Track Mate

Project Team

Zainab Azeem	21P-8025
Muawiya Kaleem	21P-8030

Session 2021-2025

Supervised by

Dr. Ali Sayyed

Department of Computer Science

National University of Computer and Emerging Sciences
Peshawar, Pakistan

June, 2021

Student's Declaration

We declare that this project titled "*Track Mate*", submitted as requirement for the award of degree of Bachelors in Computer Science, does not contain any material previously submitted for a degree in any university; and that to the best of our knowledge, it does not contain any materials previously published or written by another person except where due reference is made in the text.

We understand that the management of Department of Computer Science, National University of Computer and Emerging Sciences, has a zero tolerance policy towards plagiarism. Therefore, We, as authors of the above-mentioned thesis, solemnly declare that no portion of our thesis has been plagiarized and any material used in the thesis from other sources is properly referenced.

We further understand that if we are found guilty of any form of plagiarism in the thesis work even after graduation, the University reserves the right to revoke our BS degree.

Zainab Azeem Signature: ________________

Muawiya Kaleem Signature: ________________

____

Verified by Plagiarism Cell Officer
Dated:

Certificate of Approval

The Department of Computer Science, National University of Computer and Emerging Sciences, accepts this thesis titled *Track Mate*, submitted by Zainab Azeem (21P-8025), and Muawiya Kaleem (21P-8030), in its current form, and it is satisfying the dissertation requirements for the award of Bachelors Degree in Computer Science.

Supervisor

Dr. Ali Sayyed Signature: ______________

____

Name of FYP Coordinator

FYP Coordinator
National University of Computer and Emerging Sciences, Peshawar

____

Dr. Head of Computer Science Department

HoD of Department of Computer Science
National University of Computer and Emerging Sciences

Acknowledgements

I would like to express my heartfelt gratitude to the following individuals and organizations for their invaluable contributions and support during the course of this project: My sincere thanks to my project supervisor Dr. Ali Sayyed, for his unwavering guidance, expertise, and continuous encouragement throughout the project. I extend my appreciation to FAST NUCES for providing a conducive academic environment and access to research facilities. I am grateful to my dedicated colleagues and team member for their tireless efforts and collaboration. My deepest thanks to my family and friends for their unwavering support, understanding, and encouragement. I acknowledge the participation of the volunteers and test subjects who made this research possible. Special thanks to the IT department and library staff at FAST NUCES for their technical and research assistance. The project benefited greatly from the references and resources provided by Library and Online resources. Lastly, I would like to reflect on the personal growth and learning this project has facilitated, making it a transformative experience. The completion of this project would not have been possible without the unwavering support and contributions of these individuals and entities. Thank you all for being an integral part of this journey

Zainab Azeem

Muawiya Kaleem

Abstract

The research addresses the critical problem of limited mobility and safety for visually impaired individuals who rely on traditional aids, such as white canes, that are insufficient for detecting complex obstacles like stairs and water hazards. This limitation leads to a lack of confidence and increased reliance on others for navigation. The methodology involves designing and developing a smart stick equipped with ultrasonic and infrared sensors to detect obstacles at various heights and distances. The device includes a GSM module for emergency communication, allowing users to send alerts to guardians when needed. The system is built using a microcontroller for reliable performance and low power consumption. Key results demonstrate that the smart stick effectively identifies and signals the presence of obstacles through audio alerts and vibration, providing real-time feedback to users. Testing showed enhanced detection capabilities and responsiveness in both indoor and outdoor environments. The conclusion highlights that the developed smart stick significantly improves independent mobility for visually impaired individuals, offering a user-friendly and cost-effective solution that promotes safety and confidence.

Contents

List of Figures

List of Tables

Chapter 1

Introduction

The development of assistive technology for visually impaired individuals is essential to enhancing their independence and quality of life. Traditional mobility aids, such as white canes, provide basic assistance but have significant limitations when it comes to detecting complex obstacles like stairs, water hazards, and above-waist objects. These limitations can pose safety risks, reduce confidence, and increase dependence on others for navigation.

The need for innovative solutions that address these challenges is evident. A smart stick that integrates advanced technology can serve as a transformative tool for visually impaired users. By incorporating sensors capable of detecting various types of obstacles and providing real-time feedback through audio and vibration signals, such a device can empower users to navigate their environment more safely and confidently.

The project aims to develop a smart stick that not only identifies ground-level obstacles but also detects stairs, water, and above-waist-level hazards. Additionally, the inclusion of an emergency communication feature, such as a GSM module, ensures that users can alert guardians or caregivers in critical situations. This approach emphasizes both the safety and independence of visually impaired individuals, offering a comprehensive solution to improve mobility and reduce reliance on others.

Overall, the project's success will be measured by the device's reliability, accuracy in obstacle detection, user feedback on ease of use, and the effectiveness of emergency communication capabilities. The development of this smart stick represents a step forward in assistive technology, promoting greater autonomy and safety for those who need it most.

- **The purpose of the investigation**: The purpose of this investigation is to design and develop an innovative smart stick that significantly enhances the mobility, safety, and independence of visually impaired individuals. By integrating advanced sensor technology and emergency communication capabilities, this project aims to provide a comprehensive solution that addresses the limitations of traditional mobility aids.

- **The problem being investigated**: Visually impaired individuals face significant challenges with existing mobility aids, such as traditional white canes, which offer only basic support and are unable to detect complex obstacles. These limitations include the inability to recognize stairs, water hazards, and above-waist-level objects, which can lead to potential safety risks, reduced confidence, and increased dependence on others for navigation.

- **The background (context and importance) of the problem (citing previous work by others)**: The development of effective mobility aids for the visually impaired has long been an area of concern in assistive technology. While traditional canes remain essential, their effectiveness is limited to detecting ground-level obstacles. Prior studies and technological advancements have shown that the integration of multisensor technology can improve obstacle detection. However, detecting specific challenges such as water and stairs has continued to be a problem in existing solutions. The importance of addressing these gaps is paramount to ensure that visually impaired individuals can navigate their environments safely and confidently.

