DEVELOPMENT OF A SMART ASSISTIVE STICK FOR VISUALLY IMPAIRED PEOPLE

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DEVELOPMENT OF A SMART ASSISTIVE STICK FOR VISUALLY IMPAIRED PEOPLE

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A project report submitted in partial fulfilment of the requirements for the award of Bachelor of Mechanical Engineering with Honours

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May 2023

DECLARATION

I hereby declare that this project report is based on my original work except for citations and quotations which have been duly acknowledged. I also declare that it has not been previously and concurrently submitted for any other degree or award at UTAR or other institutions.

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APPROVAL FOR SUBMISSION

I certify that this project report entitled **"DEVELOPMENT OF A SMART ASSISTIVE STICK FOR VISUALLY IMPAIRED PEOPLE"** was prepared by **TOR LIQIN** has met the required standard for submission in partial fulfilment of the requirements for the award of Bachelor of Mechancial Engineering with Honours at Universiti Tunku Abdul Rahman.

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ACKNOWLEDGEMENTS

I would like to thank everyone who contributed to this project's successful completion. I would like to express my gratitude to my research supervisor, Dr. Lee Poh Fong for her invaluable advice, guidance, and her enormous patience throughout the development of the research.

In addition, I would like to express my sincere gratitude to my loving parents for their support and encouragement. I also wish to express my sincere thanks to my friends for their helpful information and practical advice.

ABSTRACT

Visually impaired people are individuals who are unable to get their vision corrected to a 'normal level' or people who have difficulties to see objects clearly. They have constraints in carrying out their regular lives especially engaging in outdoor activities where they could get hurt unintentionally due to the inability to recognise obstacles. Therefore, a smart stick is proposed in this project to assist them navigate their daily lives. This smart stick is integrated with multitude of sensors, and its phone application development leverages Internet of Things (IoT) technologies. In this project, the three objectives are: first is to evaluate the technically workability of each feature in the smart stick; second is to analyse the effectiveness of the smart stick in assisting and enhancing the safety of user; third is to evaluate the accuracy of live location tracking feature for the guardian to keep track of the location of visually impaired people. The microcontroller used in this project is ESP32. Three ultrasonic sensors are placed at different positions for obstacle detection. When one out of three of the ultrasonic sensors detects an obstacle within 50 cm in proximity, the buzzer will buzz immediately. A water sensor is also installed to identify the presence of water, and the user will be alerted by a vibration produced from a motor. When the ultrasonic sensor detects the staircases, the phone application plays a corresponding audio alert via headphones. A mislocated stick can be found by pressing a button in the phone application, and the buzzer attached to the stick will respond. The user can then deactivate the buzzer by pressing designated button on the stick. The smart stick is also equipped with LED illumination feature, where it uses a LDR sensor to detect when the ambient light level is low and lights up its LEDs. There is emergency button installed in the stick to allow users to send SOS messages with their current location to their guardians through the phone application. Via the Ubidots dashboard, guardians can track the current location of the user. Based on results from the humanization test, the average walking speed of participants equipped with the smart stick throughout the first and second tests was 0.17 m/s. The average success rate of smart stick users in avoiding obstacles is 92.5% and 91.11%, respectively. The test on water detection was recorded with 100% success rate among the 17 participants. All the participants were able to successfully send the SOS message with accurate location. In conclusion, the primary stage development of the smart stick was proven a successful project with ample room for future development and improvement.

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LIST OF SYMBOLS / ABBREVIATIONS

V	voltage, V
I	current, A
R	resistance, Ω
f	frequency, Hz

NGO	non-governmental organization
CDC	Centers of Disease Control and Prevention
IAPB	International Agency for the Prevention of Blindness
WHO	World Health Organization
GPS	Global Positioning System
LED	Light Emitting Diode
iOS	iPhone Operating System
ICD 11	International Classification of Diseases 11th Edition
DME	diabetic macular edoema
PDR	proliferative diabetic retinopathy
RNIB	Royal National Institute for the Blind
IoT	Internet of Things
GSM	Global System for Mobile Communication
TLC	Traffic Light Crossing
LDR	Light Dependent Resistor
DC	Direct Current
GPIO	General Input and Output
ADC	Analog to Digital Converter
DAC	Digital to Analog Converter
PWM	Pulse Width Modulated
USB	Universal Serial Bus
MQTT	Message Queuing Telemetry Transport

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CHAPTER 1

INTRODUCTION

1.1 General Introduction

Human eye is a vital organ that supports daily activities such as walking, taking public transportation, and navigating to desired destinations independently while avoiding getting injured by obstacles. From a survey done by a non-governmental organization (NGO), 98% of visually impaired people experienced accidents while travelling (Agrawal and Gupta, 2018). Losing one's sight makes it more challenging for one to go about his/her regular life especially engaging in outdoor activities that could result in unintentional injury. This is due to the reduced ability to recognise adjacent barriers such as potholes, manholes as well as rocks. They may also lose confidence in their ability to effectively communicate with others in case of emergencies (Bharatia, Ambawane and Rane, 2019).

As defined by the Centers of Disease Control and Prevention (CDC), visual impairment is the inability of visually impaired people to get their vision corrected to a 'normal level'. This is a result of the vision system's functional limitations (Mandal, 2019). Individuals with vision impairment are reported to have less control over their surroundings and daily lives as well as a reduced quality of life (Brunes, Hansen and Heir, 2021). Globally, there are 1.1 billion people dealing with vision loss in 2020. 43 million of these people are estimated to be blind, 295 million experience moderate to severe visual impairment, 258 million suffer from mild impairment, and 510 million have issues with their near vision(The International Agency for the Prevention of Blindness, 2020). These impairments could be contributed by health factors such as glaucoma, cataract, uncorrected refractive errors, trachoma, diabetic retinopathy as well as age-related macular degeneration (World Health Organization, 2022).

Over decades, individuals who suffer from vision impairment usually use the devices such as white canes and guide dogs to identify obstacles while ambulating. However, there are drawbacks with these devices. For instance, the users are required to have a mental map of the environment, since these devices are unable to provide extensive information about the surroundings such as location and weather (Tsai, Yang and Tang, 2022). With the advent of smart technology during the past several years, technology advancement inadvertently addresses the needs of the visually impaired by providing better guidance and tackles the gap of existing devices.

The smart sticks proposed by other researchers mostly have features such as obstacles detection, water detection, an alert system to warn the user if there are any dangers as well as an emergency button to inform the user's guardian during an emergency. Nevertheless, the smart stick proposed is still at its infancy stage of development which requires further research.

This project is designed to improve the functionality of the existing smart stick and increase its reliability. The smart stick proposed in this project is integrated with various sensors and leverages Internet of Things to perform desired features. It has the ability to provide users with alerts when obstacles, staircases or water are detected. An emergency button is installed to send an SOS message to their guardian along with their current location. A misplaced smart stick can also be traced using a phone application, and the Light Emitting Diode (LED) will light up when the surrounding is dark. The additional feature that proposed in this study will be the stick's battery is rechargeable by the solar system.

1.2 Importance of the Study

The white cane is usually the mobility device for visually impaired people; however, it has the limitations such as poor overhead detection as well as lack of safety hazard aware. The development of the smart assistive stick in this study is significant to overcome the limitations of the white cane and make it easier for individuals with vision impairment to navigate unfamiliar environments safely.

Furthermore, the results of this present study may have a significant impact on building visually impaired people's confidence in the product in addition to increasing the acceptance rate of smart assistive sticks among the visually challenged group. This study may contribute to a better understanding of the problems faced by visually impaired people. Thus, the features presented in this project are more appropriate to serve the needs of those who are visually impaired. The smart assistive stick's efficiency can also be analysed through this study to improve the existing functionalities as well as to be more user-friendly. This study is important to provide visually impaired people with better mobility assistance.

1.3 Problem Statement

Obstacles can be harmful to oneself and are present everywhere. Individuals with visual impairment are unable to take appropriate action when confronted with obstructions such as poles, doors, bushes, and other obstacles (Shah et al., 2021a). Visionless may make one feel helpless and anxiety while navigating around unfamiliar places. Often, they may find themselves in dangerous situations during emergency and unable to get prompt assistance. It has been shown that vision impairment is related to low quality of life and poor health outcomes. Visually impaired people are more likely to have psychological issues, including despair and anxiety. They will also be highly depending on family members. Low-vision assistive products that may raise the quality of life of visually impaired people are much needed (Sivakumar et al., 2020).

On top of that, from an interview conducted, the visually challenged people are concerned about the weight, performance in different environments, usability in terms of battery life, and durability of the smart cane (Milallos et al., 2021). These may be the factors that cause visually impaired people feeling unassured toward the consistency of the smart cane and reluctant to adopt it as their mobility tool.

1.4 Aim and Objectives

This project aims to design and develop a wearable smart assistive stick that helps visually impaired individuals move about both indoors and outdoors. The two specific objectives needed to be achieved in this project are stated below:

1. To evaluate the technically workability of each feature in the smart stick.
2. To analyse the effectiveness of the smart stick in improving the safety of visually impaired people.

3. To evaluate the accuracy of live location tracking feature for the guardian to keep track of the location of visually impaired people.

1.5 Scope and Limitation of the Study

This project is focused on the development of a smart assistive stick that can assist visually impaired people to navigate safely with the application of various sensors to identify the obstacles faced by the user. The sensors are integrated into the smart stick through coding in Arduino, while the phone application that will be paired with the stick is developed by building the blocks in MIT app inventor.

The development of the phone application is limited by the availability of converting the phone application created by MIT app inventor into an application for iPhone Operating System (iOS) devices. The iOS users can only test the phone application through the interpreter that is available in the app store. Additionally, the user's walking speed is restricted when using the smart stick as the ultrasonic sensor's ability to detect obstacles reduces with increasing walking speed. Moreover, the smart stick requires a Wi-Fi or cellular data connection to function.

1.6 Contribution of the Study

The smart assistive stick develops in this project has the ability to detect obstacles, staircases, and the presence of water. It can also notify the user of threats. When the ambient lighting is weak, the LEDs on the sides of the stick will light up. When an emergency arises, the emergency button can reach vision-impaired people's guardians. Through a phone application, the mislocated stick can easily be found with the sound of the buzzer. While the battery can be recharged by the solar system. Therefore, this smart stick is useful in the visually impaired community where it can assist them to navigate around safely. Hence, this project is able contribute to the Sustainable Development Goal by achieving the target 3.6 in goal 3 'Good Health and Well-Being' by reducing the road injuries and deaths.

1.7 Outline of Report

This report is divided into five chapters, where chapter one provides a broad overview of the project. The literature review on the smart assistive stick for people with visual impairments is covered in chapter two. Details of the development process for the smart assistive stick are presented in chapter three. While chapter four shows the project's preliminary results and chapter five discusses the issue and the project's resolution.

CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

The five senses that humans have are sight, sound, smell, taste, and touch. Among these, sight is the most significant sense because it plays an important role in every stage of a human's life. Loss of vision may contribute to the struggle in navigating, reading, and other daily activities. Vision impairment develops when an eye disorder affects the visual system and its functions. The severity of visual impairment is measured by visual acuity.

This chapter offers a brief description of the visual system in addition to vision function, and problem faced by visually impaired people to gain a better comprehension of the topic of vision impairment. This chapter examines the conventional mobility aids used by individuals with vision impairment and evaluates their efficacy. The various smart assistive sticks proposed over the past few years are reviewed and studied in this chapter to determine their deficiencies. Thus, the development of a smart assistive stick in this project will be more appropriate in terms of its functionalities towards visually impaired people.

2.2 Visual system

The visual system includes optic nerves, paths to and from various brain structures, and the eyes. The primary sensory organ for the visual system, the eye, is responsible of gathering, concentrating, and processing the initial neuronal impulses of the visual pathway. In order for the light to reach the retina, it must pass through ocular media, which include the cornea, lens, tear film, posterior-chamber vitreous, and anterior chamber (Prasad and Galetta, 2011). While the light is transformed into nerve impulses in the retina, these impulses pass-through optic nerves and other channels to the visual cortex, a particular region of the brain. Once in many other brain areas, these impulses interact with additional inputs including memory or hearing to assist individuals in comprehending their environment and react appropriately (World Health Organization, 2019).

2.3 Problem Faced by Visually Impaired Group

Since the moment of birth, vision has been essential to humans at every stage of development. People with visual impairment experience difficulties with mobility, employment, education, and physical activity. However, the study's most concerning issue to be reviewed is mobility. In order to better comprehend the difficulty of visually impaired people having this issue and to provide a more viable solution.

2.3.1 Mobility

One of the biggest challenges for those who are visually impaired is being able to move around safely and effectively, which is essential for social inclusion and quality of life (Ball and Nicolle, 2015). Visually impaired people still struggle greatly with independent mobility in outside settings. Independent street crossing is one of the biggest daily problems that the visually impaired confront. Unaware of the presence of traffic lights may lead to severe injury. In many nations, most pedestrian traffic lights do not provide an associated assistance sound indication, despite the fact that this is a common remedy to the problem (Ghilardi et al., 2018). The risk of falling and colliding increases when walking without sight. The problem that visually impaired people typically encounter while ambulating both indoors and outdoors include head-level and trip accidents. According to the survey, trucks, construction equipment, tree branches, poles, and signs were the main causes of outdoor head-level incidents. When visually impaired people are not aware of the safety sign posted at construction sites, they may not only experience head-level accidents but also be put in a dangerous scenario. Besides, doors, cabinets left open, shelves, tables, staircases, and walls are frequently to blame for accidents that occur indoors. According to the research study, head-level incidents occurred to at least 13% of respondents at least once per month and walking falls to at least 7% of respondents once per month (Manduchi and Kurniawan, 2018). From a research study, visually impaired people also faced the problem of having a hard time on pavements due to the obstacles such as uneven surfaces, open gutters hawkers, parked cars, crowds, and beggars sleeping on the road. This issue causes impediments for the respondents, raising the chance of damage (Arora and Shetty, 2012).

Traveling in public places presents its own set of challenges for visually impaired people because many environmental cues are ineffective. Technologies like indoor navigation systems and accessible maps fall short of filling the need for independent navigation because they lack necessary accessibility and obstruction information. It can be difficult for people to find their way around public places which makes them less likely to venture outside on their own. Since visually impaired people are limited in their ability to notice environmental cues such as light, scent, noise, and randomly placed obstacles, moving through unfamiliar, congested, and wide-open environments presents additional challenges. As a result, developing a mental map and becoming comfortable with their surroundings may take a long time for visually impaired individuals. Most of the visually impaired respondents struggle to navigate unfamiliar areas on their first visit (Jeamwatthanachai, Wald and Wills, 2019).

2.4 Early Mobility Tool before Smart Stick Introduced

There were a few types of assistance introduced to assist visually impaired people in conducting daily activities before the smart assistive stick was implemented. For example, white cane, human guidance, and guide dog. They play a significant role in reducing the chance of visually impaired people getting injured while navigating around. However, they all possess limitations in assisting visually impaired people to perform their daily routines.

2.4.1 White Cane

White cane is a representation of visually impaired people as well as a tool that can be utilised to seek independence. The cane has existed as a form of travelling aid for visually impaired people throughout history (Strong, 2009). White cane as shown in Figure 2.1 is the most common mobility aid for individuals with visual impairment to travel independently. It is a flexible fibreglass or lightweight metal tube that may be presented in one piece or folded into several pieces (Attia and Asamoah, 2020). White canes are also the first step for individuals that are visually impaired to acquire mobility autonomy, which is essential for restoring their dignity and self-worth, enabling them to live independently and pursue possibilities in education and employment. The primary use of a white cane is spotting or negotiating obstacles. However, visually impaired people who utilise a white cane must pay close attention to their surroundings to stay safe. People with vision impairment use white canes for a variety of reasons, including uncertainty about their surroundings. When confronted with an unknown environment, those with vision impairment will prefer to explore the road ahead by using a white cane (Tsai, Yang and Tang, 2022).

The white cane has several advantages over other assistive devices, including simplicity, affordability, a significant signalling effect, and direct physical contact with the environment. Nevertheless, there are a few limitations to utilising white cane. One of the limitations is having a limited sensing range and the inability to detect obstacles that are higher than the ground, such as hanging objects that are at the head or trunk level that frequently result in accidents (Pyun et al., 2013). The white cane has drawbacks where visual impaired people struggle to move around independently in an unfamiliar area, even with the aid of a white cane. It is because a white cane is not a navigational aid that simply shows how to get to their destination but rather a device for detecting obstacles (Shiizu et al., 2007). A person with vision impairment requires assistance even while holding a white cane when they are in a crowded area such as a train station or encounter dangerous circumstances such as crossing the street.

Figure 2.1: White cane (Tai, Jiang and Liou, 2019).

2.4.2 Guide Dog

A guide dog is a primary mobility aid intended to improve the quality of life for those who are visually impaired by enabling independent travel (Lloyd et al., 2016). Behavioural characteristics such as sensitivity and attention to environmental cues, trainability, fearfulness and stress behaviour, attachment behaviour, low aggression, as well as energy levels are the main emphasis of current dog suitability assessments of being a guide dog (Craigon et al., 2017). Guide dogs need to pass training before leading the visually impaired people as shown in Figure 2.2. Basic commands like forward, stop, turn left and turn right are taught to them during the training. Inferred from anecdotal evidence and limited study, guiding dogs may also offer other advantages such as friendship, support, and security. Mobility issues can significantly limit opportunities for social connection, which can lead to feelings of exclusion or loneliness. While guide dogs can stimulate and enable social contact in a variety of ways, they can draw attention, offer entertainment, serve as a conversation starter, boost owners' social skills and interpersonal relationships, make owners appear more attractive, and serve as a status symbol (Whitmarsh, 2005).

