF=2");//Get GPS Coordinates
   delay(250);

   //Flushing AT+CGPSINF=2 Line.
   while( Serial1.available() && i< 16) {
         Serial1.read();
         i++;
     }
    i =0;

    //Reading AT Command Responce
    //Buffer Reading Code Taken from: http://linux-utils.blogspot.ae/2010/10/arduino-serial-
read-line.html
    if(Serial1.available()){
       delay(100);
        while( Serial1.available() && i< 1000) {
             commandbuffer[i++] = Serial1.read();
         }
       commandbuffer[i++]='\0';
      }

    if(i>0)
    {
       Serial.println((char*)commandbuffer);
    }

    //Flushing Buffer
    while( Serial1.available()) {
        Serial1.read();}


     //Starting SMS Ready Function and Ending Ready GPS Coordinate Function
    GPSReadFlag = 0;
    SMSFlag = 1;

    Serial1.println("AT+CGPSPWR=0");//Power Off GPS
    delay(250);
}
```

```
//Read GPS Status Function
void GPSStatus()
{
   int i =0;
   Serial1.println("AT+CGPSSTATUS?");//Get GPS Coordinates
   delay(250);

   //Flushing AT+CGPSSTATUS? Line.
   while( Serial1.available() && i< 18) {
         Serial1.read();
         i++;
     }
    i =0;

    //Reading AT Command Response
    if(Serial1.available()){
       delay(100);
        while( Serial1.available() && i< 1000) {
              statusbuffer[i++] = Serial1.read();
         }
       statusbuffer[i++]='\0';
      }


    if(i>0)
    {
       Serial.println((char*)statusbuffer);
    }

    //Flushing Buffer
    while( Serial1.available()) {
        Serial1.read();}

    counterGPS++;
    if(counterGPS==850) //Reset After 5Mins Not Connected.
    {
       Serial1.println("AT+CGPSPWR=0");//Power Off GPS
       delay(250);
       GPSStatusFlag = 0;
       GPSStartFlag =1;
       counterGPS = 0;
    }

   //Checking for 2D or 3D connected GPS statalite
    if( (statusbuffer[22] == '2') || (statusbuffer[22] == '3') )
    {
       GPSReadFlag = 1;
       GPSStatusFlag = 0;
       counterGPS = 0;
    }
}

//Starts Buzzer
void Buzzer()
{
  digitalWrite(Battery,HIGH);
  delay(500);
  digitalWrite(Battery,LOW);
  BuzzerFlag = 0;
}
```

```
long microsecondsToCentimeters(long microseconds)
{
  // The speed of sound is 340 m/s or 29 microseconds per centimeter.
  // The ping travels out and back, so to find the distance of the
  // object we take half of the distance travelled.
  return microseconds / 29 / 2;
}

//******************************************** END of CODE
**********************************************************
```

10.3 Appendix C

10.3.1 GSM/GPS in USB Mode [10]

```
void setup()
 {
   //Initializing the driver pins for GSM function
    pinMode(3,OUTPUT);
    pinMode(4,OUTPUT);
    pinMode(5,OUTPUT);
   //Output GSM Timing
    digitalWrite(5,HIGH);
    delay(1500);
    digitalWrite(5,LOW);
}
 void loop()
 {
    digitalWrite(3,HIGH);  //disable GSM TX、RX
    digitalWrite(4,HIGH);  //disable GPS TX、RX`
 }
```

10.3.2 SMS from Arduino Mode [10]

```
byte gsmDriverPin[3] = {
  3,4,5};//The default digital driver pins for the GSM and GPS mode
//If you want to change the digital driver pins
//or you have a conflict with D3~D5 on Arduino board,
//you can remove the J10~J12 jumpers to reconnect other driver pins for the module!
void setup()
{
  //Initializing the driver pins for GSM function
  pinMode(13,OUTPUT);
  digitalWrite(13,LOW);
  for(int i = 0 ; i < 3; i++){
    pinMode(gsmDriverPin[i],OUTPUT);
  }
  digitalWrite(5,HIGH);//Output GSM Timing
  delay(1500);
  digitalWrite(5,LOW);
  digitalWrite(3,LOW);//Enable the GSM mode
  digitalWrite(4,HIGH);//Disable the GPS mode
  delay(2000);
  Serial.begin(9600); //set the baud rate
  delay(5000);//waiting for call ready
  delay(5000);
  delay(5000);
}

void loop()
{
  Serial.println("AT"); //Start Send AT command
  delay(2000);
  Serial.println("AT");
  delay(2000);
  //Send message
  Serial.println("AT+CMGF=1");
  delay(1000);
```

```
  Serial.println("AT+CMGS=\"0504819747\"");//Change the receiver phone number
  delay(1000);
  Serial.print("Hello from Arduino using code");//the message you want to send
  delay(1000);
  Serial.write(26);
  digitalWrite(13,HIGH);
  while(1);
}
```

10.3.3 GPS from Arduino Mode [10]