- **Your thesis and general approach**: This project posits that a smart stick equipped with ultrasonic and infrared sensors, combined with a GSM module for emergency communication, can overcome the limitations of traditional mobility aids. The approach involves using an Arduino Uno microcontroller for its reliability and low power consumption, integrating real-time feedback mechanisms such as audio alerts and vibration signals to inform users of potential obstacles. The development process includes extensive testing to validate the accuracy and responsiveness of the system in various settings, ensuring it meets user needs effectively.

- **The criteria for your study's success**: The success of this project will be determined by:
  - The accuracy and reliability of the smart stick in detecting stairs, water hazards, and above-waist-level objects.
  - The effectiveness of real-time feedback provided through audio and vibration alerts.
  - Positive user feedback indicating ease of use and increased confidence in mobility.
  - The successful operation of the emergency communication feature, ensuring that alerts can be sent to caregivers when needed.
  - Overall improvements in the safety and independence of visually impaired users, validated through user testing and performance metrics.

Chapter 2

Review of Literature

Introduction

This literature review explores recent developments in assistive technologies for visually impaired individuals, focusing on sensor-based smart sticks, canes, and wearable aids. These devices are designed to enhance user independence by detecting obstacles, staircases, and environmental hazards using a variety of sensor integrations and communication modules. Through a critical analysis of contemporary systems developed over the last decade, this review identifies strengths, gaps, and trends that inform the design of the Track Mate project.

AIoT-Based Smart Stick for Visually Impaired (Jivrajani et al., 2023)

Jivrajani et al.[1] proposed a smart stick enhanced with AIoT capabilities. The system integrates deep learning models for object and currency recognition and includes GPS and pulse sensors to monitor the user's health and location. A mobile app supports real-time updates, enabling both user awareness and caregiver monitoring. With a reported detection accuracy of 91.7%, this system represents a comprehensive yet cost-effective solution, blending health, safety, and navigational support.

Belt for Blind Navigation (Hossain et al., 2011)

In contrast to high-tech solutions, Hossain et al.[2] designed a belt-based navigation aid that emphasizes simplicity and affordability. It employs basic sensors to detect nearby obstacles and offers directional cues. Although it provides core functionality, it lacks health monitoring, GPS tracking, or alert mechanisms, making it suitable for low-cost environments but less adaptable in dynamic or emergency-prone scenarios.

Low-Cost Smart Stick with Water Detection (Ashrafuzzaman et al., 2021)

Building on the idea of simple yet efficient systems, Ashrafuzzaman et al.[3] introduced a smart stick with ultrasonic and water sensors, supported by GSM and GPS modules for emergency communication. While it improves over Hossain's design by integrating alert and location features, its reliance on basic sensors still limits nuanced perception of the surroundings.

Smart Stick with Multiple Sensors (Sharma et al., 2017)

Sharma et al.[4] expanded functionality by incorporating multiple ultrasonic sensors at different heights, coupled with Bluetooth communication. The stick provides both audio and vibration feedback, aiding users in crowded environments. However, similar to Ashrafuzzaman et al.'s approach, it lacks health monitoring and remains limited to reactive feedback without predictive or learning capabilities.

Arduino-Based Walking Stick (Buddha et al., 2023)

Buddha et al.[5] developed a low-cost Arduino-powered smart stick focused on obstacle and staircase detection. It uses ultrasonic sensors and audio alerts to assist navigation. The system is notable for affordability and basic hazard awareness, but its limited range and depth sensing reduce effectiveness in complex urban environments compared to higherend models like that of Jivrajani et al.

Smart Cane with Staircase and Water Detection (Wickramasinghe et al., 2020)

Wickramasinghe et al.[6] developed a smart cane equipped with infrared and water sensors. Its design excels in detecting staircases and puddles, offering vibration and audio alerts. However, unlike the models by Ashrafuzzaman or Jivrajani, it lacks communication modules such as GSM or GPS, reducing its emergency responsiveness and broader tracking potential.

Hybrid Approach for Staircase Detection (Habib et al., 2019)

Addressing the specific challenge of staircase detection, Habib et al.[7] proposed a hybrid system that integrates machine learning with traditional sensors. This system is especially suited for detecting depth variations in staircases, tackling a gap in simpler sensor-only models. However, its increased complexity and processing demands may pose barriers in terms of affordability and energy efficiency.

Conclusion

The reviewed literature reflects an evolution from basic, sensor-driven aids to intelligent, multi-functional systems. Early designs prioritized affordability and core obstacle detection, but lacked comprehensive support. In contrast, modern systems—especially AIoT-enhanced solutions like that of Jivrajani et al.—offer integrated tracking, health monitoring, and user feedback. However, with increased functionality comes increased cost and complexity, which may restrict accessibility. Therefore, future designs should aim to balance advanced features with cost-efficiency and ease of use to ensure inclusivity in diverse user environments.