Nonetheless, there are drawbacks of using guide dogs. One of the drawbacks is that because guiding dogs are unable to communicate with humans, individuals who are visually impairment need to rely on their senses of hearing, smell, and touch to notice changes in surroundings. All other decisions such as where the traffic lights are located and which way to go are left to the discretion of those who need them because a guide dog's main role is to detect obstacles and assist those with vision impairment in avoiding them. Therefore, people with vision impairment need to construct a fully developed mental map of their surroundings before they can navigate it if they are in a completely unfamiliar place. They must also be aware of the route, including traffic signals and number of interactions they must pass along the way to prevent major injury (Tsai, Yang and Tang, 2022).

Figure 2.2: Guide Dog (The International Agency for the Prevention of Blindness, 2017).

2.4.3 Human guidance

Walking assistance for those with vision impairment can be provided through human guidance. The guide moves their elbow when an individual with vision impairment places their left hand on their right elbow to assist the individual's walking. For instance, the arm of the guide may need to be shifted behind the visually impaired person's body as shown in Figure 2.3 when the two must switch from walking shoulder to shoulder to one walking in front of the other due to physical constraints. Visually impaired people then walk behind the guide in accordance with the physical suit. In addition, the guide must pause for one or two seconds in front of the staircases before descending as shown in Figure 2.4. Therefore, individuals who are visually impaired can follow the guide down the steps by feeling the rise and fall through the arm of the guide. Human guidance is more practical and reliable than white canes and guide dogs. Visually challenged people do not need to create a mental map before navigating a strange area where sighted persons can see traffic lights and overhanging obstacles.

Yet, there are drawbacks to using this strategy for visually impaired people to navigate. One of the disadvantages is that people with vision impairment may experience damage to their sense of self-worth and worry about troubling other people. Additionally, even if they are able to overcome their psychological barriers and request assistance, an individual with visual impairment may also be concerned about the ability of the person guiding them. This is due to the fact that many people drag the white cane to guide those who are visual impairment as shown in Figure 2.5. This causes people with vision impairments to be less likely to notice obstacles in the way of steps and increases their anxiety and risk of falling (Tsai, Yang and Tang, 2022).

Figure 2.3: Walk in Narrow Space (Sue Stevens, 2003).

Figure 2.4: Steps, Stairs, Slope (Sue Stevens, 2003).

Figure 2.5: Improper Way of Guiding (Sue Stevens, 2003).

2.5 Evolution of Smart Assistive Stick

Over the past few years, numerous studies on the development of smart assistive sticks have been carried out. Smart assistive sticks now come with more capabilities that can help people who are visually impaired more effectively as a result of technological advancements.

A cheap, reliable, and accurate smart stick that can detect both frontal impediments that are knee-height or above and obstacles that are lower than knee-height was proposed. This stick has the ability to detect staircases by multiple ultrasonic sensors positioned correctly to carry out these functions. The stick can inform the user by vibrating and playing sound in the user's ear. The Arduino uno R3 is used as the microcontroller for this stick (Sharma, et al., 2017).

Shah et al. (2021) have proposed a smart walking stick that makes use of an Arduino Uno as a microcontroller. Using an ultrasonic sensor, the smart stick can detect objects up to 15 cm away from the user, and a buzzer will sound to warn them and help to prevent injury. While a light sensor module is specifically attached to the smart stick to track the intensity of ambient light. When the environment is determined to be dark, the LED will turn on to convey a signal to the area, preventing visually impaired people from getting into accidents at night like collisions with bikers or bus drivers.

Natarajan, Yogeshwaran and Canessane (2022) put forth a design that successfully incorporated the Arduino Uno processor and required sensors to create an Internet of Things (IoT) model. This suggested smart stick is not only capable of detecting obstacles up to 100 cm away and determining the range of obstacles using ultrasonic sensor and infrared sensor, but it is also capable of identifying wet surfaces using a water sensor. Meanwhile, the buzzer will sound to let the users know if there are any impediments to avoid.

The suggested capabilities of the three smart sticks mentioned above are too constrained, and ambulation for those with visual impairments still presents many difficulties. Therefore, the smart stick has been improved by adding more functionalities. It has more functions than only standard ones, such as the ability to detect the presence of water using a water sensor in the road to prevent slipperiness and to detect obstacles such as stones, pits, and boulders using ultrasonic sensor. But it also suggested an additional function that would use a RF transmitter and receiver to help those who are visually impaired to find a mislocated stick. It also has the benefit of using GPS and Global System for Mobile Communication (GSM) to track the location of the visually impaired people and when the panic button is triggered, the information will send to their guardians upon any emergency happens (Agrawal and Gupta, 2018).

Johari et al. (2020) proposed a stick based on the Traffic Light Crossing (TLC) Algorithm for guiding and navigating visually impaired people through streets and traffic lights. Obstacles can be detected using an ultrasonic sensor on the smart stick, and when obstacles are found, an LED blinks and a buzzer buzz. Traffic light colour can be detected using a colour sensor, and an audio alert system is suggested to ensure that the user hears an alert when a traffic light is detected. GSM is also used to send message alerts in case of emergencies. To boost the accuracy of detecting the traffic light colour, it can be enhanced with other module such as recognition of object using cloud vision API.

Bharatia, Ambawane and Rane (2019) proposed a smart stick that has more sophisticated features included in. It includes features for employing an ultrasonic sensor to identify obstacles. The buzzer will buzz with vary frequencies of sound depending on the distance of barriers faced, which is unique compared to earlier studies. In this project, the Light Dependent Resistor (LDR) sensor is also employed to detect the approaching vehicles' headlights. A camera module attached to the stick for object detection utilising cloud API has been suggested. Assistance with navigation, text recognition, face detection, image attributes and image labelling are a few of the features offered by the Vision API. An Android application with features such as stick detection, call placing, GPS navigation, live location tracking, message sending to relatives of visually impaired people when a stick button is pressed, and voice-controlled communication is developed in this study to better assist visually impaired people.

2.6 Summary

This chapter gives a basic description of the visual system and explains how to evaluate visual function. To increase awareness of the challenges experienced by visually impaired people, a review of the issues they face in mobility, is being conducted. The use and shortcomings of each early navigation aid including white cane, guide dog and human assistance are being studied. These limitations have given rise to the notion of implementing a smart assistive stick. As shown in Table 2.1, the smart assistive stick has improved over the past few years, going from just one feature, obstacle detection to multiple features such as water detection, dark activated support, audio alert system, find the mislocated stick, GPS navigation, panic button, live location tracking, traffic light detection, and object recognition.

Table 2.1: Summary of Evolution of Smart Stick

Features of Smart Stick	Component used	Reference
Detect obstacles at knee-height or above and below, detect staircase, alert system	Arduino uno R3, Ultrasonic sensors, Buzzer, Vibrating Motor, HC-05 Bluetooth module	Sharma et al. (2017)
Detect objects up to 15 cm away, alert system, track intensity of ambient light	Arduino uno R3, ultrasonic sensor, light sensor module, LED	Shah et al. (2021)
Detect obstacles, identify wet surfaces, alert system	Arduino uno R3, ultrasonic sensor, infrared sensor, water sensor, buzzer	Natarajan, Yogeshwaran and Canessane (2022)

Detect the presence of water, detect obstacles, stick detection, location tracking	Arduino uno R3, water sensor, ultrasonic sensor, RF transmitter and receiver, SKG1 3BL GPS module and SIM 800 GSM module, buzzer, button	Agrawal and Gupta (2018)
Detect obstacles, detect traffic light colour, audio alert system, send SOS message	Arduino Uno, ultrasonic sensor, LED, buzzer, TCS3200 colour sensor, Speaker, GSM module	Johari et al. (2020)
Detect obstacles, alert system, detect approaching vehicles' headlights, object recognition, GPS navigation, live location tracking, voice-controlled communication	Arduino Uno, ultrasonic sensor, buzzer, LDR sensor, camera module, push button	Bharatia, Ambawane and Rane (2019)

CHAPTER 3

METHODOLOGY AND WORK PLAN

3.1 Introduction

This chapter begins with a brief overview of the methodology and moves on to the description of the proposed features with a block diagram. Table 3.1 below contains a summary of chosen materials used in this project. This chapter provides further detail on the software system used. The proposed circuit diagram of the system was prepared and a flowchart for each of the features of the proposed system was provided to give a general concept on how to operate the features in this chapter. The design of smart assistive stick was finalised in this chapter. The fabrication process, steps for testing the prototype, and methods for gathering and analysing data were also covered in this chapter.

3.2 Methodology

Figure 3.1 shows the flowchart of the overall work. Initially, this project was started with planning and purchasing. It is essential to identify the project issue statement and goals at the outset by reading journals. After that, proceed to plan the appropriate features that is able to assist the visually impaired people as well as to achieve the objectives of the project. Before beginning with the development of the prototype, the necessary materials, as listed in Table 3.1, were purchased after the features have been decided. The second stage of the project deals with the development of a smart assistive stick. To facilitate the fabrication of the prototype, the design of the smart stick and circuit are finalised as illustrated in Figure 3.17 and Figure 3.3, respectively. 3D printing, soldering and assembly are all the steps in the fabrication of prototype.

Besides, the third stage of the project deals with pilot testing and result analysis. Before moving on to the humanization test, the prototype must pass a technical test. The humanization test involved a total 17 students, and the interview session involved five visually impaired people. The testing results will then be further examined and represented in tabular and graphical form. The project was completed with the discussion and supporting documents.

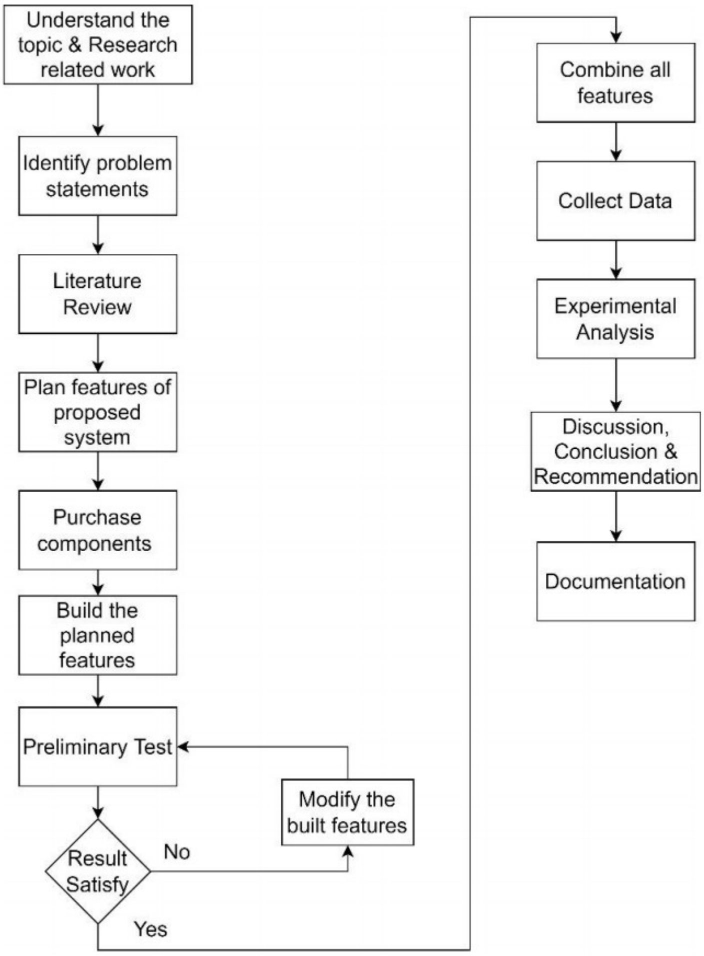

Figure 3.1: Flowchart of Overall Work.

3.3 Block Diagram

Figure 3.2 depicts the block diagram of the smart stick. Few sensors were employed in this project to provide the required functionality. This system uses the ESP32 as a microcontroller. When the ultrasonic sensors detect stairs and impediments, signal will be sent to the microcontroller. The data will be processed by microcontroller and sent over Message Queuing Telemetry Transport (MQTT). The information was kept in Ubidots cloud for both situations. The microcontroller will transmit the signal to the buzzer to buzz after processing the data collected for obstacles detection. However, the data from the sensor was retrieved from Ubidots cloud and sent to the phone application to provide users with an auditory alert when stairs are detected. The water sensor works similarly to an ultrasonic sensor such that it detects the presence of water and transmits the information to the Ubidots cloud for storing. The stick will vibrate once water is detected to warn the user. Pressing the emergency button on the stick can communicate with Ubidots cloud during an emergency. The MIT App Inventor will then receive the signal immediately. Through live location monitoring, the program will notify the guardian of the user's present location via live location tracking. Ubidots dashboard allows the guardian of the user to monitor their location via the implication of the Internet of Things. Users can also find their mislocated stick via a phone application and the buzzer will buzz. When the stick is found, the buzzer can be deactivated by pressing the stick button. The LDR sensor was used to gauge the amount of light present, and the LEDs would turn on when it became dark outside. The microcontroller is powered by a rechargeable battery module. The battery is rechargeable either with a universal serial bus (USB) cable or by the solar system when there is sunlight. MAX17043 LiPo Fuel Gauge IC was employed to monitor the battery condition, and data was stored in Ubidots Cloud. The information will then be published to the phone application, and the user will receive an auditory alert if the battery level is low.

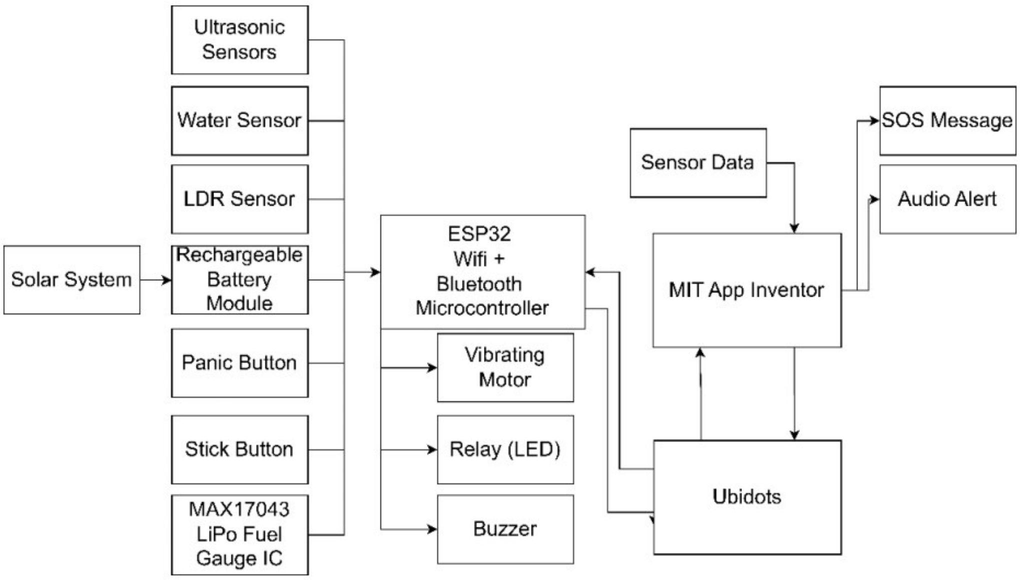

Figure 3.2: Block Diagram.

3.4 List of Materials

The materials and their quantities that were used in this project to carry out the specific functionality are listed in Table 3.1.

Table 3.1: Material List.

Component	Quantity	Description
ESP32	1	Microcontroller 38 pins
Ultrasonic Sensor	4	Obstacles Detection, Staircases Detection
Flat Vibrating Motor	1	Water Detection
Water Level sensor	1	Water Detection
LDR sensor	1	LED Illumination
LED	6	LED Illumination
2 V 150 mA Solar Panel	1	Power System
DC 1-5 V To DC 5 V Voltage Step Up Boost Module	1	Power System
TP4056 1 A Li-ion Battery Charging Module	1	Power System
5 V 1 way channel Opto Isolator Isolated Optocoupler Trigger Switch Relay Module	1	LED Illumination
3.7 V 18650 Li-ion Battery	1	Power System
18650 Battery Holders	1	Power System
MAX 17043 Lithium LiPo Battery Level Fuel Gauge Sensor Module	1	Power System
Tactile switch	2	Live Location Tracking, Stick Detection
Power switch	1	Power System
Buzzer	1	Obstacles Detection, Stick Detection
Resistor 1000 Ω	1	Extra Electrical Components
Resistor 100 Ω	6	Extra Electrical Components
Jumper Wire Female to Female 40P 20cm	1	Extra Electrical Components

Jumper Wire Female to Female 40P 30cm	1	Extra Electrical Components
Jumper Wire Female to Male 40P 30cm	1	Extra Electrical Components
1N4007 Diode	1	Extra Electrical Components
White cane	1	Stick

3.5 Software Platform

The software platforms used in this project include MIT App Inventor, Ubidots Cloud and Arduino IDE. They were employed to create phone application, store and visualize data as well as to program the microcontroller to carry perform the necessary functionality, respectively. Besides, these platforms also enable data exchange between the phone application, cloud, and microcontroller.

3.5.1 Arduino IDE

Arduino IDE is an open-source software that uses the C programming language. The written code can be uploaded to the board and run to implement the functionality of the smart assistive stick.

3.5.2 MIT App Inventor

The objective of the online platform MIT App inventor is to introduce computational thinking ideas through the creation of mobile applications. The design editor and block editor are the two primary editors found on the MIT App Inventor user interface. The components' layout of an application's user interface is done using a drag-and-drop interface called a design editor. With the use of coloured blocks that fit together in puzzled pieces to represent the software, the user may visually lay down the logic of their application in the block editor. App Inventor Companion, a phone application offered by MIT App Inventor enables programmers to test and modify the behaviour of their application (Patton, Tissenbaum and Harunani, 2019). The microcontroller in this project is able to communicate with the phone application created using MIT App Inventor with the aid of Ubidots cloud. The phone application is important for the functionality of providing audible alerts, live location tracking and finding the mislocated smart stick.