```
byte gsmDriverPin[3] = {
  3,4,5};//The default digital driver pins for the GSM and GPS mode
//If you want to change the digital driver pins
//or you have a conflict with D3~D5 on Arduino board,
//you can remove the J10~J12 jumpers to reconnect other driver pins for the module!
void setup()
{
  //Initializing the driver pins for GSM function
  pinMode(13,OUTPUT);
  digitalWrite(13,LOW);
  for(int i = 0 ; i < 3; i++){
    pinMode(gsmDriverPin[i],OUTPUT);
  }
  digitalWrite(5,HIGH);//Output GSM Timing
  delay(1500);
  digitalWrite(5,LOW);
  digitalWrite(3,LOW);//Enable the GSM mode
  digitalWrite(4,HIGH);//Disable the GPS mode
  delay(2000);
  Serial1.begin(9600); //set the baud rate
  delay(5000);//call ready
  delay(5000);
  delay(5000);
}

void loop()
{
  int i =0;
  char var[160];
  char commandbuffer[1000];
   Serial1.println("AT+CGPSPWR=1");//GPS Power ON
   delay(2000);
    Serial1.println("AT+CGPSRST=1");//GPS Auto mode
   delay(2000);
   //Flushing Buffer
   while( Serial1.available()) {
        Serial1.read();}
   Serial.begin(9600);
   while(1)
   {
     Serial1.println("AT+CGPSINF=2");//Get GPS Information
   delay(2000);
    while( Serial1.available() && i< 16) {
         Serial1.read();
         i++;
     }
    i =0;
 //Reading from Buffer
//Code from: http://linux-utils.blogspot.ae/2010/10/arduino-serial-read-line.html
 if(Serial1.available()){
```

```
      delay(100);
      while( Serial1.available() && i< 1000) {
         commandbuffer[i++] = Serial1.read();
      }
      commandbuffer[i++]='\0';
   }
     delay(1000);
     if(i>0)
   {
      Serial.println((char*)commandbuffer);
   }

   digitalWrite(13,HIGH);
      while( Serial1.available()) {
         Serial1.read();}
    i =0;
    counterGPS++;
   }
}
```

10.3.4 SMS and GPS from Arduino Mode [10]

```
int counterGPS = 0; //Number of Times Loops Repeats to Wait for GPS
int comma_count =0; //Number of Comma
char lat[11] ; //Latitude Array
char lon[11] ; //Longitude Array
char Dlat; //Direction of Latitude
char Dlon; //Direction of Longitude
char UTC[6]; //GMT Time before Spacing
char GMT[8]; //GMT Time after Spacing
int counterArray=0; //Counter for Array Length
byte gsmDriverPin[3] = {3,4,5};//The default digital driver pins for the GSM and GPS mode
void setup()
{
  //Initializing the driver pins for GSM function
  pinMode(13,OUTPUT);
  digitalWrite(13,LOW);
  for(int i = 0 ; i < 3; i++){
  pinMode(gsmDriverPin[i],OUTPUT);
  }
  digitalWrite(5,HIGH);//Output GSM Timing
  delay(1500);
  digitalWrite(5,LOW);
  digitalWrite(3,LOW);//Enable the GSM mode
  digitalWrite(4,HIGH);//Disable the GPS mode
  delay(2000);
  Serial1.begin(9600); //set the baud rate
  delay(5000);//waiting for call ready
  delay(5000);
  delay(5000);
}

 void loop()
{
  int i =0;
  char var[160];
  char commandbuffer[1000];

  Serial1.println("AT+CGPSPWR=1");//GPS Power On
   delay(2000);
```

```
    Serial1.println("AT+CGPSRST=1");//GPS Auto Mode
   delay(2000);
    //Flushing The Buffer
   while( Serial1.available()) {
        Serial1.read();}
   Serial.begin(9600);
   while(counterGPS <40)
   {
   Serial1.println("AT+CGPSINF=2");//Getting GPS Information
   delay(2000);
   while( Serial1.available() && i< 16) {
         Serial1.read();
         i++;
     }
    i =0;
//Reading from Buffer
//Code from: http://linux-utils.blogspot.ae/2010/10/arduino-serial-read-line.html
  if(Serial1.available()){
     delay(100);
     while( Serial1.available() && i< 1000) {
        commandbuffer[i++] = Serial1.read();
     }
     commandbuffer[i++]='\0';
  }
      delay(1000);
    if(i>0)
  {
     Serial.println((char*)commandbuffer);
  }
    digitalWrite(13,HIGH);
     while( Serial1.available()) {
        Serial1.read();}
   i =0;
   counterGPS++;
  }
  //Parsing GPS Data
    i =0;
  comma_count =0;
   while(comma_count < 6)
   {
     if(commandbuffer[i] != ',')
     {
       if(comma_count == 1)
       {
         UTC[counterArray] = commandbuffer[i];
         counterArray++;
       }
       else if(comma_count == 2)
       {
         lat[counterArray] = commandbuffer[i];
         counterArray++;
       }
       else if(comma_count == 3)
       {
         Dlat = commandbuffer[i];
       }
       else if(comma_count == 4)
       {
         lon[counterArray] = commandbuffer[i];
         counterArray++;
       }
```