2.1 Literature review table

Table 2.1: Literature Review Table

No	Year	Title	Objectives	Methodology	Results
1	2019	Staircase Detection to Guide Visually Impaired People: A Hybrid Approach	To develop a hybrid system for staircase detection to guide visually impaired individuals in navigating stairs safely.	Employs a Faster R-CNN model for image-based staircase detection, with ultrasonic sensor validation.	Effectively detects stairs in real time, aiding navigation on both ascending and descending staircases.
2	2020	Smart Cane for Staircase and Water Detection	To build a low-cost smart cane for safer navigation by detecting stairs and wet areas.	Uses IR sensors for stair detection and water sensors for puddles; alerts via buzzer.	Provides real-time audio alerts, improving mobility and safety.
3	2020	Smart Stick for Blind People	To assist visually impaired users in detecting obstacles and locating the stick if misplaced.	Uses ultrasonic, IR sensors, and a radio beacon system.	Detects obstacles and supports locating the stick via audio feedback.
4	2021	Design and Development of a Low-cost Smart Stick for Visually Impaired People	To create an affordable smart stick for obstacle and water detection, with emergency alerts.	Uses ultrasonic sensors, a water sensor, GPS/GSM modules, and Arduino UNO.	Provides real-time alerts, detects hazards, and sends GPS-based notifications to family.
5	2021	Smart Blind Stick Design and Implementation	To develop a smart stick for safe obstacle detection and real-time alerts.	Utilizes ultrasonic sensors, GPS for tracking, and a buzzer, controlled by Arduino.	Successfully detects nearby obstacles and provides immediate feedback to guide the user.
6	2023	An AIoT-Based Smart Stick for Visually Impaired Person	To use AI and IoT for hazard detection, health tracking, and smart navigation.	Employs Raspberry Pi, GPS, camera, object recognition, and mobile app integration.	Delivers comprehensive support including mobility, object detection, and health monitoring.
7	2023	Low-Cost Walking Stick for Obstacle and Stair Detection Using Arduino	To create a low-cost walking stick to detect both obstacles and stairs, with alert functionality.	Uses Arduino UNO, ultrasonic sensors, a GSM module for SMS alerts, and a buzzer.	Supports obstacle and stair detection with audio alerts and emergency SMS to guardians.

Figure 2.1: table

Chapter 3

Project Vision

3.1 Problem Statement

Visually impaired individuals face significant challenges with mobility and independence due to their inability to detect obstacles such as stairs, water hazards, and other environmental barriers. Traditional canes provide limited support, as they cannot identify these specific obstacles, leading to increased risks of accidents. Consequently, visually impaired people often rely on others for assistance, which reduces their confidence and autonomy in unfamiliar environments. This issue underscores the need for advanced, accessible, and user-friendly assistive technologies that can provide real-time environmental feedback to promote safer and more independent mobility.

3.2 Business Opportunity

The development of Track Mate presents a compelling business opportunity by addressing the growing demand for innovative assistive technology solutions for the visually impaired. The global market for assistive devices is expanding as more individuals seek tools that enhance their quality of life and enable greater independence. Track Mate's design, which incorporates ultrasonic, infrared, and moisture sensors to detect obstacles, stairs, and water hazards, aligns well with this demand. Furthermore, the integration of real-time auditory feedback enhances its usability, making it an attractive product in the assistive technology market. By providing a cost-effective, technologically advanced solution, Track Mate has the potential to capture a significant portion of the market, improving the lives of visually impaired individuals and supporting inclusive mobility.

3.3 Objectives

The primary objectives of the TrackMate project are as follows:

1. **Enhance Mobility and Independence for Visually Impaired Individuals**: To design and develop a smart assistive device that enables visually impaired users to navigate their environment more independently, reducing their reliance on others.

2. **Real-Time Obstacle Detection**: To integrate advanced sensors (e.g., ultrasonic, infrared, moisture sensors) that can detect various obstacles such as stairs, water hazards, and objects at different heights, providing real-time feedback to the user.

3. **User-Friendly Design**: To ensure the device is easy to use, with intuitive controls and feedback mechanisms, such as auditory or vibration alerts, to assist users in safely navigating unfamiliar environments.

4. **Affordable and Accessible Technology**: To create a cost-effective solution that is accessible to a wide range of users, including those in low-income communities, without compromising on functionality and quality.

5. **Enhanced Safety Features**: To incorporate safety features such as GPS and GSM modules, enabling emergency alerts that notify family members or caregivers of the user's location in case of distress or emergencies.

6. **Low Power Consumption and Durability**: To design the device with energy-efficient components that ensure long battery life, along with a durable build suitable for different environmental conditions.

7. **Scalability and Future Expansion**: To design the architecture of the device in a way that allows for future upgrades or additional features, such as integration with AI for advanced obstacle recognition.

3.4 Project Scope

- **Hardware Development**: Design and integration of essential hardware components, such as ultrasonic, infrared, and moisture sensors, to detect various obstacles including stairs, water hazards, and objects at multiple heights. The hardware will also include a GPS and GSM module for emergency alerts and tracking.

- **Software Development**: Development of embedded software to control and process data from the sensors, providing real-time feedback to the user. The software will also handle communication with GPS/GSM modules for emergency alerts.

- **Feedback Mechanism**: Creation of a user-friendly feedback system, utilizing auditory or vibration alerts to inform users about obstacles in their path.

- **Power Management and Durability**: Implementation of power-efficient components to ensure long battery life and robust design to withstand various environmental conditions.

- **Testing and Validation**: Comprehensive testing in various environments, including indoor and outdoor settings, to validate the device's effectiveness, reliability, and usability for visually impaired individuals.

- **Documentation and User Training**: Preparation of user manuals and training materials to guide users in effectively using the device. This also includes documentation for maintenance and troubleshooting.

- **Scalability and Future Enhancements**: Design consideration for scalability, allowing for future upgrades or additional features, such as integration with artificial intelligence for advanced obstacle recognition and smart navigation.

The project will focus on delivering a functional prototype within budget constraints and will exclude advanced machine learning features beyond basic obstacle recognition, to maintain affordability and usability for a wide range of users.

3.5 Constraints

- **Budget Constraints**: The project has a limited budget, which restricts the selection of high-end components and advanced technologies. This constraint emphasizes the need for cost-effective solutions without compromising on the essential functionalities of the device.

- **Power Consumption**: The device must operate with low power consumption to ensure long battery life. This requirement limits the use of certain power-intensive components and necessitates energy-efficient design choices.

- **Size and Weight Limitations**: The device should be lightweight and portable for easy use by visually impaired individuals. This constraint affects the choice of hardware components, as bulky or heavy parts would be impractical for daily use.

- **Environmental Durability**: The device needs to withstand various environmental conditions, such as rain, dust, and temperature fluctuations. Ensuring durability while keeping costs low is a significant constraint.