3.5.3 Ubidots

Ubidots is an online platform allows users to upload data from any Internally enabled device to the cloud, initiate actions and alerts depending on that data, and visualize the data. It was used in this project to both enable the users' guardians to track the user's present location and store the sensor data. Additionally, Besides, MIT App Inventor may retrieve data from the cloud to obtain the battery level and for staircase detection as well as live location tracking features.

3.5.4 Google Forms and Google Sheets

The guardian filled up the information of the visually impaired people by their guardian and the information was stored in the google sheets that is linked with the phone application. The user information can be retrieved and displayed at the phone application which is relatively important for live location tracking features.

3.6 Circuit Design of Proposed System

The overall circuit diagram of the system is shown in Figure 3.3. To simplify the soldering process and make it simpler to identify the pin connections, the circuit diagram of each feature was discussed separately.

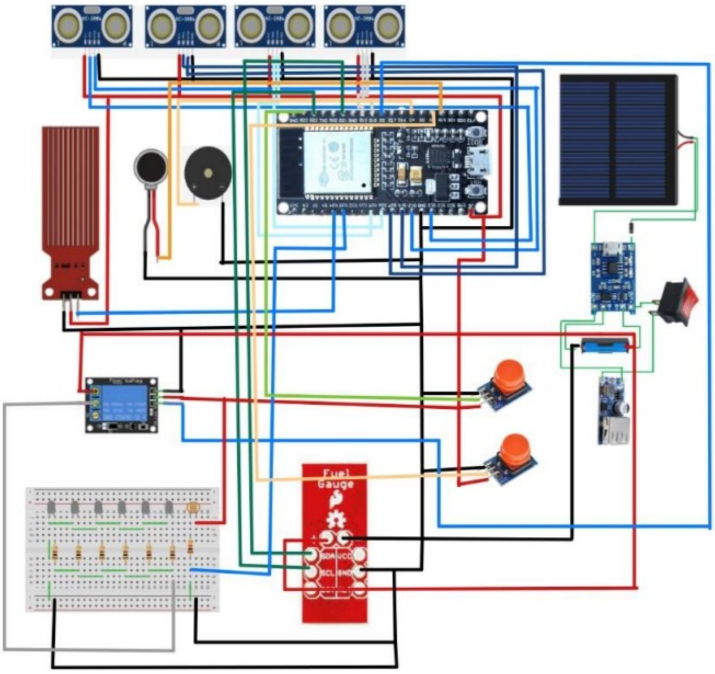

Figure 3.3: Circuit Design for Overall System.

3.6.1 Power System

The circuit connection of power system is shown in Figure 3.4. The anode of 1N4007 diode was connected to the red wire, which is the positive wire of the solar panel. The input side of the TP4056 Li-ion Battery Charger module has the IN+ connector linked to the cathode of the diode. The input side of the TP4056's IN- connector was directly linked to the black wire of the solar panel that represents the negative wire. The TP4056 has four connections on its output side which are B+, B-, OUT+, and OUT-. Holders for two 18650 Li-ion batteries were connected in parallel. The B+ connector of the TP4056 was wired to the positive terminal of the batteries. Similarly, the B- of the TP4056 was linked to the negative terminal of batteries. The step-up module's IN+ and IN- were connected to the TP4056 OUT+ and OUT-, respectively. The step-up module and TP4056 were connected via a switch that controls the on and off of the output. The step-up module was connected to the ESP32 with an USB cable. The MAX17043 Fuel Gauge's positive and negative terminals were connected to the positive and negative terminals of battery, respectively. The SDA pin and SCL pin of the fuel gauge are connected to G21 pin and G22 pin, respectively. While the Gnd pin of the fuel gauge was connected to the Gnd pin of ESP32.

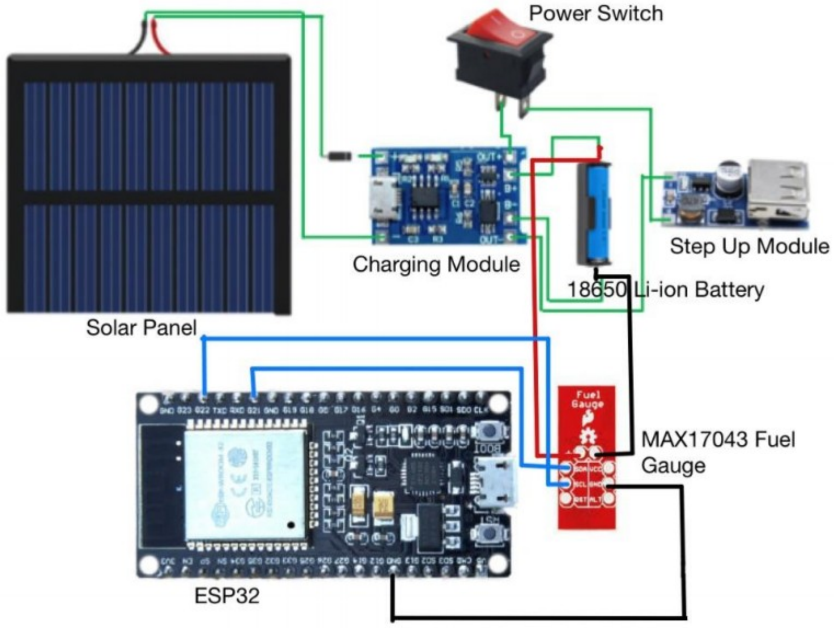

Figure 3.4: Circuit Diagram for Power System.

3.6.2 Obstacles Detection

The circuit connection for obstacles detection is shown in Figure 3.5. This function made up of three ultrasonic sensors. The Gnd pins of the three ultrasonic sensors connected to the Gnd pin of the ESP32, while their Vcc pins were connected to the V5 pin. The echo pin was connected to the G12 pin, while the trig pin for the first ultrasonic sensor connects to the G13 pin. The second trig pin of ultrasonic sensor and echo were connected to G14 and G27, respectively. The trig pin of the third ultrasonic sensor connects to the G26 pin, whereas the echo pin was connected to the G25 pin. For the buzzer, the positive terminal was connected to the G4 pin, while the negative terminal was connected to Gnd pin of ESP32.

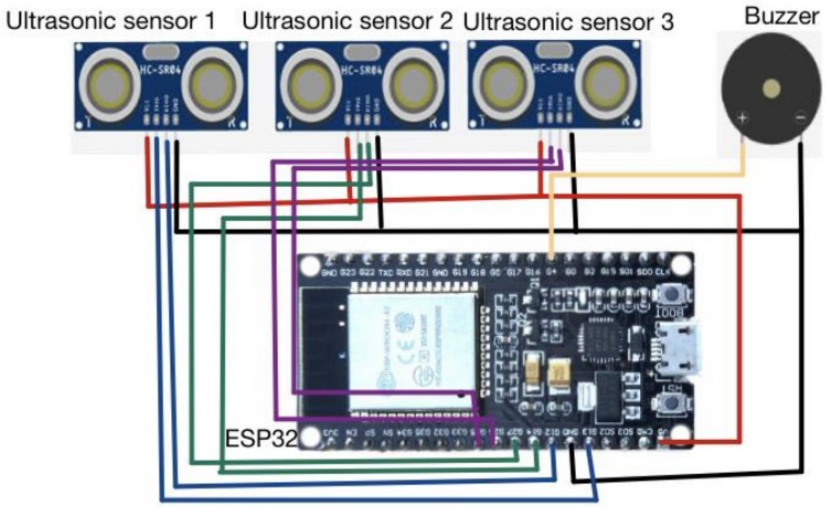

Figure 3.5: Circuit Diagram for Obstacles Detection.

3.6.3 Water Level Detection

The circuit diagram for water level detection is shown in Figure 3.6. The positive terminal of the water sensor was connected to the V5 pin, the negative terminal to the Gnd pin, and the S pin to the G32 pin of the ESP32. The positive terminal of vibration motor was connected to G15 pin, while the negative terminal was connected to the Gnd pin of ESP32.

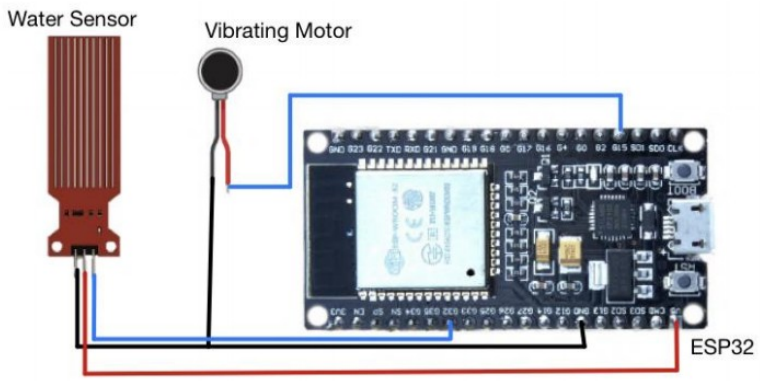

Figure 3.6: Circuit Diagram for Water Level Detection.

3.6.4 Staircase Detection

The circuit diagram for the feature of staircase detection is shown in Figure 3.7. One ultrasonic sensor was utilised for the purpose of detecting staircases. The ultrasonic sensor's Vcc pin was connected to the Vin pin, its Trig and Echo pins to G18 and G19, respectively, and its Gnd pin was joined to the ESP32's Gnd pin.

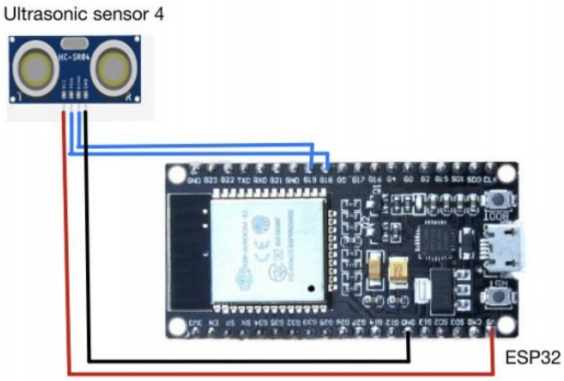

Figure 3.7: Circuit Diagram for Staircase Detection.

3.6.5 LED Illumination

The circuit diagram for the LED illumination is shown in Figure 3.8. The positive terminals of the LEDs were linked with a 100-ohm resistor to the C pin of the relay, while the negative terminals were connected to the Gnd pin. While one of the LDR sensor's terminal was linked to the V5 pin, the other terminal was connected to the G35 pin and Gnd pin of ESP32 using a 1000-ohm resistor. The NC pin of the relay will connect to positive terminal of the battery. While the Vcc pin and Gnd pin of the relay were connected to V5 and Gnd pin, while the signal pin was connected to G5 pin of ESP32.

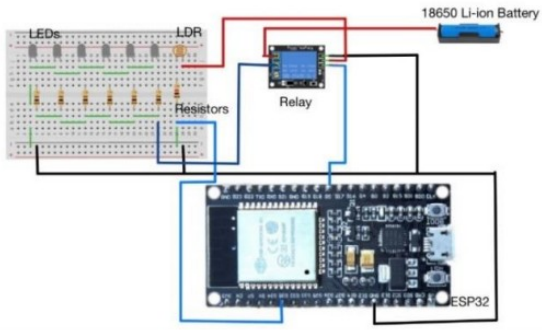

Figure 3.8: Circuit Diagram for LED Illumination.

3.6.6 Stick Detection

The circuit diagram for the stick detection feature is shown in Figure 3.9, and the buzzer, push button module and ESP32 were the components used in this module. The Vcc and Gnd pin of the button module were connected to V5 pin and Gnd pin of ESP32, respectively. While the out pin of the button module was connected to G2 pin of ESP32. The buzzer used to direct user to find the stick has the same wiring as the circuit connection for obstacles detection displayed.

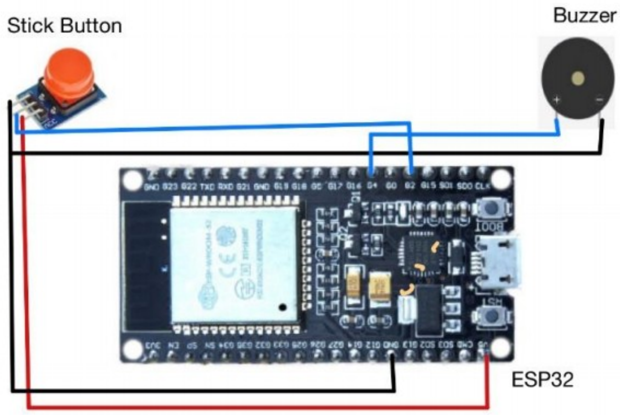

Figure 3.9: Circuit Diagram for Stick Detection.

3.6.7 Live Location Tracking

The circuit diagram for the live location tracking feature is shown in Figure 3.10. The Vcc and Gnd pin of the button module were connected to V5 pin and Gnd pin of ESP32 respectively. While the out pin of the button module was connected to G23 pin of ESP32.

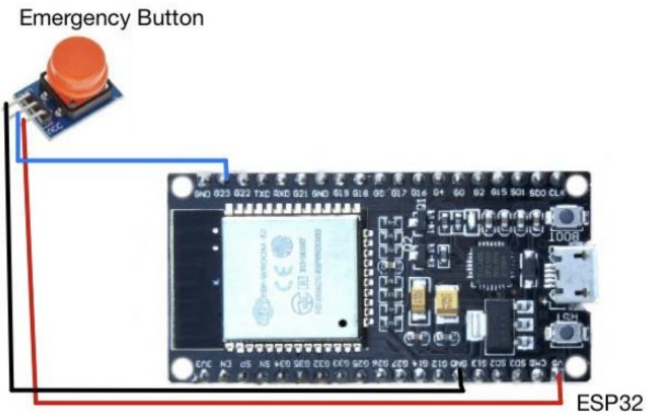

Figure 3.10: Circuit Diagram for Live Location Tracking.

3.7 Flowchart of Proposed System

For each aspect of the suggested system, a flowchart is created in this section to show the actions and choices that must be made in order to carry out the functionality. It is beneficial to visualise the issue and redesign any areas that require modification. The flowchart was drawn for each of the features to ensure that it is easier to identify if there is any issue.

3.7.1 Obstacles Detection

Ultrasonic sensors were positioned in various locations to detect obstacles for the obstacle detection features. The flowchart for obstacle detection is shown in Figure 3.11. When the system of the stick was initially configured, the ultrasonic sensor will determine the range received by the measuring distance. The data of the sensor will be read and sent to the Ubidots cloud to store it. If the measured distance for either ultrasonic sensor is less than or equal to 50 cm, the buzzer will buzz. The user will be stopped by the buzz sound to avoid running into obstacles. The operation will terminate if the power switch is pressed, else the readout of the measured distance will continue.

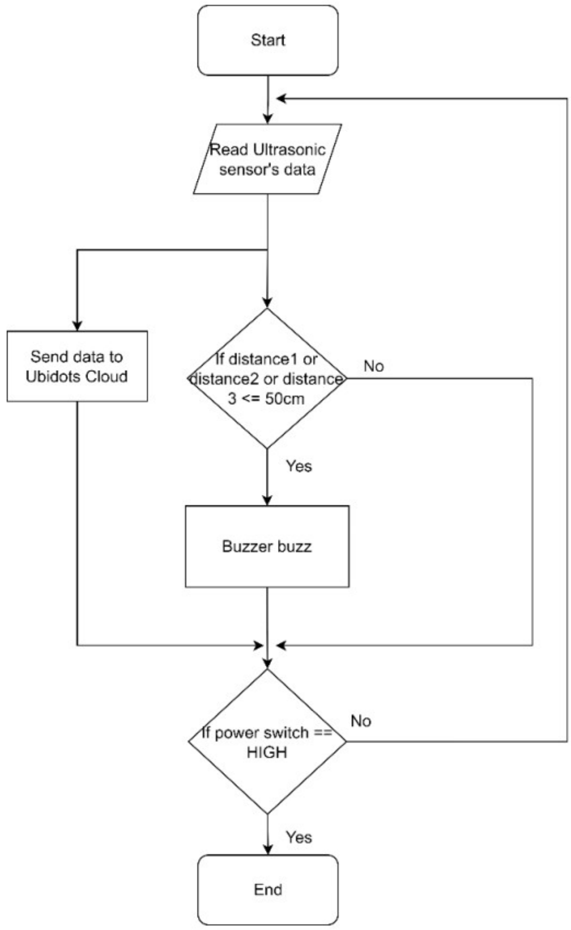

Figure 3.11: Flowchart for Obstacles Detection.

3.7.2 Water Level Detection

A water sensor is used to find out if there is water around. The flowchart for the water level detection feature is shown in Figure 3.12. Data from the sensor will be read and stored in Ubidots cloud when the system is initialised. The vibrating motor will vibrate if the value is more than zero to warn the user. The power switch's status will be checked. If the switch is switched off, the system will turn off, otherwise the procedure will proceed by looping back to read the sensor's data.