```
      else if(comma_count == 5)
      {
        Dlon = commandbuffer[i];
      }
    }
    else
    {
      comma_count++;
      counterArray = 0;
    }

    i++;
  }
  //Getting GMT Time With Spacing
  counterArray = 0;

  for(i=0; i<6; i++)
  {
    if((i == 2) || (i == 4))
    {
      GMT[counterArray] = ':';
      counterArray++;
    }

    GMT[counterArray] = UTC[i];
    counterArray++;
  }
     //Sending SMS
    Serial1.println("AT+CMGF=1");
   delay(1000);
   Serial1.println("AT+CMGS=\"0504819747\"");//Change the receiver phone number
   delay(1000);
   Serial1.println("Hi! I Need Help!\nI am at:\n");
   Serial1.print("Lat: ");
   Serial1.print((char*)lat);
   Serial1.println(Dlat);
   Serial1.print("Lon: ");
   Serial1.print((char*)lon);
   Serial1.println(Dlon);
   Serial1.print("GMT Time: ");
   Serial1.println((char*)GMT);
   Serial1.print("\nThanks!");
   delay(1000);
   Serial1.write(26);
   digitalWrite(13, LOW);
   while(1);
}
```

10.4 Appendix D

10.4.1 Power Generation: Test 3

10.4.2 0.35mm Diameter Wire

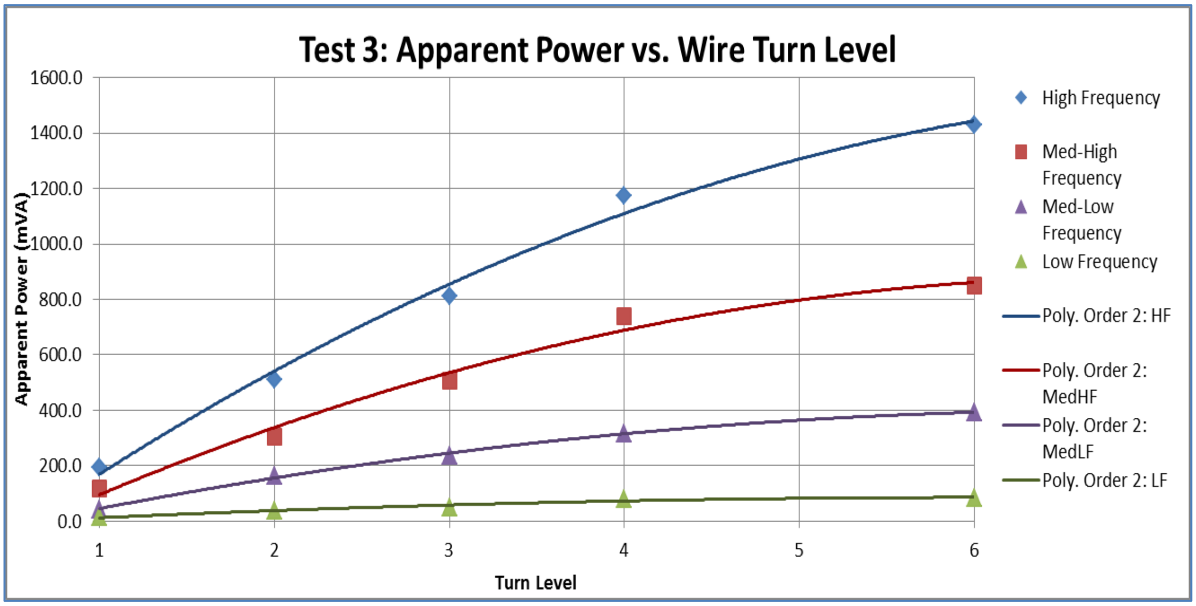