- **Technical Expertise and Resources**: The project team may have limited technical expertise in certain advanced technologies, such as machine learning and IoT integrations, which could impact the complexity of the features implemented.

- **Development Timeline**: The project has a defined timeline, and any delays in development phases such as hardware prototyping, software development, and testing may impact the overall schedule. Time constraints require efficient project management and prioritization of essential features.

- **Usability Requirements**: The device must be user-friendly for visually impaired individuals, which limits the complexity of the user interface and feedback mechanisms. Balancing simplicity with functionality is a key design constraint.

Chapter 4

Software Requirements Specifications

This chapter will have the functional and non functional requirements of the project.

4.1 List of Features

The primary features of the TrackMate project include:

- **Obstacle Detection**: Uses ultrasonic and infrared sensors to detect obstacles within a specific range, helping users navigate safely.
- **Emergency Alerts**: Equipped with a GPS and GSM module to send emergency alerts with the user's location to predefined contacts in case of distress.
- **Real-Time Feedback**: Provides immediate feedback through auditory or vibration alerts to inform users of obstacles or hazards in their path.
- **User-Friendly Interface**: Designed with simplicity in mind to ensure ease of use for visually impaired users, featuring intuitive controls and feedback mechanisms.
- **Low Power Consumption**: Optimized for low energy usage to extend battery life, allowing prolonged use without frequent charging.
- **Environmental Durability**: Built to withstand various environmental conditions such as dust, rain, and temperature fluctuations, ensuring reliability in different

settings.

- **Lightweight and Portable Design**: Compact and lightweight to make it easy to carry and handle, promoting user comfort and convenience.
- **Scalability for Future Upgrades**: Designed to support potential future enhancements, such as integrating advanced AI-based obstacle detection or additional sensors.

4.2 Functional Requirements

- Obstacle Detection: The system should detect obstacles within a 1-meter range using ultrasonic sensors.
- Emergency Alert System: In case of emergencies, the system should send GPS location data to a predefined contact.
- Real-Time Feedback: The system should provide auditory or vibration alerts to guide the user.

4.3 Quality Attributes

- **Reliability**: The system should work accurately in various environments.
- **Usability**: The device should be user-friendly and require minimal training for visually impaired users.
- **Performance**: The system should respond in real-time to ensure safe navigation.

4.4 Non-Functional Requirements

- **Portability**: The device should be lightweight and portable.

- **Power Efficiency**: The device should consume minimal power to ensure long battery life.
- **Durability**: The device should withstand various environmental conditions such as dust, rain, and temperature changes.

4.5 Use Cases/ Use Case Diagram

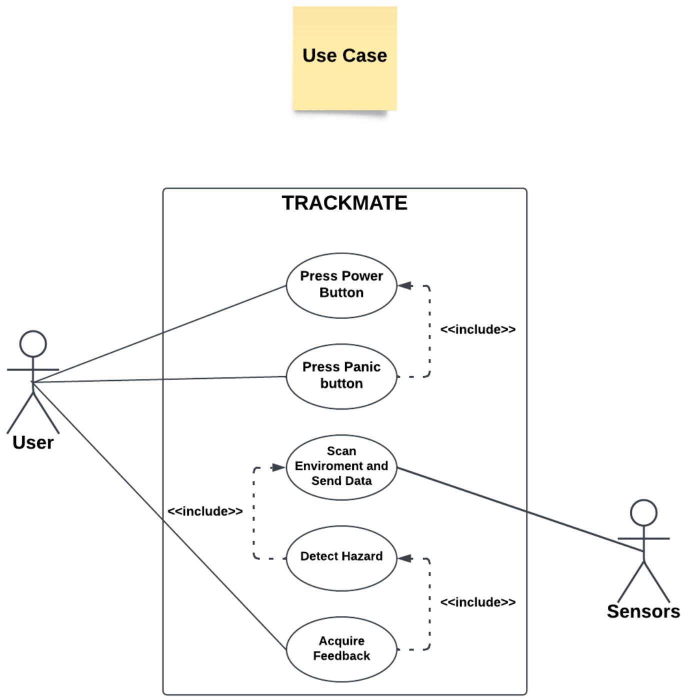

Figure 4.1: Use Case Diagram for TrackMate

Chapter 5

Iteration Plan

This chapter outlines the iteration plan for the Track Mate project. The project is divided into two main phases: FYP1 and FYP2. Each phase includes a midterm and final evaluation. The plan describes the specific goals, milestones, and deliverables for each stage to ensure systematic development and assessment of the project.

5.1 FYP1

5.1.1 Midterm FYP1

Objectives:

- Conduct initial research and literature review on assistive technologies for visually impaired individuals.
- Define the project scope and objectives.
- Set up the development environment and necessary tools.
- Start with data collection and preprocessing.

Milestones:

- Complete literature review and document findings.

- Establish a clear project plan and timeline.
- Collect a preliminary dataset of sensor readings.
- Implement basic data preprocessing steps, such as filtering noise from sensor data.

Deliverables:

- Literature review report.
- Project plan document.
- Initial dataset.
- Preprocessed data samples.

5.1.2 Final FYP1

Objectives:

- Develop the initial version of the hardware prototype with integrated sensors.
- Implement the real-time feedback system for obstacle detection.
- Perform preliminary user testing to evaluate basic functionality.

Milestones:

- Complete hardware integration, including ultrasonic, infrared, and water sensors.
- Implement real-time audio and vibration feedback.
- Conduct initial user testing and refine the prototype based on feedback.

Deliverables:

- Initial hardware prototype.
- Feedback system implementation.
- Preliminary testing report.

5.2 FYP2

5.2.1 Midterm FYP2

Objectives:

- Improve and optimize the hardware design based on initial findings.
- Expand the dataset and perform further testing in diverse environments.
- Refine the GSM module integration for emergency communication.