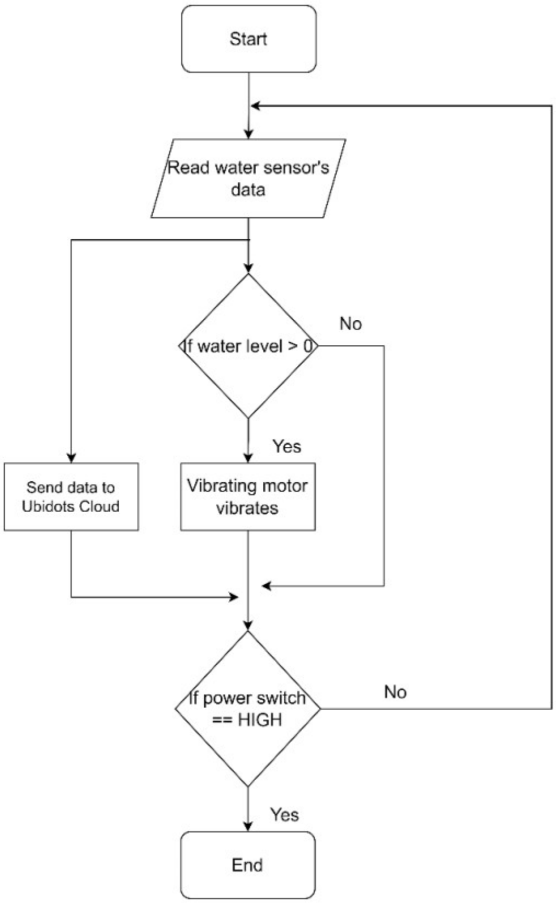

Figure 3.12: Flowchart for Water Level Detection.

3.7.3 Staircase Detection

The flowchart of staircase detection is shown in Figure 3.13. When the power of the system is turned on, it will begin to read the ultrasonic sensor's data, while the data will be stored in Ubidots cloud, and the data will be sent to the phone application for display. The phone application will provide an audio alert to alert the user about the upstairs if the distance is less than 22 cm, and an audio alert to alert the user about the downstairs if the distance is greater than 26 cm and less than 90 cm. The procedure will keep looping until the power switch is pressed and the system is turned off.

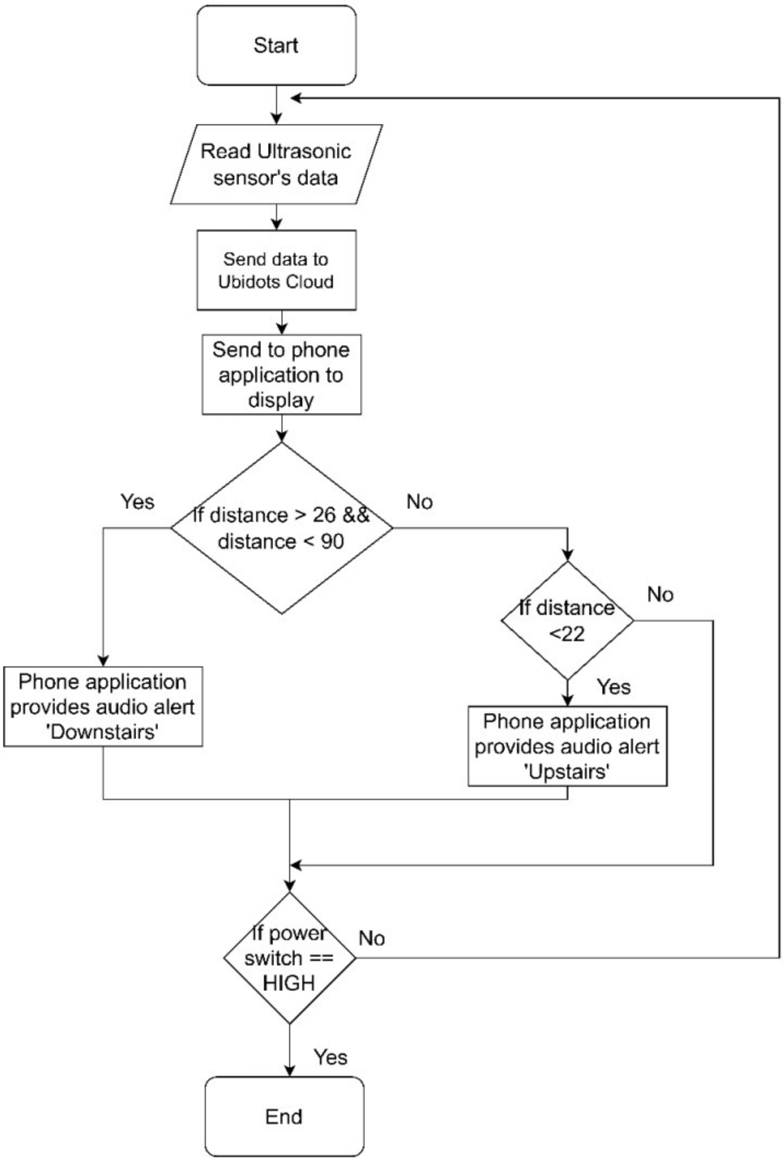

Figure 3.13: Flowchart for Staircase Detection.

3.7.4 LED Illumination

Figure 3.14 shows the flowchart for LED illumination. The LDR sensor data will be read when the power is turned on. If the resistance value is less than or equal to 500, the LEDs will turn on, else the LEDs will remain off. At the same instance, the status of LED will be update to the Ubidots cloud, The system will shut down if the power switch is turned off, otherwise the process for reading the sensor's data will be repeated.

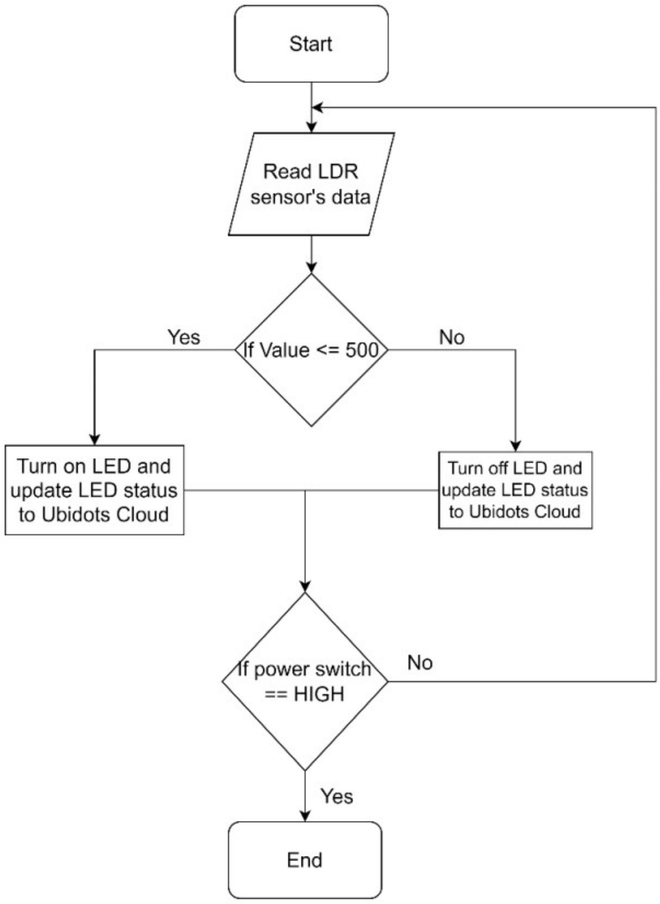

Figure 3.14: Flowchart for LED Illumination.

3.7.5 Live Location Tracking

Figure 3.15 presents the live location tracking flowchart. When the smart stick is turned on, the emergency button enables the user to call for assistance in case of an emergency. When the emergency button is pressed, the button status will be stored in the cloud and send to the phone application at the same time. The guardian of visually impaired people will receive the SOS message via a phone application. The steps for checking the status of the emergency button will continue until if the power switch is pressed, the system will turn off.

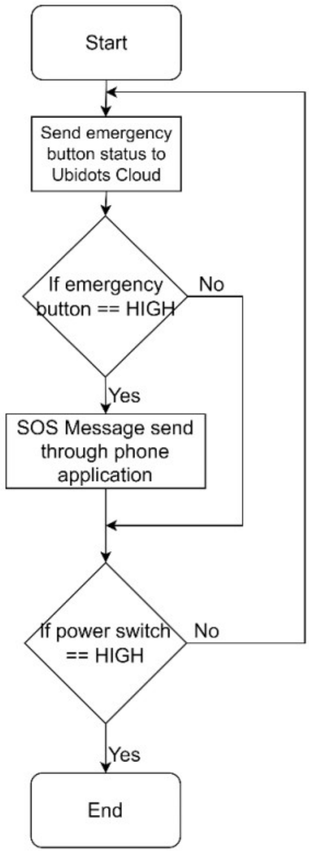

Figure 3.15: Flowchart for Live Location Tracking.

3.7.6 Stick Detection

Figure 3.16 shows the flowchart for the finding of stick. The feature is activated when the power switch attached to it is pressed. The condition of the button on the phone application will be examined. The associated buzzer on the stick will beep when the ON button is pressed to direct the user to know where the stick is and it will continue to buzz until the stick button is pressed. If the ON button is not pressed, the buzzer will not buzz. At the same time, the button status will be stored in Ubidots cloud. The processed of verifying the status of the ON button on the phone application will loop continuously until the power switch is pressed and the system is turned off.

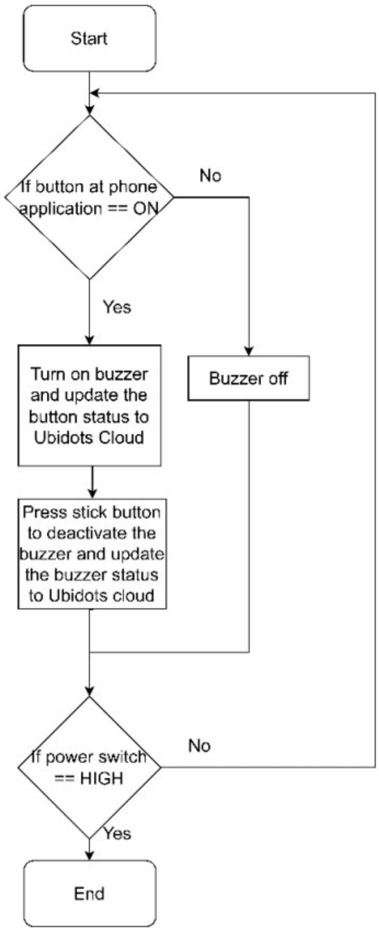

Figure 3.16: Flowchart for Stick Detection.

3.8 Finalised Design of Smart Stick

The finalised design of the smart stick is shown in Figure 3.17. Each ultrasonic sensor was positioned differently to enable the detection of obstacles at varying levels. To identify a staircase, one of the ultrasonic sensors was positioned at the lower of the stick and angled 90°. If the ultrasonic sensor is positioned at a greater height, the accuracy of the staircase detection may be compromised because the ultrasonic sensor will detect the stick itself. This is because larger ultrasonic pulses will be emitted as the measured distance increases. The water sensor, which is used to detect the presence of water, was attached to the lower tip of the stick, and emergency button was placed in a more ergonomic position. The LDR sensor was placed in a position where it can measure the amount of the environment's light intensity. While other hardware components were mounted on and inside the 3D-printed casing.

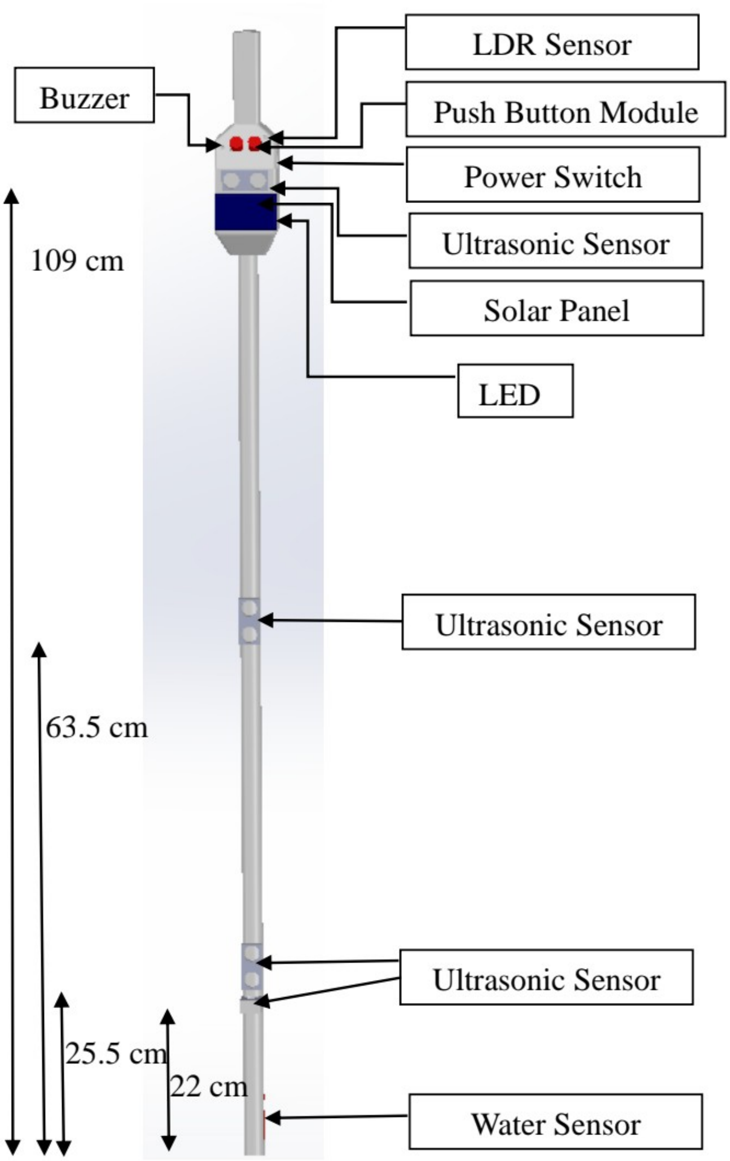

Figure 3.17: Finalised Design of Smart Stick.

3.9 Fabrication of Prototype

Fabrication of prototype involves the process of 3D printing, soldering as well as assembly.

3.9.1 3D Printing

The parts including the ultrasonic cover cases, water sensor holder, clips, and casing are 3D printed as shown in Figure 3.19. These parts were all drawn using Solidworks, and the G-CODE file was saved and sent to a 3D printer. In Figure 3.18, the 3D printing process is depicted. These parts are manufactured via 3D printing since the parts are lighter, more affordable, and rust resistant.

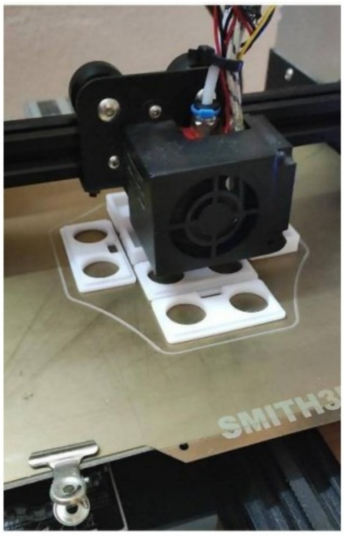

Figure 3.18: 3D Printing Process.

Figure 3.19: 3D Printed Parts.

3.9.2 Soldering

All of the wires connecting the hardware components in this project were soldered together by using a soldering iron, solder as well as soldering holder. Figure 3.20 shows the soldering kits used. The wires were soldered by referring to the circuit diagram for each of the features as shown above. Wires were soldered together to minimise the possibility of wire breaking loose from the hardware components. Figure 3.21 illustrates the soldering process.

Figure 3.20: Soldering Kits.

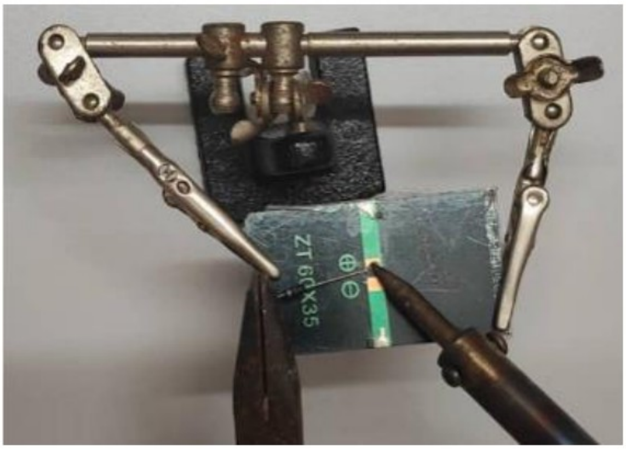

Figure 3.21: Soldering Process.

3.9.3 Assemble

The tools illustrated in Figure 3.22 were used to complete the assembly of the smart stick. The clips for ultrasonic sensors and water sensor were drilled as illustrated in Figure 3.23. The developed smart stick is shown in Figure 3.40. An ultrasonic sensor was positioned at 90° and the other three ultrasonic sensors were screwed into different height positions. The water sensor was mounted to the lower part of the stick. A hot glue gun was used to attach the solar panel to the 3D-printed casing. While the LDR sensor, buzzer, emergency button, stick button, power switch, and LEDs were assembled to the 3D printed casing and placed at their appropriate positions as shown in Figure 3.24. While the 3D printed casing included other components.

Figure 3.22: Equipment for Assemble Smart Stick.

Figure 3.23: Drilling Process.