Figure 93: Test 3 – Power Generated versus Wire Turn Level for Four Frequency Ranges (Each Level is 55 turns)

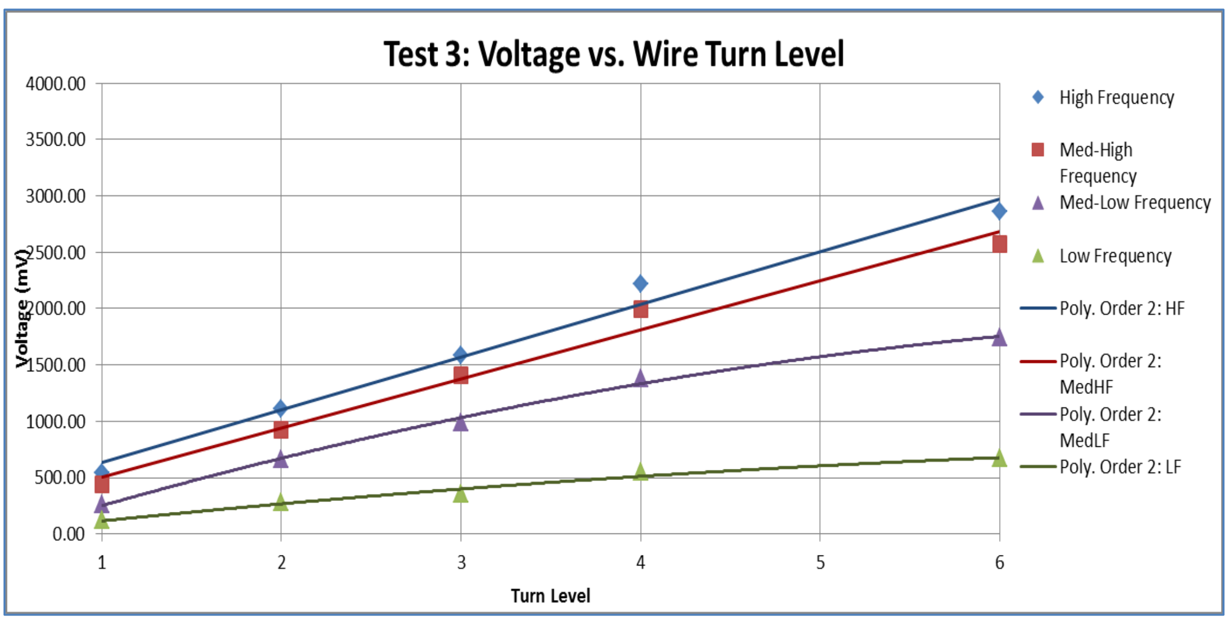


Figure 94: Test 3 – Voltage Produced versus Wire Turn Level for Four Frequency Ranges (Each Level is 55 turns)

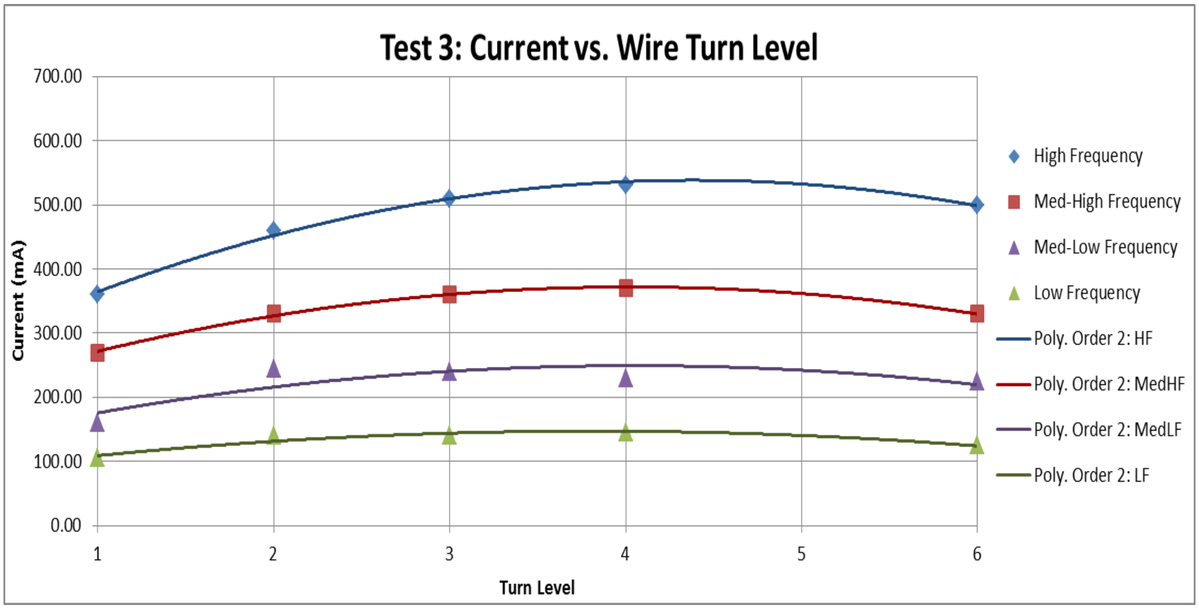


Figure 95: Test 3 – Current Produced versus Wire Turn Level for Four Frequency Ranges (Each Level is 55 turns)

10.4.3 0.40mm Diameter Wire

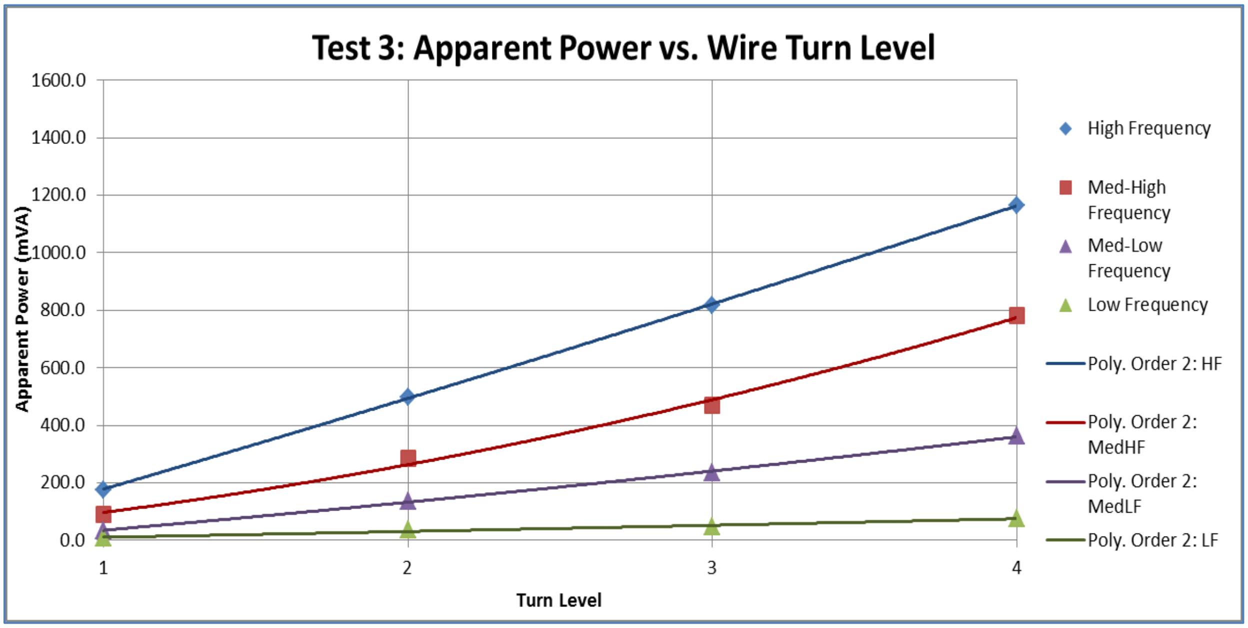


Figure 96: Test 3 – Power Generated versus Wire Turn Level for Four Frequency Ranges (Each Level is 50 turns)