Milestones:

- Optimize sensor placement for better accuracy and coverage.
- Test the device in outdoor and indoor environments.
- Validate the GSM module functionality for emergency alerts.

Deliverables:

- Optimized hardware prototype.
- Extended dataset for testing.
- Evaluation report on GSM module performance.

5.2.2 Final FYP2

Objectives:

- Finalize the model and perform extensive testing and validation.
- Develop a user-friendly interface for configuring the device.
- Prepare the final project report and presentation.

Milestones:

- Validate the device with a test dataset and document results.
- Integrate a user interface for enhanced usability.
- Compile and write the final project report.

Deliverables:

- Finalized prototype with validated performance metrics.
- User interface for device configuration.
- Final project report.
- Presentation slides.

Chapter 6

Methodology

The Track Mate project adopts a structured methodology, comprising careful selection of technologies, comprehensive algorithm development, sensor integration, and implementation of feedback mechanisms. This chapter details each methodological step to achieve a reliable, user-friendly assistive tool for visually impaired individuals, addressing object detection, ascending staircase detection, descending staircase detection, and water hazard detection.

6.1 Sensor Selection and Integration

Two primary sensors were selected on the basis ofasis of their effectiveness, cost efficiency, and reliability:

6.1.1 Ultrasonic Sensor (HC-SR04)

Utilized for detecting obstacles, height differences, ascending stairs, and descending stairs. It operates by emitting high-frequency sound waves, reflecting off nearby objects, and calculating distance based on the echo return time.

6.1.2 Water Sensor

Detects the presence of moisture or slippery surfaces, enhancing user safety. It immediately signals the Arduino microcontroller upon detecting water, activating feedback mechanisms to alert the user.

6.2 Algorithm Development

The project developed specialized algorithms for various detections using precise distance measurements provided by the ultrasonic sensors:

6.2.1 Water Hazard Detection

The water sensor detects moisture or slippery surfaces, immediately triggering feedback to alert the user of potential slipping hazards,enhancing safety during navigation.

6.2.2 Object Detection

The ultrasonic sensor continuously measures distance to detect the presence and proximity of objects or obstacles in the user's path. When an object is detected within a predefined threshold distance, immediate feedback is provided to the user.

6.2.3 Ascending Staircase Detection

For ascending stairs, the algorithm analyzes incremental patterns consistent with typical stair dimensions:

- Rise $\leq$ 7 inches
- Run $\leq$ 10 inches

The logic for stair detection can be represented by the following pseudocode:

The following diagram visually demonstrates the upstairs detection technique and algorithm, highlighting the logic and sensor measurement strategy used for detecting ascending staircases:

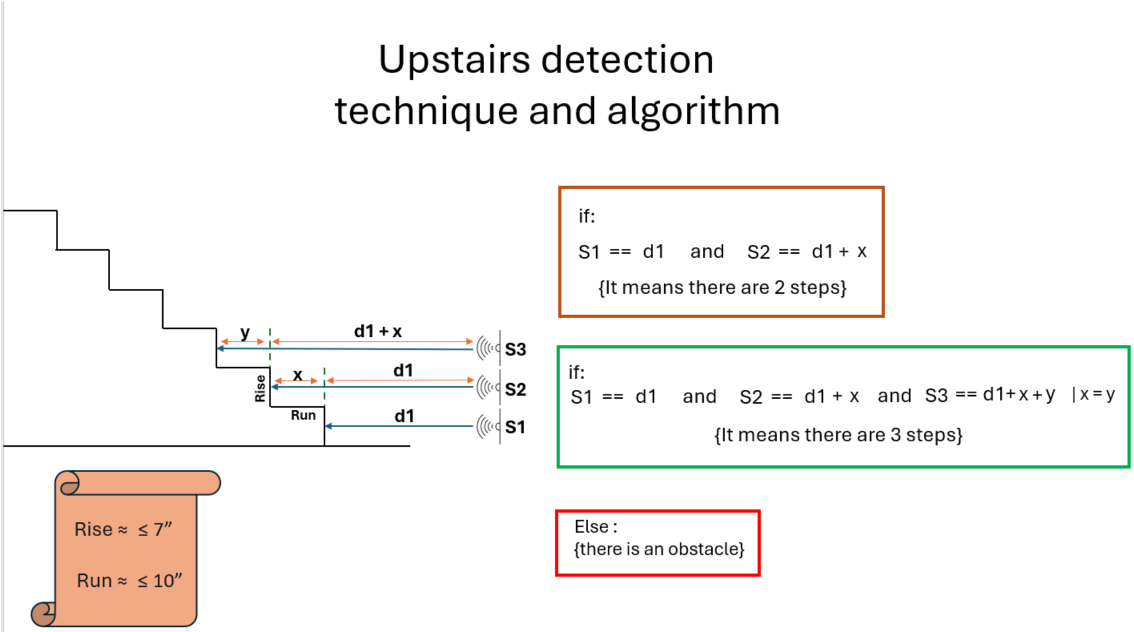

Figure 6.1: Upstairs detection technique and algorithm

This diagram clearly outlines how ultrasonic sensors (S1, S2, S3) measure distance increments to identify stairs accurately. The logic conditions evaluate sensor readings to confirm staircase detection or to classify an object as an obstacle.

6.2.4 Descending Staircase Detection

Detecting descending staircases is crucial for preventing falls and ensuring user safety, especially when the ground level suddenly drops. For this purpose, the ultrasonic sensors are positioned to continuously monitor the change in depth directly in front of the user.

The algorithm identifies a descending staircase based on a rapid increase in distance measured by the downward-facing ultrasonic sensor. If the measured distance exceeds a predefined threshold within a short movement range (indicating the absence of a reflective surface such as the floor), it is interpreted as a step down.