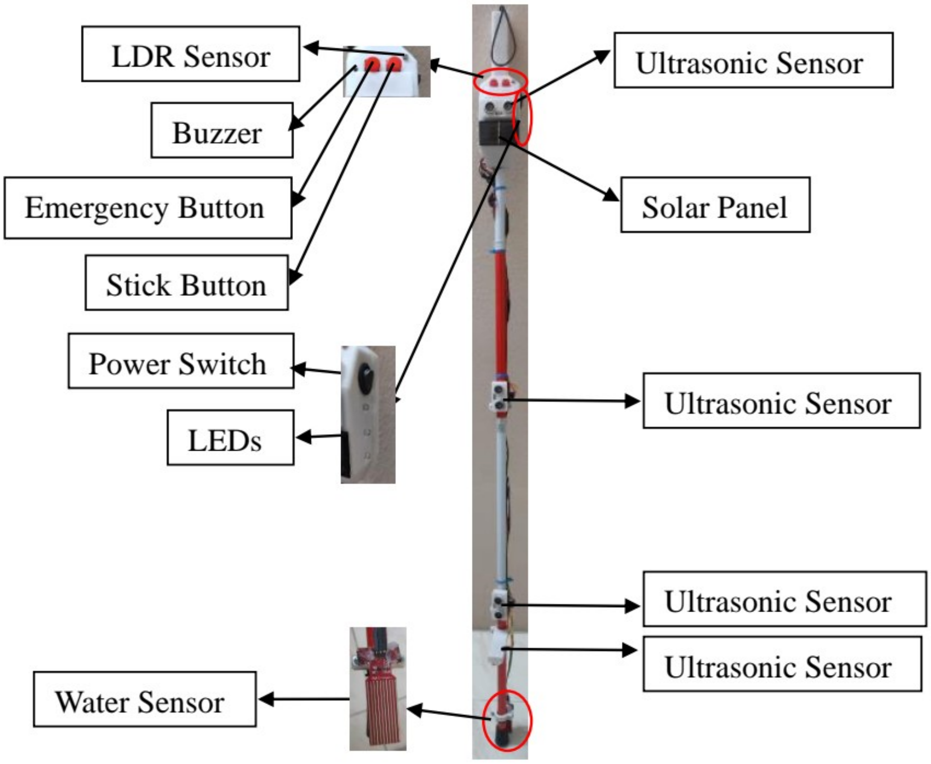

Figure 3.24: Assembly of Smart Stick.

3.10 Procedure to Test Prototype

Technical test was carried out before the humanization test to test the functionality of each feature. Prior to the humanization test, the experimental setup was prepared. As illustrated in Figure 3.25, 5 obstacles were prepared and placed within a 7 m walking path. Three water puddles were prepared within a 1.8 m walking path as shown in Figure 3.27. As indicated in Figure 3.28, the stick was placed 1.2 m from the participant. Each participant was requested to fill in their particulars on the registration form as shown in Figure 3.30. The participant was instructed to set up the phone application by long pressing the button to activate voice recognition as shown in Figure 3.31. The objective is to provide their allotted code number so that the phone application can access and display their information.

At the beginning of the humanization test, the participant was instructed to click the button on the phone application while blindfolded to find the stick. The participant was then requested to walk through the walking path with obstacles by using a normal stick and a smart stick. The participant was requested to walk through the path with water to test the water detection feature. Moreover, the emergency button was pressed by participants to test the live location tracking features. The first humanization test was repeated with 8 participants, while the second humanization test was repeated from setup 2 to 8 with 9 participants by preparing and placing ten obstacles within 10 m as shown in Figure 3.26. The water detection setup remained the same as shown in Figure 3.27. While the stick distance from the participant was extended to 1.8 m as shown in Figure 3.29.

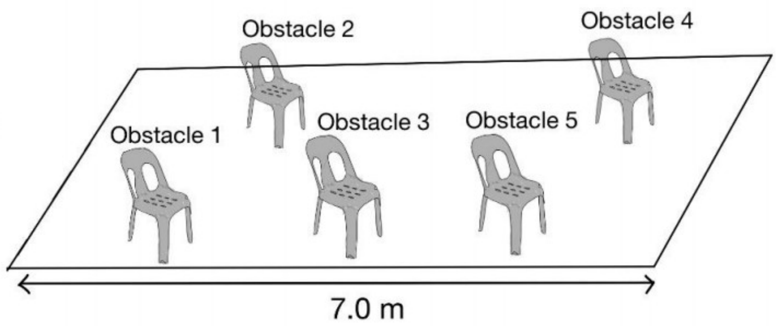

Figure 3.25: Setup for Obstacles Detection for First Humanization Test.

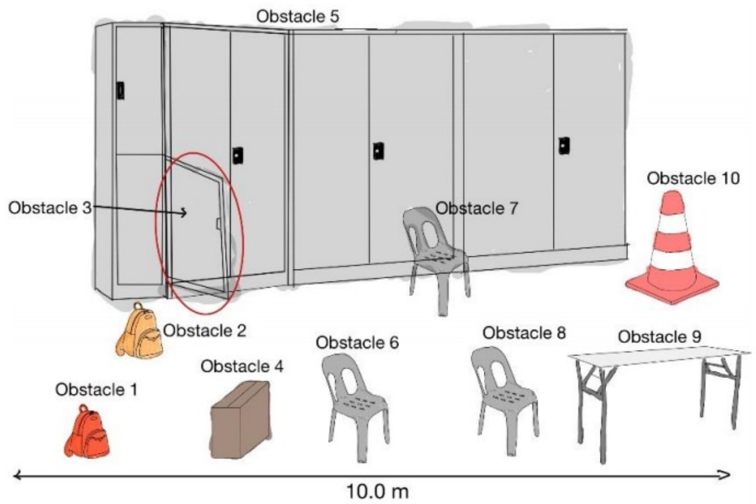

Figure 3.26: Setup for Obstacles Detection for Second Humanization Test.

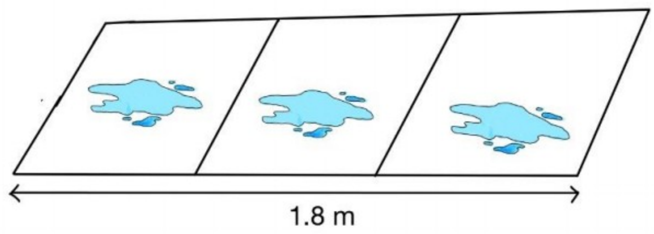

Figure 3.27: Setup for Water Detection for First and Second Humanization Test.

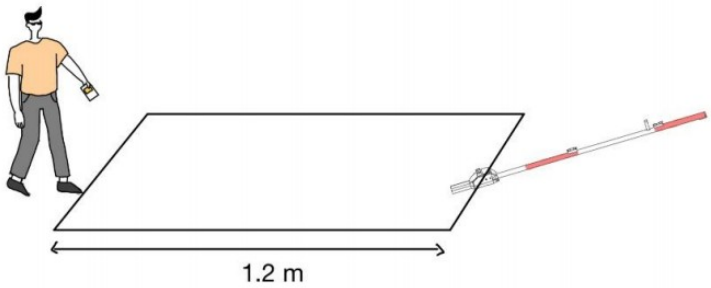

Figure 3.28: Setup for Stick Detection for First Humanization Test.

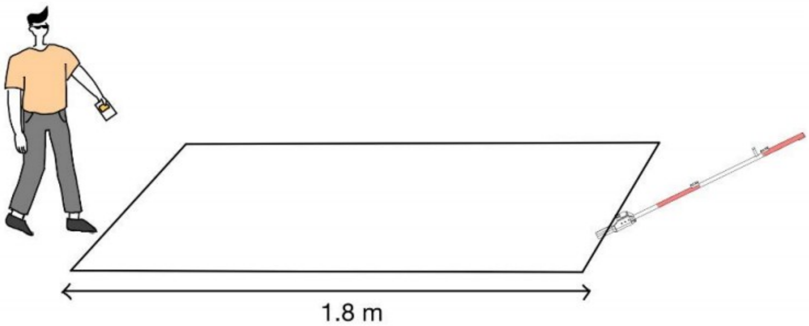

Figure 3.29: Setup for Stick Detection for Second Humanization Test.

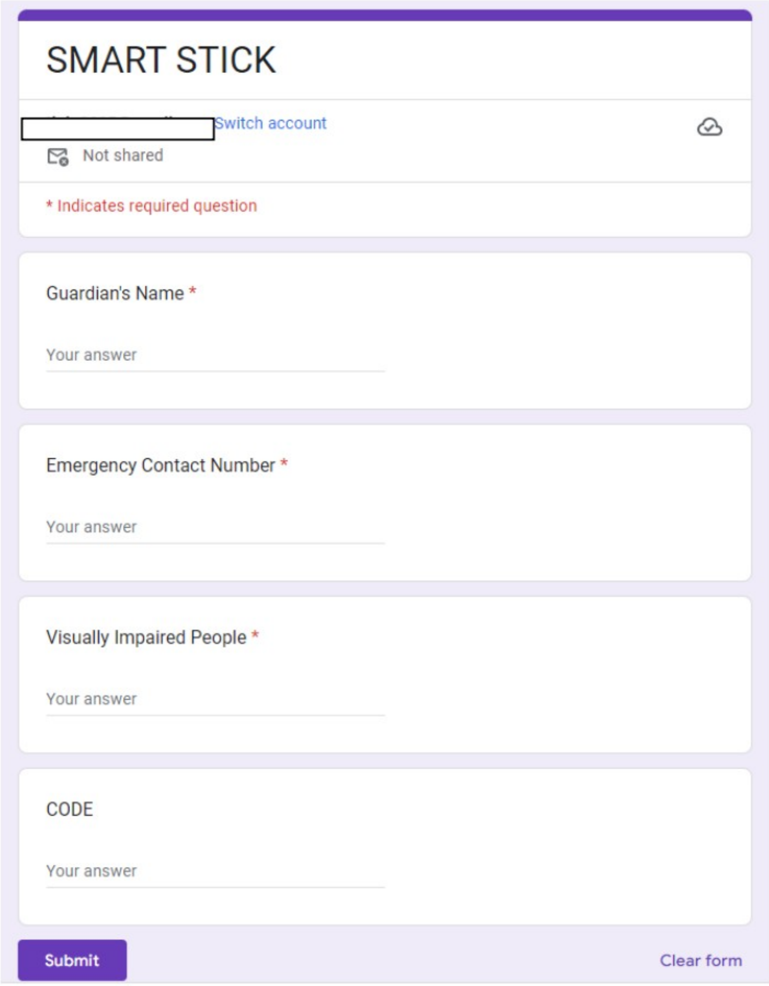

Figure 3.30: Registration Form.

Figure 3.31: Display of Phone Application.

3.11 Method of Data Collection and Data Analysis

Before the tests were conducted, the methods of collecting and analysing data for both technical test and humanization test were planned. This makes the testing run more smoothly and efficiently.

3.11.1 Technical Test

The features of obstacles detection, water detection, staircase detection, stick detection, LED illumination, live location tracking, and the solar system were tested technically. The data for the technical test was retrieved from the Ubidots cloud. The data of sensor, status of buttons and LED as well as live location of user can be visualised via Ubidots dashboard as shown in Figure 3.32. In the technical test for obstacles detection, the accuracy of three ultrasonic sensors and performance were assessed by positioning the obstacles at various distances from the sensors. This was observed and recorded on how the buzzer responded to various measured distances. For water detection feature, the condition of vibrating motor was monitored while the water sensor was submerged in a container of water.

For staircase detection, the slanted 90° ultrasonic sensor was used to detect upstairs and downstairs according to the distance measured. The efficacy of the audible alert in relation to the distance determined by the ultrasonic sensor was tested. A table was used to record the outcome. The smart stick was placed under various levels of lighting to determine whether the LED state is appropriate accordance to the LDR value. For stick detection, it was tested by observing the buzzer's reaction when a button on a phone application or the stick button was pressed. When the emergency button was pressed, the status of the SOS message was observed and recorded to test the live location tracking features. While the map on the dashboard was used to track the movement of the user to determine whether the location is updated every second.

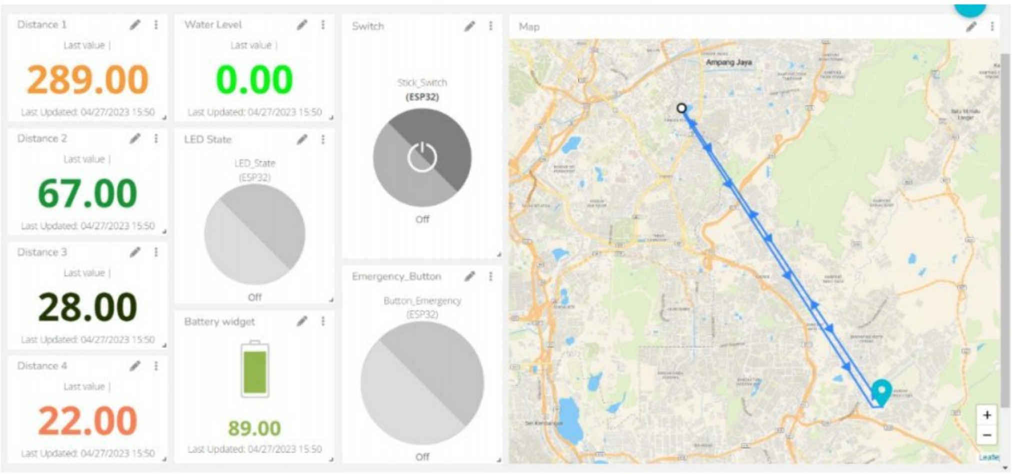

Figure 3.32: Data on Ubidots Dashboard.

3.11.2 Humanization Test

A humanization test was carried out to test the features of obstacles detection, water detection, stick detection, and live location tracking. Based on the previous research, the humanization test was carried out by 6 blind people (Nada, Fakhr and Seddik, 2015). However, the test conducted for this project increased the sample size to better analyse the effectiveness of the smart stick. The test involved 17, which is about 3 times as many participants as the previous research. This demonstrates that 17 participants are adequate for the study. The 17 participants involved in this study were randomly selected and they were divided into two groups. Eight participants took part in the first humanization test, and nine participants took part in the second. For the two tests, there were two different testing setups for the stick and obstacles detection features. However, the methods used to collect and analyse the data were the same. The time consumed by participants travelling the walking path with obstacles and the number of obstacles they collided with while utilising different devices were recorded for obstacles detection feature. The analysis of the obstacles detection feature involved calculating the walking speed of participants and the percentage of participant in avoiding the obstacles by using different devices by using the Equation 3.1 and 3.2. It is to analyse the effectiveness of the smart stick in improving the safety of the user. The result of the percentage calculated was presented in a graphical form to compare the result for both assisting device.

$$Walking\ Speed = \frac{Walking\ Distance}{Time\ taken} \tag{3.1}$$

$$Percentage\ of\ Avoiding\ Obstacles = \left|\frac{Number\ of\ obstacles\ presence - Number\ of\ obstacles\ collide}{Number\ of\ obstacles\ presence}\right| \times 100 \quad (3.2)$$

Besides, the number of water puddles detected by the participants were recorded. The effectiveness of the smart stick in detecting the water is evaluated by calculating the percentage of successfully detect water using the Equation 3.3. For stick detection feature, the time consumed by the participants to find the mislocated stick was recorded. This is to evaluate the effectiveness of the buzzer in directing the participants to find the stick. While for the live location tracking feature, the number of SOS messages successfully sent by participants was recorded and the current location of the participants was observed on the Ubidots dashboard. The effectiveness of live location tracking feature was analysed by observing the status of the SOS message and the user's movement. The accuracy of the live location tracking feature was evaluated by calculating the accuracy of measured latitude and longitude compared to the actual latitude and longitude using the Equation 3.4 and 3.5.

$$Percentage\ of\ Successfully\ Detect\ Water = \frac{Number\ of\ Water\ detected}{Number\ of\ Water\ Presence} \times 100 \quad (3.3)$$

$$Percentage\ of\ Accuracy\ of\ Measured\ Latitude = 100 - \left(\left|\frac{Actual\ Latitude - Measured\ Latitude}{Actual\ Latitude}\right| \times 100\right) \quad (3.4)$$

$$Percentage\ of\ Accuracy\ of\ Measured\ Longitude = 100 - \left(\left|\frac{Actual\ Longitude - Measured\ Longitude}{Actual\ Longitude}\right| \times 100\right) \quad (3.5)$$

3.12 Summary

This chapter wraps up the preparation work that must be done before starting the prototyping development process. This chapter also provides a detailed explanation of the fabrication process, testing procedures, as well as methods in collecting and interpreting data.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 Introduction

This chapter discusses the technical test analysis for each feature of the smart stick developed. Through the findings of humanization test, this chapter also discusses the smart stick's efficacy and efficiency. The qualitative result in this chapter provides a summary of the smart stick feedbacks collected from five visually impaired interviewers.

4.2 Technical Test Results

A technical test was carried out to test the workability of each of the features. This test was carried out before the humanization test to secure the safety of the participants while using the developed smart sticks.

4.2.1 Obstacles Detection

Based on Table 4.1, distance 1, 2 and 3 represent the measurement of ultrasonic sensor 1, 2 and 3, respectively. According to the findings, the buzzer buzz when one of the distances is less than 50 cm as shown in Figure 4.1. The findings showed that this smart stick can notify user immediately when various height obstacles are recognised.

Table 4.1: Technical Test Result for Obstacles Detection

No	Distance 1	Distance 2	Distance 3	Status of Buzzer
1	98	56	44	ON
2	100	57	35	ON
3	109	44	53	ON
4	100	46	58	ON
5	52	43	32	ON
6	35	35	31	ON
7	112	116	62	OFF
8	113	117	63	OFF

Figure 4.1: Detection of Obstacle Using Smart Stick.

4.2.2 Water Detection

Table 4.2 demonstrates that the vibrating motor status is high, indicates the motor is vibrating when the water level is higher than zero as shown in Figure 4.2. The vibrating motor status is low and implies the vibrating motor is not triggered when the water level is zero, which shows that the water sensor is not in contact with any water.