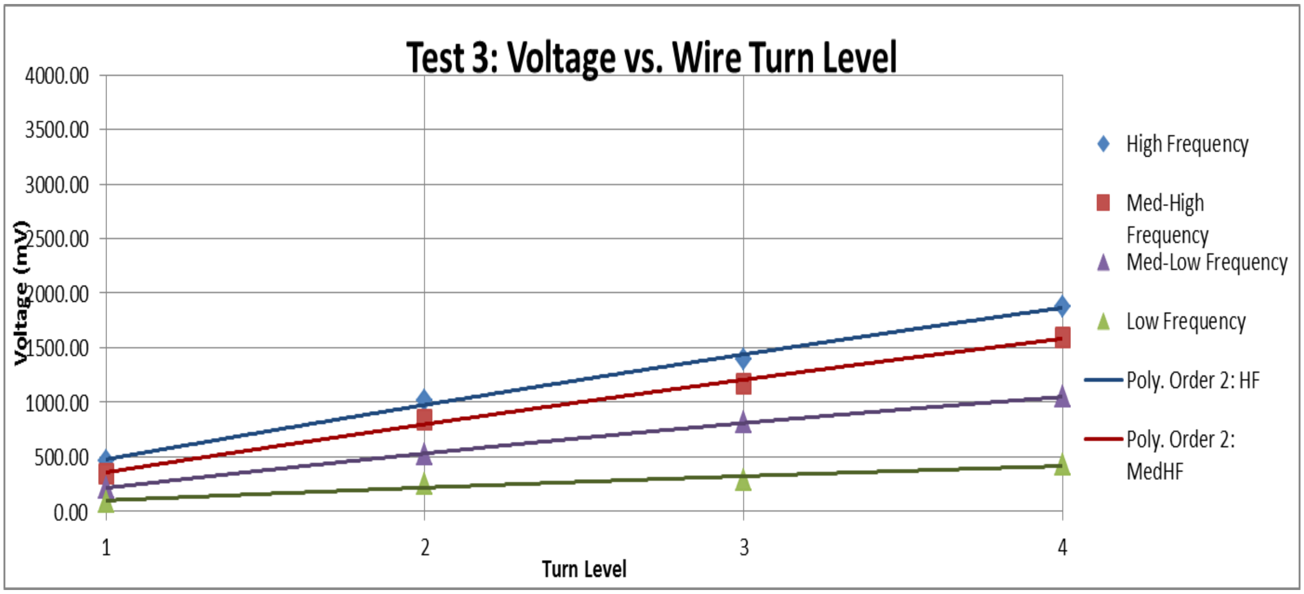


Figure 97: Test 3 – Voltage Produced versus Wire Turn Level for Four Frequency Ranges (Each Level is 50 turns)

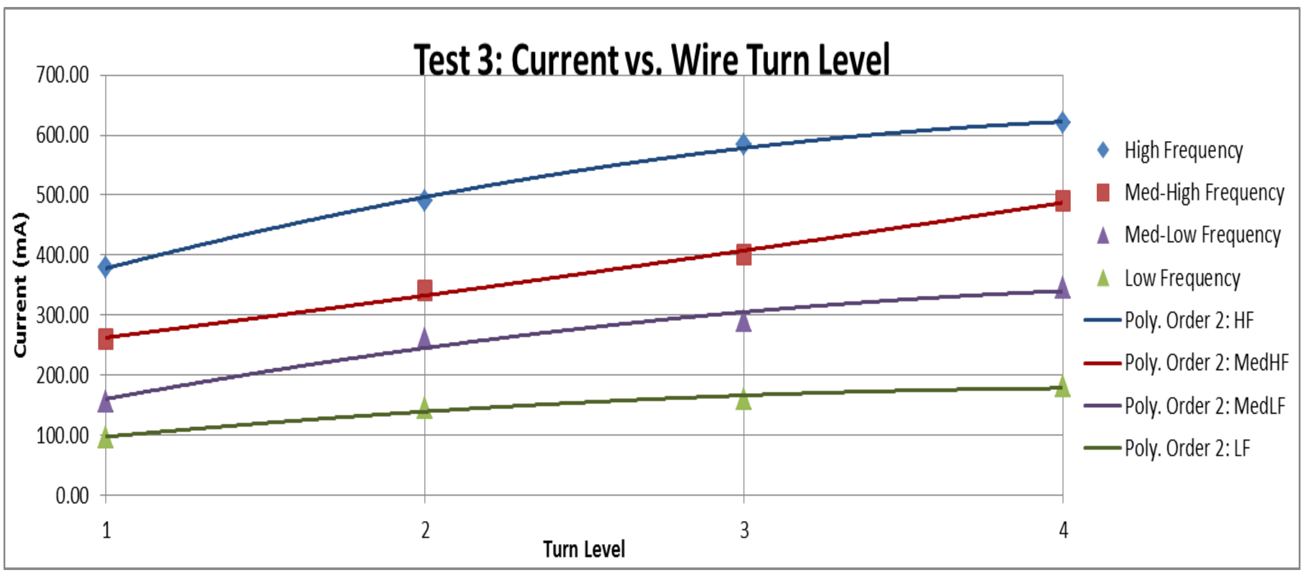
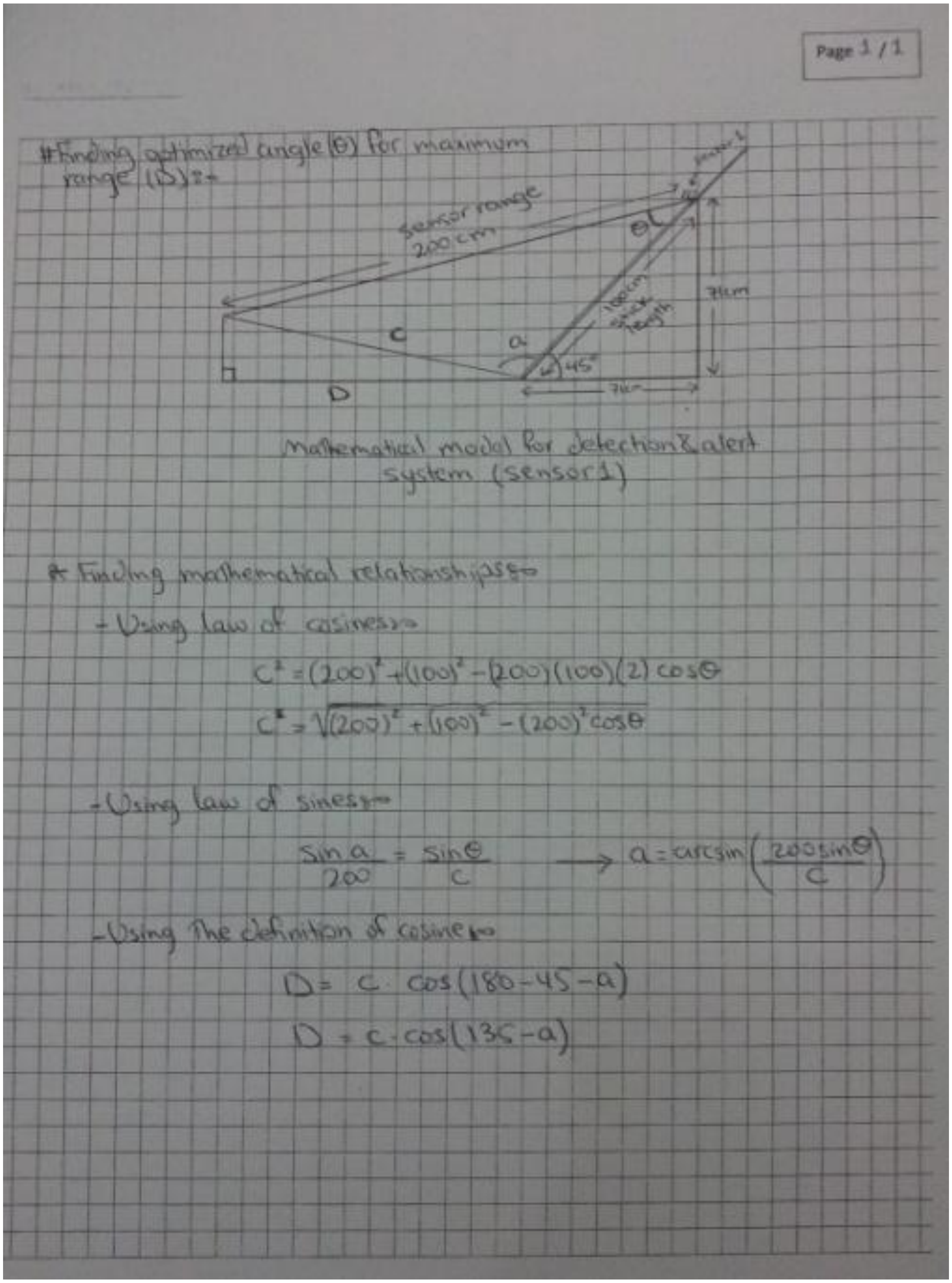


Figure 98: Test 3 – Current Produced versus Wire Turn Level for Four Frequency Ranges (Each Level is 50 turns)

10.5 Appendix E

10.5.1 Mathematical Modeling for Sensor 1



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Finding optimized angle (θ) for maximum range (D):-