The detection logic operates as follows:

- If the sensor detects a significant and consistent increase in depth (e.g., from 30 cm to 80+ cm) within a short timeframe, the system assumes a descending stair.
- A delay or averaging mechanism is used to confirm it's not a false reading from a sudden dip or shadow.
- Upon confirmation, the device triggers immediate feedback through vibration and/or audio alerts to notify the user of the downward hazard.

This approach ensures proactive warning, enabling users to prepare for a step down safely. The threshold and detection logic were calibrated during testing to differentiate between stairs and other floor-level changes such as ramps or curbs.

6.3 Flow Diagram

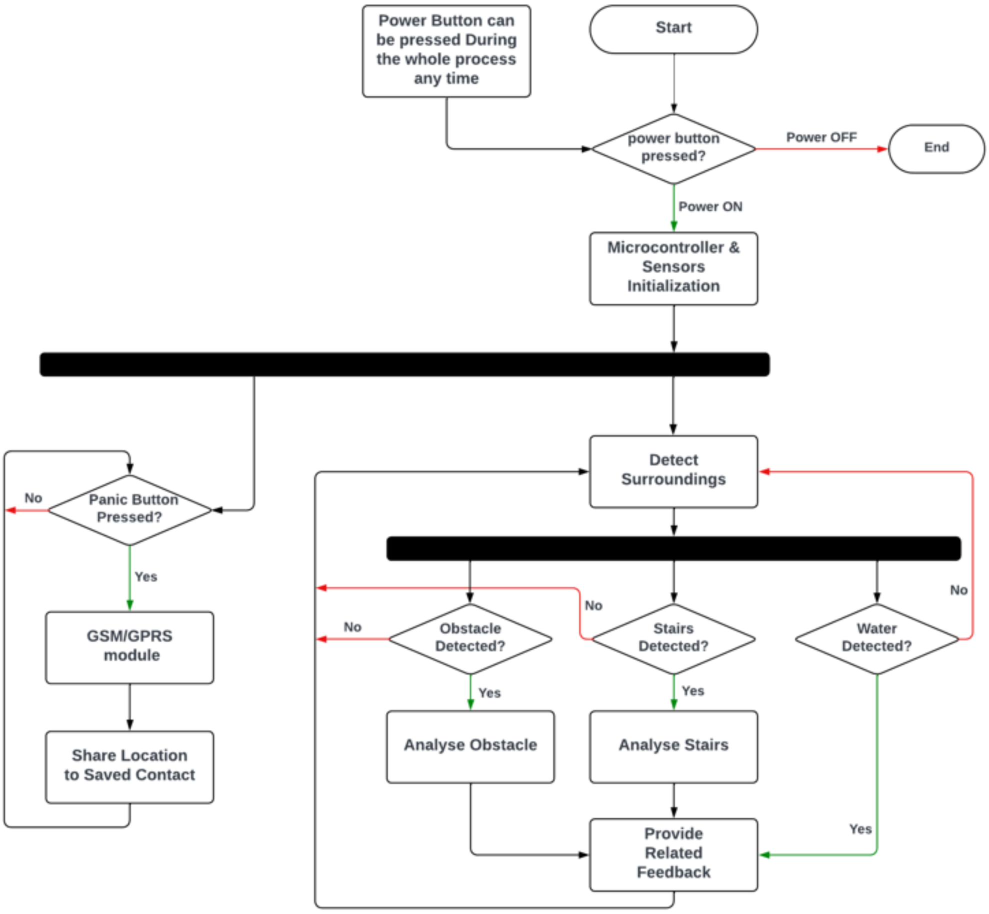

Figure 6.2: Flow Diagram of Track Mate System

6.4 Activity Diagram

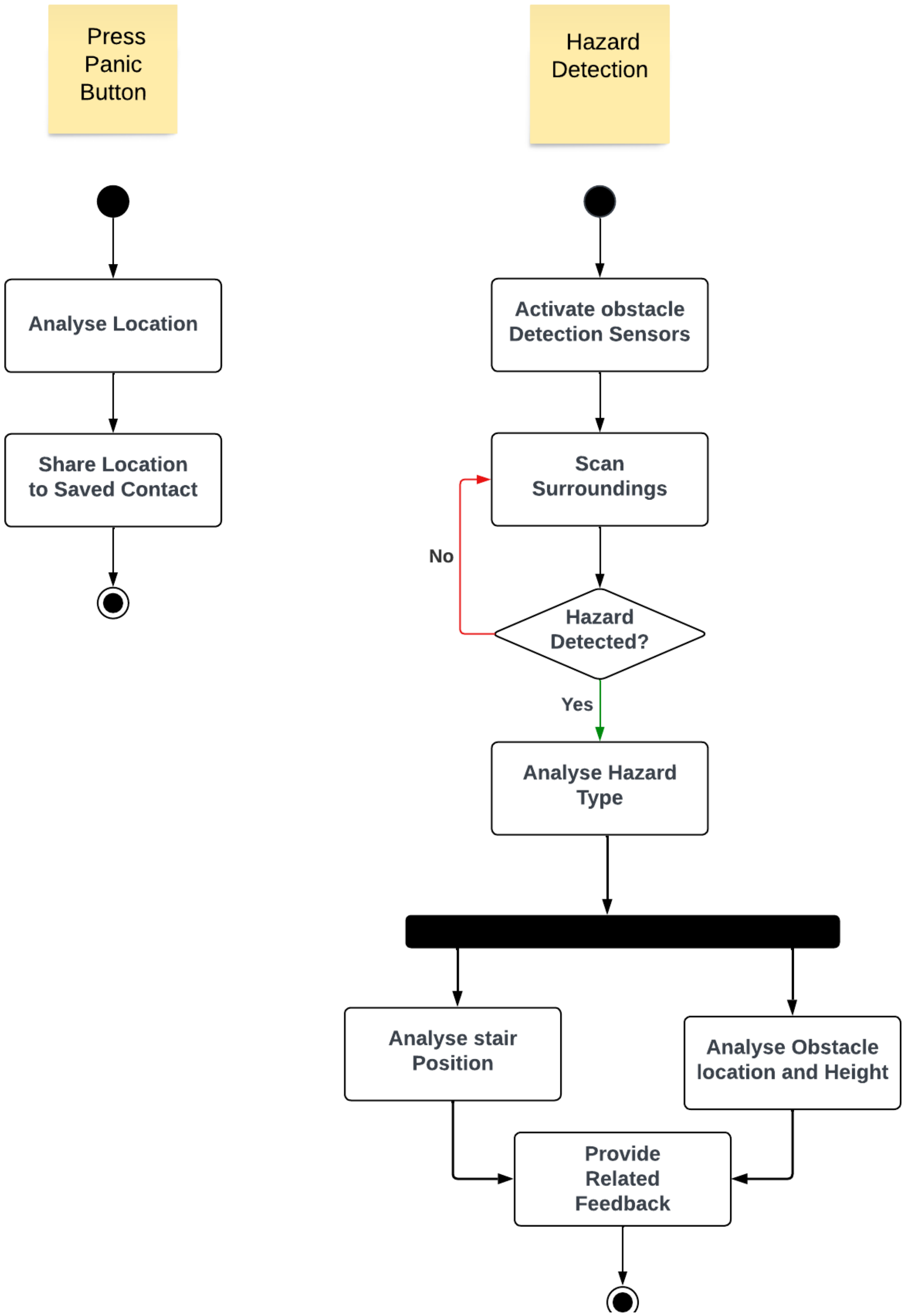

Figure 6.3: Activity Diagram

6.5 Architecture Diagram

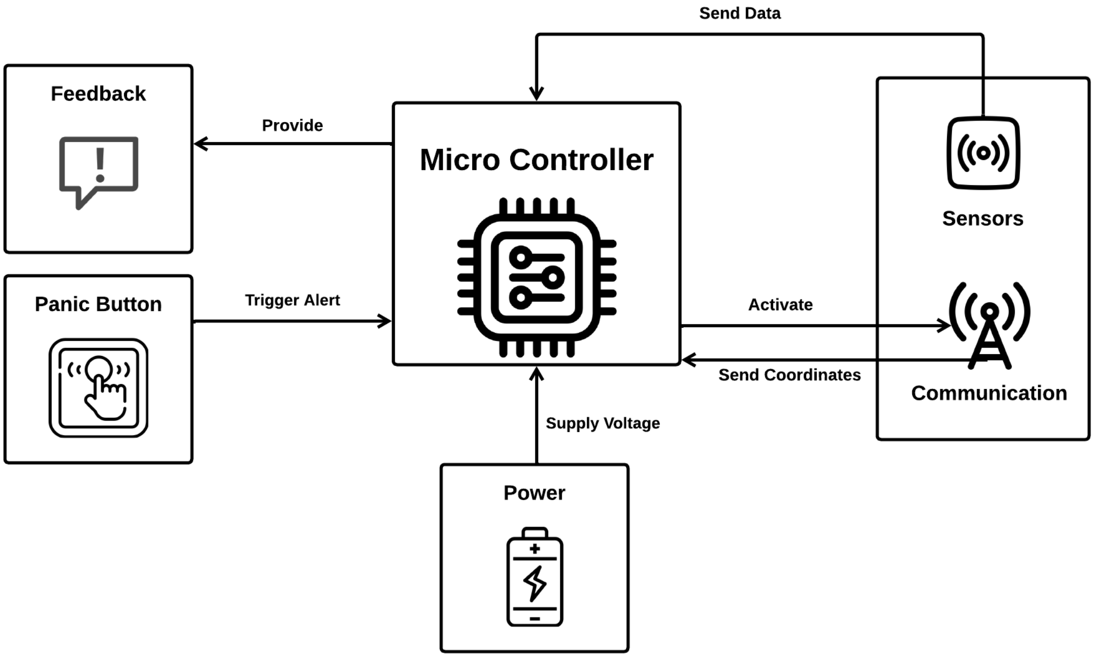

Figure 6.4: Architecture Diagram

Chapter 7

Development Phase

The development phase of the Track Mate project includes detailed hardware assembly, software implementation, and systematic integration to produce a fully functional and reliable assistive device designed for visually impaired individuals.

7.1 Hardware Development

The hardware development process involved selecting appropriate components and assembling them systematically into a user-friendly and ergonomic physical device.

7.1.1 Components and Materials

The primary components used include:

- Arduino Uno Microcontroller
- Ultrasonic Sensors (HC-SR04)
- Water Sensor
- Buzzer (auditory alerts)
- Vibration Motor (tactile feedback)

- Battery (Power supply)
- Connecting Wires
- Stick Frame

7.1.2 Hardware Structure

Components were strategically placed on the frame to ensure optimal functionality, sensor accuracy, and user comfort. The microcontroller was centrally located to simplify connections and improve sensor data handling efficiency.