Table 4.2: Technical Test Result for Water Detection

No	Water Level	Status of Vibrating Motor
1	0	LOW
2	0	LOW
3	0	LOW
4	0	LOW
5	26	HIGH
6	731	HIGH
7	189	HIGH
8	272	HIGH
9	235	HIGH
10	266	HIGH

Figure 4.2: Detection of Water Using Smart Stick.

4.2.3 Staircase Detection

Table 4.3 displays the measured distance, the audible alert, and the audio response latency. The audio alerted "Upstairs" when the distance was less than 22 cm as shown in Figure 4.3; "Downstairs" when the distance was greater than 26 cm or less than 90 cm. The audible alert can offer the proper alert in accordance with the distance calculated after a few tries. However, the reaction time for audio was 2 seconds. This is due to the delay in the phone application retrieving data from the cloud and the microcontroller updating the distance to the dashboard.

Table 4.3: Technical Test Result for Staircase Detection

No	**Distance 4**	**Audible Alert**	**Time delay for Audio Response (s)**
1	24	N/A	N/A
2	27	Downstairs	2
3	30	Downstairs	2
4	6	Upstairs	2
5	6	Upstairs	2
6	5	Upstairs	2
7	5	Upstairs	2
8	32	Downstairs	2
9	22	N/A	N/A
10	28	Downstairs	2

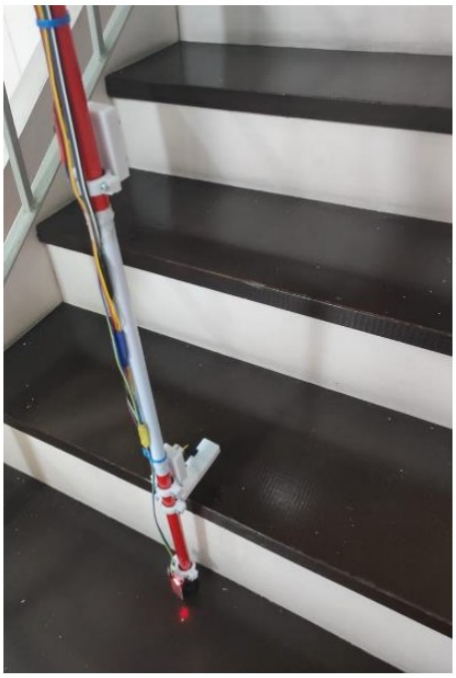

Figure 4.3: Detection of Staircase Using Smart Stick.

4.2.4 LED Illumination

The LED condition at various LDR values is displayed in Table 4.4. The light intensity has an impact on the LDR value. The LED will light up if the value is less than 500 as shown in Figure 4.4. This demonstrates that the LED can react in accordance with the LDR value, and this capability enables other users to recognise the presence of visually impaired people when navigating in a dark environment and reduces the possibility of a collision with a vehicle or another user.

Table 4.4: Technical Test Result for LED Illumination

No	LDR value	Status of LED
1	38	ON
2	14	ON
3	0	ON
4	33	ON
5	451	ON
6	186	ON
7	761	OFF
8	795	OFF
9	752	OFF
10	947	OFF

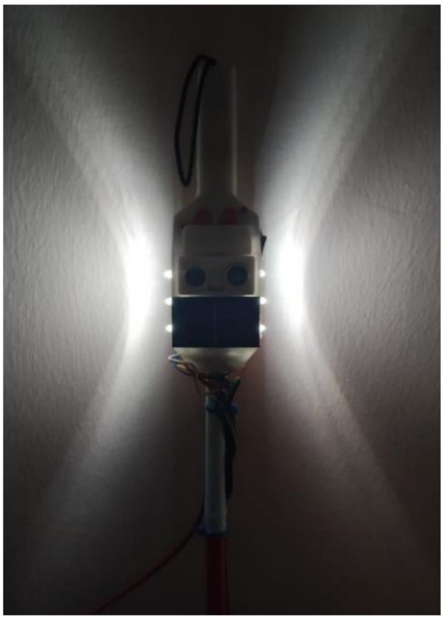

Figure 4.4: Smart Stick in Dark Environment.

4.2.5 Stick Detection

Table 4.5 displays the buzzer response according to the status of find button and stick button. When the button on the phone application is pressed, the buzzer status is high, indicating that the buzzer is buzzing. Whereas when the stick button is pressed, the buzzer status is low, indicating that the buzzer is inactive. The results in Table 4.5 demonstrate the effectiveness of this stick detection feature.

Table 4.5: Technical Test Result for Stick Detection

No	Status of Find Button	Status of Stick Button	Status of Buzzer
1	1	0	HIGH
2	0	1	LOW
3	1	0	HIGH
4	0	1	LOW
5	1	0	HIGH
6	0	1	LOW

4.2.6 Live Location Tracking

When the emergency button is pressed, the cloud status changes to 1, and the message was successfully sent, as shown in Table 4.6 for the live location tracking feature. The current location of the user was included in the SOS message, and Figure 4.1 displays the user location on a map on the Ubidots dashboard. These allow a guardian to track a location of the user in case of an emergency.

Table 4.6: Technical Test Result for Live Location Tracking

No	Status of Emergency Button	Status of SOS Message
1	1	Sent
2	1	Sent
3	1	Sent
4	1	Sent
5	1	Sent

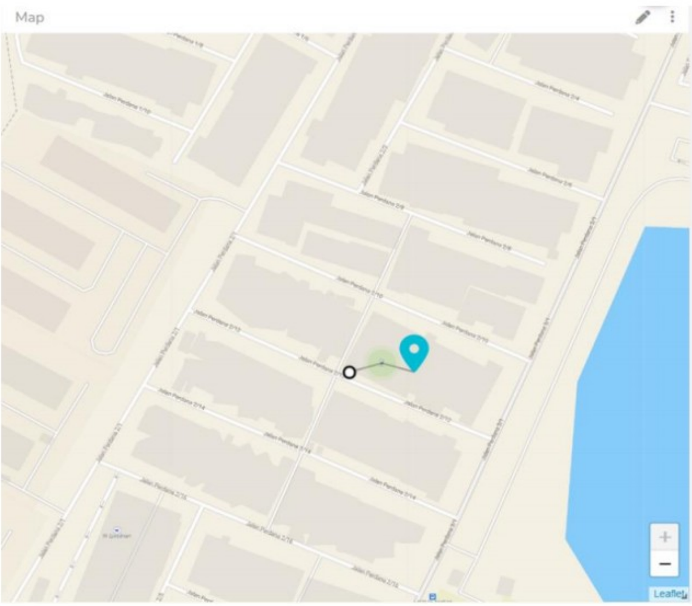

Figure 4.5: User's Location on Map in Ubidots Dashboard.

4.2.7 Solar System

The voltage and current are measured to determine the functionality of the solar panel while a torchlight is held above it. The voltage and current supply were measured using a digital Multimeter, as depicted in Figures 4.6 and Figure 4.7, respectively. Solar panels can provide up to 0.995 V of voltage and

0.083 mA of current. This demonstrates that the solar panel can charge the battery. At this stage of development, the low current output of solar panel required longer charging time due to its low efficiency.

Figure 4.6: Testing of Voltage of Solar Panel.

Figure 4.7: Testing of Current of Solar Panel.

4.3 Humanization Test Results

The humanization test involved a total of 17 participants with normal vision. The 17 participants were requested to be blindfolded for entire test. By considering the safety of the participants, the staircase detection was not tested in the humanization test. While the 17 participants were split into two groups to test the features of obstacles detection, water detection, stick detection, and live location tracking with different setups. This was conducted to assess the effectiveness and efficiency of the smart stick more accurately.

4.3.1 Obstacles Detection

The results of the first test are shown in Table 4.7 and Table 4.8. Participants using normal stick and smart stick walked on average speed which is 0.17 m/s. Figure 4.8 demonstrates that for all participants, the smart stick considerably increased the proportion of collision avoidance over the normal stick. This is corroborated by the average success rate of avoiding obstacles with a normal stick being 52.5%, compared to 92.5% for a smart stick.

The second test included more obstacles and a further walking distance. The results were shown in Table 4.9 and Table 4.10. The highest walking speed of participant among nine participants using normal stick which is 0.22 m/s. However, the participant with highest walking speed has only 30% of success rate to avoid obstacles with normal stick. The highest walking speed of participant among nine participants is 0.24 m/s and its success rate for avoiding obstacles with a smart stick is 100%. Participants using smart stick walked faster on average speed which is 0.17 m/s than those using normal stick with 0.14 m/s. Figure 4.9 demonstrates that for second test, all participants who used smart stick experienced higher collision avoidance rates than those who used normal sticks. This is further reinforced by the average success rate of avoiding obstacles using a normal stick, which is 40% compared to a smart stick, which is 91.11%. The results demonstrated that the smart stick is effective in assisting the participants by avoiding obstacles as well as increasing the speed of walking. This feature can lower the risk of users getting injured and increase their level of safety.

Table 4.7: Time Consumed and Number of Obstacles Collide for Normal Stick and Smart Stick in First Test.

Participant	Time consumed with normal stick (s)	Number of obstacles collide	Time consumed with smart stick (s)	Number of obstacles collide
1	43	3	37	0
2	50	2	33	0
3	37	1	36	0
4	54	5	51	1
5	34	3	41	0
6	56	0	50	0
7	34	2	45	1
8	41	3	47	1

Table 4.8: Walking Speed of Participant and Percentage of Successful Avoid Obstacles Using Normal Stick and Smart Stick in First Test.

Participant	Walking speed with normal stick (m/s)	Percentage of successful avoid obstacles with normal stick	Walking speed with smart stick (m/s)	Percentage of successful avoid obstacles with smart stick
1	0.16	40	0.19	100
2	0.14	60	0.21	100
3	0.19	80	0.19	100
4	0.13	0	0.14	80
5	0.21	40	0.17	100
6	0.13	100	0.14	100
7	0.21	60	0.16	80
8	0.17	40	0.15	80
Average	0.17	52.5	0.17	92.5

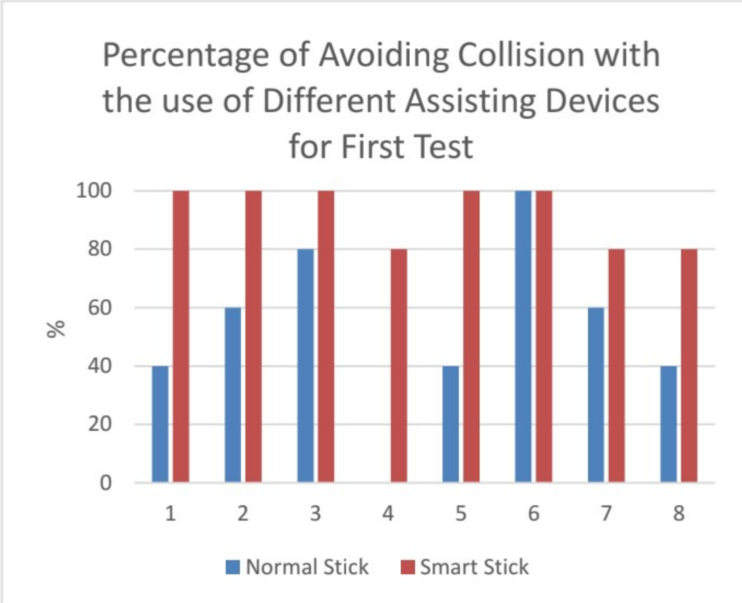

Figure 4.8: Percentage of Avoiding Collision Using Normal Stick and Smart Stick for First Test.

Table 4.9: Time Consumed and Number of Obstacles Collide for Normal Stick and Smart Stick in Second Test.

Participant	Time consumed with normal stick (s)	Number of obstacles collide	Time consumed with smart stick (s)	Number of obstacles collide
1	114	5	45	0
2	73	5	52	1
3	61	6	41	0
4	46	7	74	2
5	60	6	80	2
6	103	6	49	1
7	65	6	60	1
8	88	6	115	1
9	89	7	83	0

Table 4.10: Walking Speed of Participant and Percentage of Successful Avoid Obstacles Using Normal Stick and Smart Stick in Second Test.

Participant	Walking speed with normal stick (m/s)	Percentage of successful avoid obstacles with normal stick	Walking speed with smart stick (m/s)	Percentage of successful avoid obstacles with smart stick
1	0.09	50	0.22	100
2	0.14	50	0.19	90
3	0.16	40	0.24	100
4	0.22	30	0.14	80
5	0.17	40	0.13	80
6	0.10	40	0.20	90
7	0.15	40	0.17	90
8	0.11	40	0.09	90
9	0.11	30	0.12	100
Average	0.14	40	0.17	91.1111

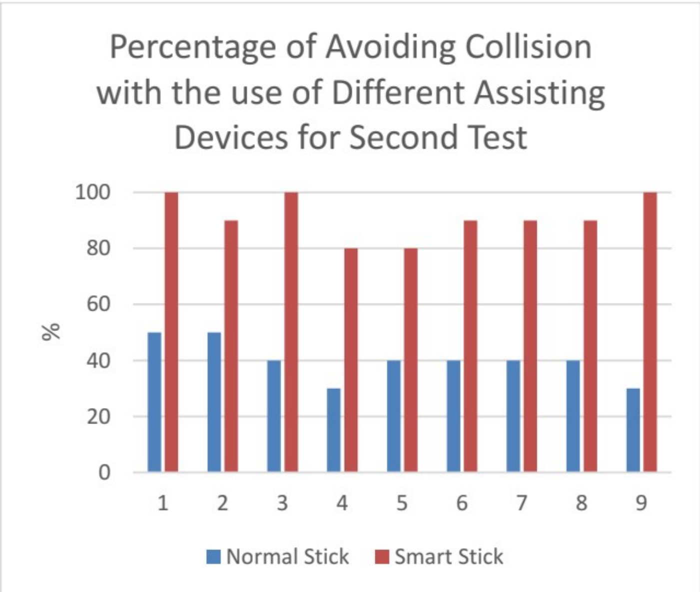

Figure 4.9: Percentage of Avoiding Collision Using Normal Stick and Smart Stick for Second Test.

4.3.2 Water Detection

According to Table 4.11, participants with were able to feel the vibration when all water puddles were detected by using smart stick, and the average success rate for detecting water was 100%. With a 100% accuracy rate, it indicates that this smart stick can increase user's safety by lowering the probability that visually impaired people will fall because of water on the floor.

Table 4.11: Number of Water Puddles Detected and Percentage of Successful to Detect Water.

Participant	Number of Water Puddles detected	Percentage of successful to detect water (%)
1	3	100
2	3	100
3	3	100
4	3	100
5	3	100
6	3	100
7	3	100
8	3	100
9	3	100
10	3	100
11	3	100
12	3	100
13	3	100
14	3	100
15	3	100
16	3	100
17	3	100
Average	3	100

4.3.3 Stick Detection

Stick detection is a feature that assists the user to find the stick. The first test results to identify the smart stick of 8 participants are shown in Table 4.12 based on the findings. The average time for participants to find the stick was 7.5 seconds, and all the individuals were successful in locating the stick. For the second test, all nine participants were successful in locating a stick. Table 4.13 displays the time consumed of nine participants to find the stick. However, the distance between the participants and the stick is greater for the second test. Therefore, the average time to find stick is longer for second test which is 12.33s compared to first test. From this humanization test, it shows that the buzzer's sound was able to direct the participants to find the stick.

Table 4.12: Time Consumed to Find Stick for First Test.

Participant	Time Consumed to Find Stick (s)
1	8
2	7
3	8
4	7
5	6
6	6
7	10
8	10
Average	7.5

Table 4.13: Time Consumed to Find Stick for Second Test.

Participant	Time Consumed to Find Stick (s)
1	10
2	11
3	10
4	10
5	16
6	12
7	20
8	12
9	10
Average	12.33

4.3.4 Live Location Tracking

Based on Table 4.14, it can be observed that the SOS was sent, and the status of the emergency button was updated to the cloud when the participant pressed it. The message received by the guardian is depicted in Figure 4.10. According to the findings in Table 4.14, all participants pressed the emergency button have successfully sent an SOS message to their guardians. As a result, the guardian can react promptly when any emergencies happen. Additionally, the location of the participant was updated every second to the cloud, allowing the guardian to monitor the user movement via Ubidots dashboard as shown in

Figure 4.11. Furthermore, Table 4.15 shows the latitude and longitude coordinates taken from each participant during the testing. According to the results, the average latitude and longitude measurements have the accuracy of 99.988% and 99.999%, respectively. This allows the guardian to keep track of the location of the user accurately. This also showed that the live location tracking feature works effectively in improving the safety of visually impaired people.

Table 4.14: Status of SOS Message Accordance to Emergency Button Status.

Participant	**Status of Emergency Button**	**Status of SOS Message**
1	1	SENT
2	1	SENT
3	1	SENT
4	1	SENT
5	1	SENT
6	1	SENT
7	1	SENT
8	1	SENT
9	1	SENT
10	1	SENT
11	1	SENT
12	1	SENT
13	1	SENT
14	1	SENT
15	1	SENT
16	1	SENT
17	1	SENT

Table 4.15: Latitude and Longitude Measurements during Testing.