Mathematical model for detection & alert system (sensor 1)

* Finding mathematical relationships:-

- Using law of cosines:-

$$C^2 = (200)^2 + (100)^2 - (200)(100)(2)\cos\theta$$

$$C = \sqrt{(200)^2 + (100)^2 - (200)^2\cos\theta}$$

- Using law of sines:-

$$\frac{\sin a}{200} = \frac{\sin\theta}{C} \longrightarrow a = \arcsin\left(\frac{200\sin\theta}{C}\right)$$

- Using the definition of cosine:-

$$D = C \cdot \cos(180 - 45 - a)$$

$$D = C \cdot \cos(135 - a)$$

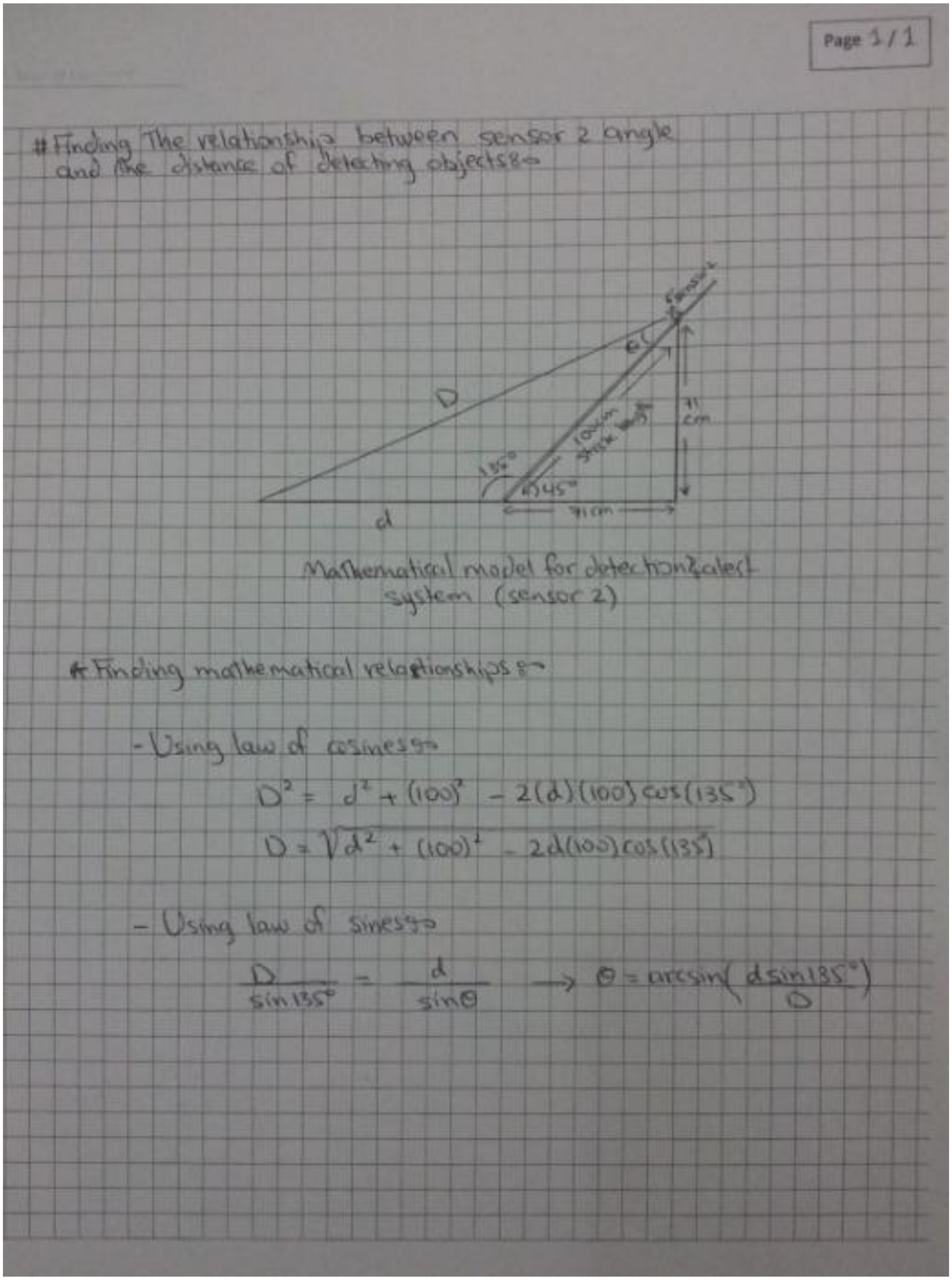
Figure 99: Mathematical model for sensor 1

10.5.2 MATLAB Code

```
%% This code finds the relationship between the angle theta for sensor 1
% and the distance in front of the tip of the stick that determines the
% radial range at which the sensor can cover

% Symbolic variables
syms theta a c D

% Using the law of cosines
c = sqrt(50000 - 40000*cos(theta));

% Using the law of sines
a = asin((200*sin(theta))/c);

% Using the definition of cosine
D = c*cos(2.356 - a);

% Plotting the graph
ezplot(D)
title('The Detection Range for Different Angles of Sensor 1');
xlabel('Theta (radians)');
ylabel('Radius of Radial Range (cm)');
```

10.6 Appendix F

10.6.1 Mathematical Modeling for Sensor 2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Finding The relationship between sensor 2 angle and the distance of detecting objects:-

Mathematical model for detection & alert system (sensor 2)

* Finding mathematical relationships:-

- Using law of cosines:-

$$D^2 = d^2 + (100)^2 - 2(d)(100)\cos(135^\circ)$$

$$D = \sqrt{d^2 + (100)^2 - 2d(100)\cos(135^\circ)}$$

- Using law of sines:-

$$\frac{D}{\sin 135^\circ} = \frac{d}{\sin\theta} \longrightarrow \theta = \arcsin\left(\frac{d \sin 135^\circ}{D}\right)$$

Figure 100: Mathematical model for sensor 2

10.6.2 MATLAB Code

```
%% This code finds the relationship between sensor 2 angle and the distance
% of detecting objects.  It also draws the mapping from the actual distance
% of the object to the measured distance by sensor 2

d = 0:1:140; % Distance measured from the tip of the stick
a = pi - (pi/4);

% Using law of cosines
D = sqrt( d.^2 + (100)^2 - 200*d.*cos(a));

% Using law of sines
theta = asin((d.*sin(a))./D);

% Plotting the graphs
figure; plot(d,theta*180/pi); grid;
title('The Relationship between Sensor 2 Angle and Distance of Detecting Objects');
xlabel('Distance of object from the tip of the stick (cm)');
ylabel('Angle(degrees)');

figure; plot(d + 71,D); grid;
title('The Relationship between the Actual Distance of the Object and Sensor 2
Distance Measurement');
xlabel('Actual distance of the object from the user(cm)');
ylabel('Sernor 2 distance measurement(cm)');
```

10.6.3 Experimental Data Verifying the Distance Mapping

Table 14: Experimental data for mapping from actual object distances to sensor 2 distance measurements using 12*12*12 cm object

Actual Distance of the Object(cm)	Measured Distance using Sensor 2 (cm)
71	98
81	105
91	112
101	120
111	128
121	136
131	145
141	154
151	162
161	171
171	180
181	190
191	200
201	209
211	219
221	228
231	237
241	248