Participant	**Latitude**	**Measured Latitude**	**Accuracy, %**	**Longitude**	**Measured Longitude**	**Accuracy, %**
1	3.03969	3.0393	99.987	101.793	101.79397	99.999
2	3.03969	3.03933	99.988	101.793	101.79397	99.999
3	3.03969	3.03933	99.988	101.793	101.794	99.999
4	3.0396	3.03935	99.989	101.793	101.794	99.999

	9					
5	3.03969	3.03933	99.988	101.793	101.79401	99.999
6	3.03969	3.03933	99.988	101.793	101.79401	99.999
7	3.03969	3.03932	99.988	101.793	101.79399	99.999
8	3.03969	3.0393	99.987	101.793	101.79398	99.999
9	3.03969	3.03934	99.988	101.793	101.79398	99.999
10	3.03969	3.03933	99.988	101.793	101.79398	99.999
11	3.03969	3.03931	99.987	101.793	101.79395	99.999
12	3.03969	3.03929	99.987	101.793	101.79396	99.999
13	3.03969	3.0393	99.987	101.793	101.79398	99.999
14	3.03969	3.03944	99.992	101.793	101.79399	99.999
15	3.03969	3.03936	99.989	101.793	101.79401	99.999
16	3.03969	3.03932	99.988	101.793	101.79399	99.999
17	3.03969	3.03932	99.988	101.793	101.79396	99.999
Average	N/A	N/A	99.988	N/A	N/A	99.999

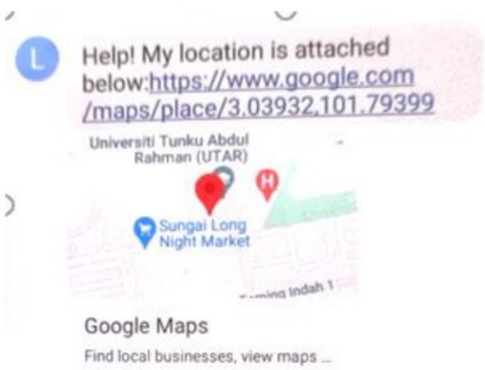

Figure 4.10: SOS Message Received by Guardian.

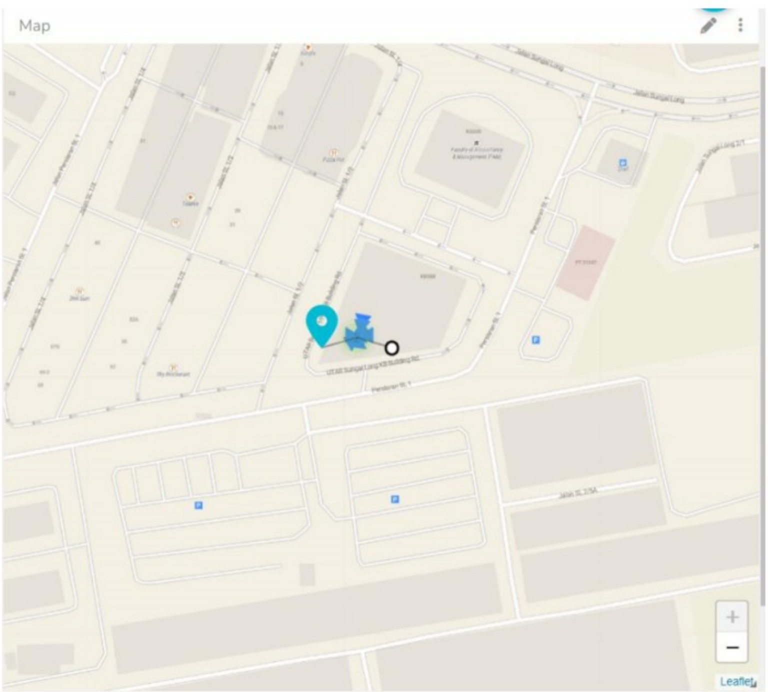

Figure 4.11: User's Movement on Map in Ubidots Dashboard.

4.4 Qualitative Result

Five visually impaired people were involved in an interview session, and they have provided a few feedbacks to this developed smart stick. Most of them remarked on the length, weight, handle, and design of the smart stick. According to them, the stick is longer and heavier than a standard white cane. They preferred a cane that is as light as their original cane and a cane that can fit their height better. Additionally, they found that the handle of the smart stick was difficult for them to grasp, and the design was bulky as compared to the normal stick they currently own. Furthermore, they demanded for the smart stick that is foldable, which is more convenient to carry along. Moreover, they requested for a smart stick with a more precise sensor that can detect obstacles accurately and able to cope with their walking speed. The limitations of ultrasonic sensor prevent it from identifying obstacles precisely and providing the appropriate alert when the stick was swung quickly. However, this smart stick has a water detection feature that can assist the visually impaired people to detect water by providing them proper alerts. By using their original stick, they are unable to detect the presence of water. Therefore, they could only feel the presence of water when they are stepping on it. Their opinions indicated that further improvements are needed to increase the commercial viability of the smart stick.

4.5 Summary

In this chapter, the technical test and the humanization test were analysed and discussed. While the qualitative result included a summary of the comments from the visually impaired people.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Conclusions

In conclusion, the smart assistive stick was developed and evaluated in this project. This smart stick, which was equipped with multitude of sensors and leveraged Internet of Things, can assist the visually impaired people to move around safely and enable them to seek for assistance in case of an emergency and reduce their risk of injury. Through technical testing, the functionality of obstacles detection, water detection, staircase detection, stick detection, LED illumination, live location tracking, and solar system was assessed. The findings demonstrated that each feature was functioning as expected. The humanization test was carried out to analyse the effectiveness of the smart stick in improving the safety of the visually impaired people. It was also used to evaluate the accuracy of the live location tracking feature for the guardian to keep track of the location of visually impaired people.

According to the results of humanization test for the obstacle detection feature, the smart stick can assist the participants to walk more quickly and successfully avoid obstacles. Based on the test results, the average walking speed for both the first and second test participant was 0.17 %. For the first and second tests, the smart stick typically avoided obstacles with a success rate of 92.5% and 91.11%, respectively. In both tests, the smart stick had a substantially higher average success rate in avoiding obstacles than normal stick. With the use of smart stick, all of the participants were able to detect water puddles accurately with the percentage of 100% by noticing the vibration for the water detection feature. As a result, this smart stick effectively and efficiently helped visually impaired people to navigate by minimising the probability that they would trip over obstacles or slip.

The stick detection feature was suggested so that user can always find the misplaced stick. The stick is important for visually impaired people because it is able to assists them to navigate. As a result, their safety may be threatened while navigating around without stick. According to the results, participants were successful in finding the mislocated stick. This live location tracking feature is crucial to improve the safety of visually impaired people. Their guardian can keep track of their locations in case of an emergency via Ubidots dashboard. This feature also enables the visually impaired people to send an SOS message in an emergency. According to the results, all 17 participants were able to press the emergency button and successfully send the SOS message with accurate location. The measurements of latitude and longitude taken from each participants have the average of 99.988% and 99.999%, respectively. The objectives of this project were achieved through the technical test and the humanization test.

5.2 Recommendations for Future Work

The phone application should be improved in future work. It could be more user-friendly by adding the feature of voice commanding. Additionally, it is suggested to concentrate on improving the smart stick design. It is recommended to develop a foldable and length-adjustable smart stick. This is to make sure that the stick can be used by individuals of all heights, and the foldable stick makes it easy for them to take it around. In order for them to grasp the stick handle, it is also suggested that the handle can be designed with a longer length as well as more comfortable. The casing can be made smaller by streamlining the wiring and the weight of the stick is suggested to reduce by employing a lighter material.

Additionally, it is recommended to improve on the sensitivity and response rate of the sensors especially ultrasonic sensor. Thereby, visually impaired people can walk faster and avoid obstacles with a higher success rate using the smart stick. It is suggested to include the feature of object recognition using the camera sensor in future research to identify vehicles or staircases accurately to increase safety of the user while navigating.

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APPENDICES

Appendix A: Gantt Chart

Gantt Chart

No.	Project Activities	Planned Completion Date	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17
1.	Project planning 1. Identify the importance of the study 2. Identify the problem statement 3. Study and plan features of the prototype 4. Prepare block diagram	2022-07-03																	
2.	Literature review	2022-08-28																	
3.	Preliminary testing/investigation 1. Build and test every single feature of the project	2022-09-04																	
4.	Report writing & presentation 1. Complete and submit the report 2. Prepare presentation slide	2022-09-11																	

Figure A - 1: Gantt Chart for FYP 1.

Gantt Chart

No.	Project Activities	Planned Completion Date	W1	W2	W3	W4	W5	W6	W7	W8	W9	W10	W11	W12	W13	W14	W15	W16	W17
1.	Build Prototype 1. Modify planned features 2. Assemble	2023-02-19																	
2.	Pilot Testing 1. Test prototype 2. Analyse the result 3. Make necessary modification	2023-03-19																	
3.	Report Writing and Presentation 1. Complete and submit final report 2. Prepare poster 3. Prepare slide	2023-04-23																	

Figure A - 2: Gantt Chart for FYP 2.

Appendix B: Figures

Figure B - 1: Technical Test for Obstacle Detection by Middle Sensor.

Figure B - 2: Technical Test for Obstacle Detection by Lower Sensor.

Figure B - 3: Technical Test for Staircase Detection Feature.

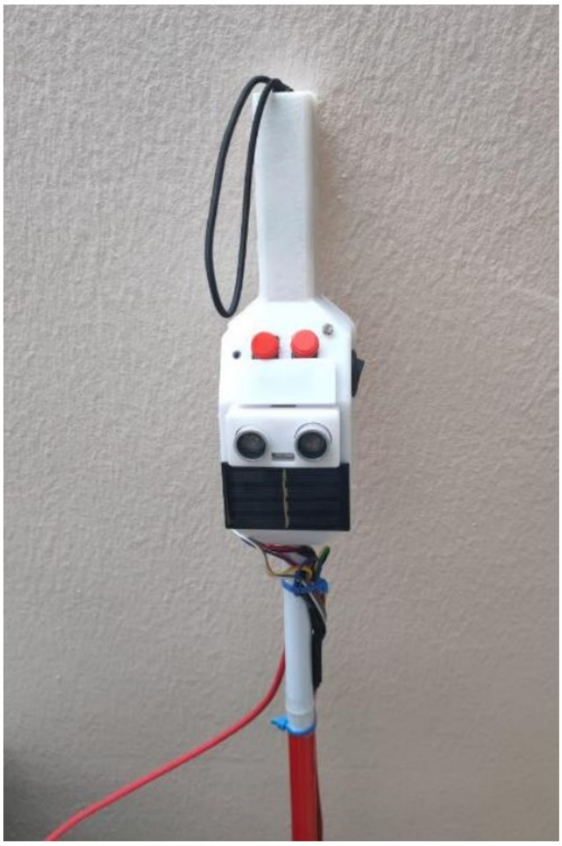

Figure B - 4: Technical Test for LED Illumination Feature.

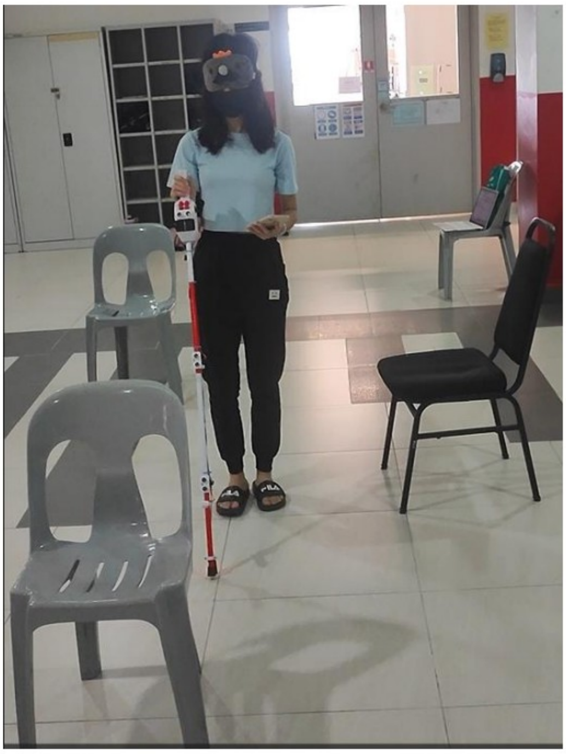

Figure B - 5: Obstacles Detection for First Humanization test.

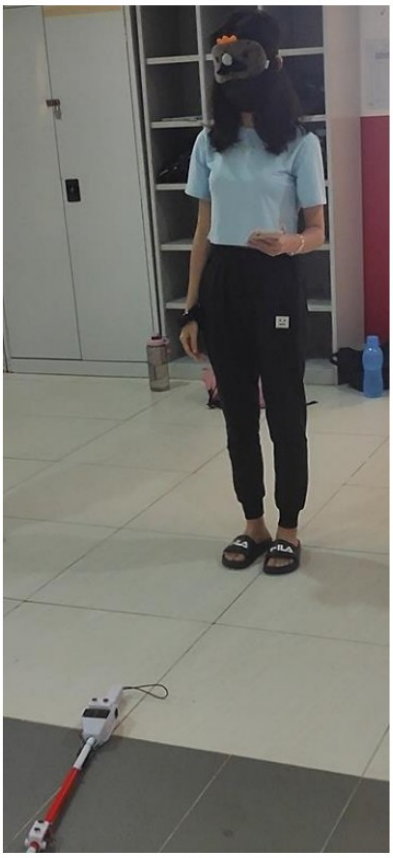

Figure B - 6: Stick Detection for First Humanization Test.

Figure B - 7: Obstacles Detection for Second Humanization Test.

Figure B - 8: Stick Detection for Second Humanization Test.

Figure B - 9: Water Detection for Humanization Test.

Figure B - 10: Live Location Tracking for Humanization Test.

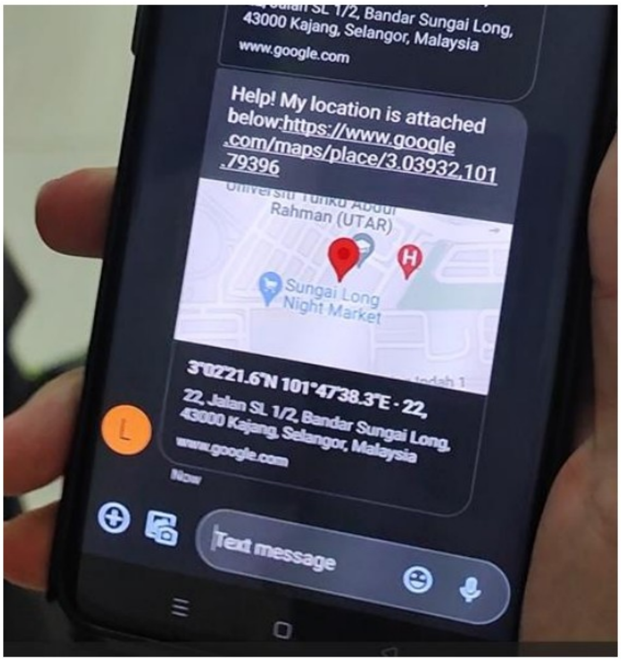

Figure B - 11: SOS Message Received.

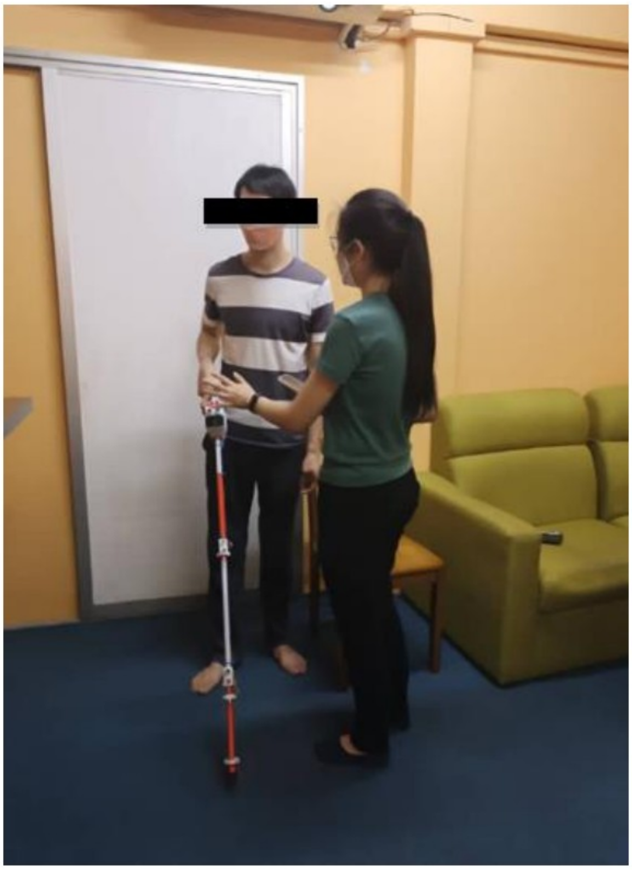

Figure B - 12: Prototype Testing by Visually Impaired People.

Appendix C: Technical Test Results

Table C- 1: Full Technical Test Results for Obstacles Detection.

No	Distance_1	Distance_2	Distance_3	Status of Buzzer
1	157	54	53	OFF
2	98	56	44	ON
3	100	57	35	ON
4	99	57	36	ON
5	100	57	36	ON
6	100	56	36	ON
7	99	57	36	ON
8	99	58	36	ON
9	98	64	46	ON
10	95	60	46	ON
11	95	60	54	OFF
12	94	60	47	ON
13	98	62	54	OFF
14	96	61	54	OFF
15	94	56	54	OFF
16	87	64	44	ON
17	91	63	54	OFF
18	97	59	56	OFF
19	96	60	54	OFF
20	115	59	46	ON
21	114	60	52	OFF
22	93	59	46	ON
23	113	58	46	ON
24	112	59	46	ON
25	92	58	53	OFF
26	91	58	54	OFF
27	91	58	46	ON
28	96	57	52	OFF
29	97	59	47	ON
30	102	58	45	ON
31	90	58	46	ON
32	98	58	45	ON
33	112	59	44	ON
34	114	59	45	ON
35	89	54	46	ON
36	107	56	46	ON
37	100	72	64	OFF
38	98	48	54	ON

39	109	44	53	ON
40	100	46	58	ON
41	87	59	58	OFF
42	98	49	45	ON
43	95	68	59	OFF
44	98	65	56	OFF
45	98	62	55	OFF
46	141	66	65	OFF
47	155	55	63	OFF
48	158	55	58	OFF
49	180	91	63	OFF
50	152	53	83	OFF
51	142	110	34	ON
52	112	116	62	OFF
53	113	117	63	OFF
54	113	116	113	OFF
55	113	117	61	OFF
56	111	117	62	OFF
57	114	117	63	OFF
58	114	117	62	OFF
59	111	116	62	OFF
60	111	115	61	OFF
61	111	115	69	OFF
62	113	116	65	OFF
63	114	116	64	OFF
64	114	116	63	OFF
65	112	115	62	OFF
66	109	114	64	OFF
67	119	118	26	ON
68	116	121	62	OFF
69	119	121	63	OFF
70	117	118	62	OFF
71	118	122	63	OFF
72	117	119	73	OFF
73	122	121	29	ON
74	149	117	61	OFF
75	150	54	13	ON
76	52	53	35	ON
77	163	162	45	ON
78	71	86	45	ON
79	37	36	30	ON
80	39	35	30	ON
81	36	35	31	ON

82	35	35	31	ON
83	84	78	54	OFF
84	103	53	37	ON
85	52	43	32	ON
86	57	51	43	ON
87	124	130	45	ON
88	152	57	55	OFF
89	154	56	54	OFF
90	153	57	56	OFF
91	149	58	58	OFF
92	145	60	54	OFF
93	150	58	65	OFF
94	148	59	54	OFF
95	149	58	54	OFF
96	148	59	53	OFF
97	148	57	55	OFF
98	148	58	54	OFF
99	149	57	56	OFF
100	150	57	54	OFF
101	148	59	54	OFF
102	147	60	54	OFF
103	94	44	61	ON
104	92	44	48	ON
105	91	44	41	ON
106	91	78	53	OFF
107	96	44	45	ON
108	206	159	32	ON
109	209	161	33	ON
110	207	160	33	ON
111	211	212	26	ON
112	147	56	26	ON
113	151	148	26	ON
114	204	207	33	ON
115	204	191	45	ON
116	203	188	51	OFF
117	204	206	50	OFF
118	73	64	54	OFF
119	101	95	27	ON
120	142	55	45	ON
121	208	206	53	OFF
122	149	65	54	OFF
123	149	66	56	OFF
124	149	357	45	ON

125	111	209	53	OFF
126	202	200	27	ON
127	201	156	26	ON
128	202	64	26	ON
129	209	205	62	OFF
130	179	172	44	ON
131	213	174	44	ON
132	211	207	66	OFF
133	152	58	63	OFF
134	155	149	45	ON
135	154	58	66	OFF
136	204	203	63	OFF
137	202	205	54	OFF
138	154	53	66	OFF
139	165	63	54	OFF
140	165	63	45	ON
141	107	52	53	OFF
142	27	30	34	ON
143	44	31	31	ON
144	79	68	56	OFF
145	164	62	46	ON
146	164	62	54	OFF
147	164	62	49	ON

Table C- 2: Full Technical Test Results for Water Detection.

No	**Water_Level**	**Status of Vibrating Motor**
1	0	LOW
2	0	LOW
3	0	LOW
4	0	LOW
5	0	LOW
6	0	LOW
7	0	LOW
8	0	LOW
9	0	LOW
10	0	LOW
11	0	LOW
12	0	LOW
13	0	LOW
14	0	LOW

15	0	LOW
16	0	LOW
17	0	LOW
18	0	LOW
19	0	LOW
20	0	LOW
21	0	LOW
22	0	LOW
23	0	LOW
24	0	LOW
25	0	LOW
26	0	LOW
27	0	LOW
28	0	LOW
29	0	LOW
30	0	LOW
31	0	LOW
32	0	LOW
33	0	LOW
34	0	LOW
35	0	LOW
36	0	LOW
37	0	LOW
38	0	LOW
39	0	LOW
40	0	LOW
41	0	LOW
42	0	LOW
43	0	LOW
44	0	LOW
45	0	LOW
46	0	LOW
47	0	LOW
48	0	LOW
49	0	LOW
50	0	LOW
51	0	LOW
52	0	LOW
53	0	LOW
54	0	LOW
55	0	LOW
56	0	LOW
57	0	LOW

58	0	LOW
59	0	LOW
60	0	LOW
61	0	LOW
62	0	LOW
63	0	LOW
64	0	LOW
65	0	LOW
66	0	LOW
67	0	LOW
68	0	LOW
69	0	LOW
70	0	LOW
71	0	LOW
72	0	LOW
73	0	LOW
74	0	LOW
75	0	LOW
76	0	LOW
77	0	LOW
78	0	LOW
79	0	LOW
80	0	LOW
81	0	LOW
82	0	LOW
83	0	LOW
84	0	LOW
85	0	LOW
86	0	LOW
87	0	LOW
88	0	LOW
89	0	LOW
90	0	LOW
91	0	LOW
92	0	LOW
93	0	LOW
94	0	LOW
95	0	LOW
96	0	LOW
97	0	LOW
98	0	LOW
99	0	LOW
100	0	LOW

101	0	LOW
102	0	LOW
103	0	LOW
104	0	LOW
105	0	LOW
106	0	LOW
107	0	LOW
108	0	LOW
109	0	LOW
110	0	LOW
111	0	LOW
112	0	LOW
113	0	LOW
114	0	LOW
115	0	LOW
116	0	LOW
117	0	LOW
118	26	HIGH
119	731	HIGH
120	189	HIGH
121	272	HIGH
122	235	HIGH
123	266	HIGH
124	307	HIGH
125	258	HIGH
126	413	HIGH
127	432	HIGH
128	675	HIGH
129	615	HIGH
130	619	HIGH
131	656	HIGH
132	694	HIGH
133	2464	HIGH
134	2006	HIGH
135	0	LOW
136	0	LOW
137	0	LOW
138	0	LOW
139	0	LOW
140	0	LOW
141	0	LOW
142	0	LOW
143	0	LOW

144	0	LOW
145	0	LOW
146	0	LOW
147	0	LOW

Table C- 3: Full Technical Test Results for Staircase Detection.

No	Distance_4	Audio Alert	Time delay for Audio Response
1	22	N/A	N/A
2	22	N/A	N/A
3	22	N/A	N/A
4	22	N/A	N/A
5	22	N/A	N/A
6	23	N/A	N/A
7	23	N/A	N/A
8	22	N/A	N/A
9	22	N/A	N/A
10	22	N/A	N/A
11	22	N/A	N/A
12	22	N/A	N/A
13	23	N/A	N/A
14	22	N/A	N/A
15	26	N/A	N/A
16	22	N/A	N/A
17	31	DOWNSTAIRS	2s
18	32	DOWNSTAIRS	2s
19	27	DOWNSTAIRS	2s
20	22	N/A	N/A
21	22	N/A	N/A
22	22	N/A	N/A
23	22	N/A	N/A
24	22	N/A	N/A
25	23	N/A	N/A
26	32	DOWNSTAIRS	2s
27	37	DOWNSTAIRS	2s
28	21	UPSTAIRS	2s
29	24	N/A	N/A
30	27	DOWNSTAIRS	2s
31	30	DOWNSTAIRS	2s
32	6	UPSTAIRS	2s
33	6	UPSTAIRS	2s
34	5	UPSTAIRS	2s
35	5	UPSTAIRS	2s

36	32	DOWNSTAIRS	2s
37	22	N/A	N/A
38	28	DOWNSTAIRS	2s
39	44	DOWNSTAIRS	2s
40	22	N/A	N/A
41	27	DOWNSTAIRS	2s
42	40	DOWNSTAIRS	2s
43	39	DOWNSTAIRS	2s
44	39	DOWNSTAIRS	2s
45	39	DOWNSTAIRS	2s
46	39	DOWNSTAIRS	2s
47	39	DOWNSTAIRS	2s
48	39	DOWNSTAIRS	2s
49	39	DOWNSTAIRS	2s
50	39	DOWNSTAIRS	2s
51	39	DOWNSTAIRS	2s
52	39	DOWNSTAIRS	2s
53	39	DOWNSTAIRS	2s
54	39	DOWNSTAIRS	2s
55	39	DOWNSTAIRS	2s
56	39	DOWNSTAIRS	2s
57	39	DOWNSTAIRS	2s
58	39	DOWNSTAIRS	2s
59	23	N/A	N/A
60	23	N/A	N/A
61	22	N/A	N/A
62	22	N/A	N/A
63	22	N/A	N/A
64	22	N/A	N/A
65	22	N/A	N/A
66	23	N/A	N/A
67	27	DOWNSTAIRS	2s
68	39	DOWNSTAIRS	2s
69	39	DOWNSTAIRS	2s
70	39	DOWNSTAIRS	2s
71	39	DOWNSTAIRS	2s
72	39	DOWNSTAIRS	2s
73	39	DOWNSTAIRS	2s
74	39	DOWNSTAIRS	2s
75	39	DOWNSTAIRS	2s
76	39	DOWNSTAIRS	2s
77	39	DOWNSTAIRS	2s
78	39	DOWNSTAIRS	2s

79	39	DOWNSTAIRS	2s
80	39	DOWNSTAIRS	2s
81	39	DOWNSTAIRS	2s
82	39	DOWNSTAIRS	2s
83	39	DOWNSTAIRS	2s
84	39	DOWNSTAIRS	2s
85	39	DOWNSTAIRS	2s
86	26	N/A	N/A
87	42	DOWNSTAIRS	2s
88	41	DOWNSTAIRS	2s
89	52	DOWNSTAIRS	2s
90	52	DOWNSTAIRS	2s
91	39	DOWNSTAIRS	2s
92	39	DOWNSTAIRS	2s
93	39	DOWNSTAIRS	2s
94	39	DOWNSTAIRS	2s
95	39	DOWNSTAIRS	2s
96	39	DOWNSTAIRS	2s
97	38	DOWNSTAIRS	2s
98	39	DOWNSTAIRS	2s
99	39	DOWNSTAIRS	2s
100	39	DOWNSTAIRS	2s
101	22	N/A	N/A
102	22	N/A	N/A
103	22	N/A	N/A
104	42	DOWNSTAIRS	2s
105	32	DOWNSTAIRS	2s
106	6	UPSTAIRS	2s
107	5	UPSTAIRS	2s
108	5	UPSTAIRS	2s
109	4	UPSTAIRS	2s
110	5	UPSTAIRS	2s
111	5	UPSTAIRS	2s
112	12	UPSTAIRS	2s
113	5	UPSTAIRS	2s
114	4	UPSTAIRS	2s
115	4	UPSTAIRS	2s
116	4	UPSTAIRS	2s
117	4	UPSTAIRS	2s
118	4	UPSTAIRS	2s
119	4	UPSTAIRS	2s
120	4	UPSTAIRS	2s
121	4	UPSTAIRS	2s

122	10	UPSTAIRS	2s
123	43	DOWNSTAIRS	2s
124	32	DOWNSTAIRS	2s
125	42	DOWNSTAIRS	2s
126	5	UPSTAIRS	2s
127	6	UPSTAIRS	2s
128	48	DOWNSTAIRS	2s
129	50	DOWNSTAIRS	2s
130	38	DOWNSTAIRS	2s
131	32	DOWNSTAIRS	2s
132	27	DOWNSTAIRS	2s
133	22	N/A	N/A
134	22	N/A	N/A
135	22	N/A	N/A
136	22	N/A	N/A
137	118	N/A	N/A
138	125	N/A	N/A
139	68	DOWNSTAIRS	2s
140	59	DOWNSTAIRS	2s
141	55	DOWNSTAIRS	2s
142	63	DOWNSTAIRS	2s
143	113	N/A	N/A
144	63	DOWNSTAIRS	2s
145	7	UPSTAIRS	2s
146	9	UPSTAIRS	2s

Table C- 4: Full Technical Test Results for LED Illumination.

No	LDR value	Status of LED
1	1392	OFF
2	1734	OFF
3	1344	OFF
4	1137	OFF
5	1047	OFF
6	1072	OFF
7	1910	OFF
8	1341	OFF
9	853	OFF
10	1006	OFF
11	1830	OFF
12	1825	OFF
13	1136	OFF
14	1471	OFF

15	311	ON
16	1963	OFF
17	209	ON
18	518	OFF
19	691	OFF
20	720	OFF
21	697	OFF
22	1121	OFF
23	49	ON
24	378	ON
25	782	OFF
26	623	OFF
27	867	OFF
28	263	ON
29	1014	OFF
30	195	ON
31	423	ON
32	642	OFF
33	1296	OFF
34	1089	OFF
35	1151	OFF
36	328	ON
37	905	OFF
38	1605	OFF
39	2346	OFF
40	2222	OFF
41	2249	OFF
42	2384	OFF
43	2427	OFF
44	2229	OFF
45	1511	OFF
46	240	ON
47	1509	OFF
48	109	ON
49	400	ON
50	797	OFF
51	457	ON
52	743	OFF
53	624	OFF
54	1578	OFF
55	1401	OFF
56	2192	OFF
57	1986	OFF

58	37	ON
59	52	ON
60	55	ON
61	0	ON
62	76	ON
63	78	ON
64	57	ON
65	2	ON
66	48	ON
67	60	ON
68	48	ON
69	41	ON
70	48	ON
71	61	ON
72	101	ON
73	70	ON
74	48	ON
75	48	ON
76	0	ON
77	50	ON
78	52	ON
79	38	ON
80	14	ON
81	0	ON
82	33	ON
83	451	ON
84	186	ON
85	761	OFF
86	795	OFF
87	752	OFF
88	947	OFF
89	1235	OFF
90	1233	OFF
91	1361	OFF
92	1227	OFF
93	1333	OFF
94	1247	OFF
95	1490	OFF
96	1307	OFF

Table C- 5: Full Technical Test Results for Live Location Tracking.

No	**Status of**	**Status of SOS**

	Emergency Button	Message
1	0	UNSEND
2	0	UNSEND
3	0	UNSEND
4	0	UNSEND
5	0	UNSEND
6	0	UNSEND
7	0	UNSEND
8	0	UNSEND
9	0	UNSEND
10	1	SENT
11	0	UNSEND
12	0	UNSEND
13	0	UNSEND
14	0	UNSEND
15	0	UNSEND
16	0	UNSEND
17	0	UNSEND
18	0	UNSEND
19	0	UNSEND
20	0	UNSEND
21	0	UNSEND
22	0	UNSEND
23	0	UNSEND
24	0	UNSEND
25	0	UNSEND
26	0	UNSEND
27	1	SENT
28	0	UNSEND
29	0	UNSEND
30	0	UNSEND
31	0	UNSEND
32	0	UNSEND
33	0	UNSEND
34	0	UNSEND
35	0	UNSEND
36	0	UNSEND
37	0	UNSEND
38	0	UNSEND
39	0	UNSEND
40	0	UNSEND
41	0	UNSEND

42	0	UNSEND
43	0	UNSEND
44	0	UNSEND
45	0	UNSEND
46	0	UNSEND
47	0	UNSEND
48	0	UNSEND
49	0	UNSEND
50	0	UNSEND
51	0	UNSEND
52	0	UNSEND
53	0	UNSEND
54	0	UNSEND
55	0	UNSEND
56	0	UNSEND
57	0	UNSEND
58	0	UNSEND
59	0	UNSEND
60	0	UNSEND
61	0	UNSEND
62	0	UNSEND
63	0	UNSEND
64	0	UNSEND
65	0	UNSEND
66	0	UNSEND
67	0	UNSEND
68	0	UNSEND
69	0	UNSEND
70	0	UNSEND
71	0	UNSEND
72	0	UNSEND
73	0	UNSEND
74	0	UNSEND
75	0	UNSEND
76	0	UNSEND
77	0	UNSEND
78	0	UNSEND
79	0	UNSEND
80	0	UNSEND
81	0	UNSEND
82	0	UNSEND
83	0	UNSEND
84	0	UNSEND

85	0	UNSEND
86	0	UNSEND
87	0	UNSEND
88	0	UNSEND
89	0	UNSEND
90	0	UNSEND
91	0	UNSEND
92	0	UNSEND
93	0	UNSEND
94	0	UNSEND
95	0	UNSEND
96	0	UNSEND
97	0	UNSEND
98	0	UNSEND
99	0	UNSEND
100	0	UNSEND
101	0	UNSEND
102	0	UNSEND
103	0	UNSEND
104	0	UNSEND
105	0	UNSEND
106	0	UNSEND
107	0	UNSEND
108	0	UNSEND
109	0	UNSEND
110	0	UNSEND
111	0	UNSEND
112	0	UNSEND
113	0	UNSEND
114	0	UNSEND
115	0	UNSEND
116	0	UNSEND
117	0	UNSEND
118	0	UNSEND
119	0	UNSEND
120	0	UNSEND
121	0	UNSEND
122	0	UNSEND
123	0	UNSEND
124	0	UNSEND
125	0	UNSEND
126	0	UNSEND
127	0	UNSEND

128	0	UNSEND
129	0	UNSEND
130	0	UNSEND
131	0	UNSEND
132	0	UNSEND
133	0	UNSEND
134	0	UNSEND
135	0	UNSEND
136	0	UNSEND
137	0	UNSEND
138	0	UNSEND
139	0	UNSEND
140	0	UNSEND
141	1	SENT
142	0	UNSEND
143	0	UNSEND
144	0	UNSEND
145	0	UNSEND
146	0	UNSEND
147	0	UNSEND
148	1	SENT
149	1	SENT