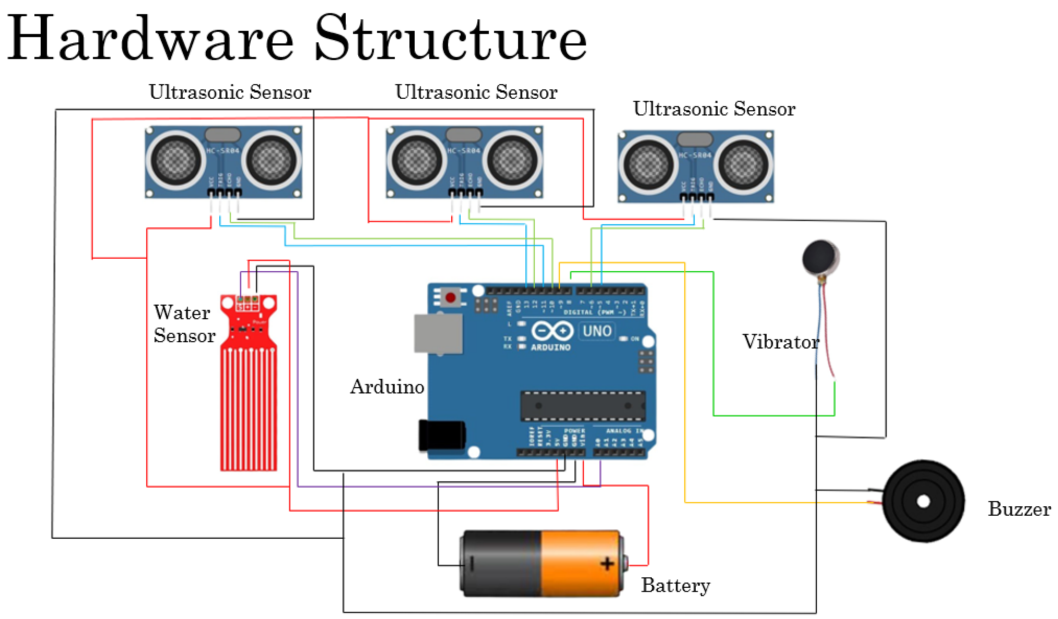

Figure 7.1: Hardware Structure and Component Integration of Track Mate

The diagram clearly illustrates the physical arrangement, component connectivity, and the overall integration of hardware within the device.

7.2 Software Development

Software development involved crafting algorithms to manage sensor data effectively, process inputs accurately, and deliver timely feedback to users.

7.2.1 Software Tools

Arduino IDE was selected for its ease of use, efficient coding, extensive library support, and reliable debugging tools.

7.2.2 Algorithm Implementation

Software algorithms were developed to handle real-time processing of sensor inputs. These algorithms identified obstacles, detected stairs (both ascending and descending), and recognized water hazards. The software ensured rapid data interpretation and swift user feedback.

7.2.3 Feedback Mechanisms

Software was programmed to activate auditory signals (buzzer) and tactile alerts (vibration motors) promptly upon hazard detection, enhancing the user's navigational safety.

7.3 System Integration

Integration testing was crucial in ensuring coherent operation among hardware components, software algorithms, and alert mechanisms. Multiple iterations were conducted, involving testing, debugging, and refining interactions between components.

Chapter 8

Testing

The testing phase aimed to verify the performance, reliability, and usability of the Track Mate device through a series of rigorous and systematic tests.

8.1 Sensor Accuracy Testing

Sensors were tested extensively to ensure accuracy and reliability under varied conditions.

8.1.1 Ultrasonic Sensor Testing

Accuracy of ultrasonic sensors in detecting objects, stairs, and height differences was validated through controlled experiments. Distance measurements were consistently accurate within the sensor range (2 cm to 400 cm).

8.1.2 Water Sensor Testing

The water sensor was tested to validate instant moisture detection and reliable triggering of alerts. Tests confirmed its effectiveness in identifying slippery surfaces rapidly.

8.2 Real-Time Feedback Testing

Feedback mechanisms were tested extensively to ensure immediate and clear alerts for detected hazards.

8.2.1 Auditory Feedback

Tests confirmed the buzzer's ability to provide loud and distinguishable auditory alerts upon hazard detection, effectively notifying users instantly.

8.2.2 Tactile Feedback Testing

Vibration motors were evaluated to confirm their capability to deliver instantaneous and recognizable tactile feedback to the user.

8.3 Integration and Stability Testing

Integration tests assessed the seamless cooperation among hardware, software, and feedback modules, focusing on:

8.3.1 Reliability Tests

Prolonged continuous-use tests were conducted, confirming stability and reliability under different conditions.

8.3.2 Response Time Tests

Testing confirmed that the device responded swiftly to sensor inputs, triggering feedback mechanisms without noticeable delays.

8.4 User Testing

User testing involved real-world usage scenarios with visually impaired individuals, evaluating device performance, user comfort, and overall system effectiveness.

8.4.1 Usability and Comfort

Users reported high ease-of-use and comfort during navigation tests, confirming Track Mate's suitability as a practical assistive tool.

8.4.2 User Feedback and Improvement

Direct feedback from test participants provided valuable insights, driving further refinements to enhance user satisfaction and device efficiency.

8.5 Evaluation Metrics

To quantitatively assess the system's performance and reliability, the following evaluation metrics were used:

- **Accuracy:** Measures the proportion of correctly identified hazards (obstacles, stairs, water) out of all detection attempts.
- **Precision:** Indicates how many of the detected hazards were actual hazards, minimizing false positives.
- **Recall (Sensitivity):** Indicates how many actual hazards were correctly identified, minimizing false negatives.
- **F1-Score:** Harmonic mean of precision and recall, providing a balanced measure when false positives and false negatives are equally important.

- **Specificity:** Measures the system's ability to correctly ignore non-hazardous conditions.
- **Response Time:** Time interval between hazard detection and feedback generation. This was found to be within an acceptable range for real-time usage.
- **False Positive Rate (FPR):** Rate at which the system signaled hazards that were not present.
- **False Negative Rate (FNR):** Rate at which the system failed to signal actual hazards.
- **Battery Efficiency:** Average operating time before requiring recharge, indicating power optimization effectiveness.
- **User Satisfaction:** Feedback from real users, gathered through interviews and structured surveys, covering comfort, trust, and usability.

These metrics provided a comprehensive understanding of the Track Mate's performance in both controlled and real-world scenarios. They were used to validate system improvements and inform refinements before final deployment.

Chapter 9

Conclusions and Future Work

9.1 Conclusions

The **Track Mate** project successfully achieved its objective of designing and developing a smart assistive stick that enhances mobility and safety for visually impaired individuals. By integrating ultrasonic sensors, infrared sensors, and a water sensor, the device is capable of detecting obstacles, staircases (both ascending and descending), and wet surfaces. Additionally, the inclusion of a GSM module facilitates emergency communication, allowing users to send alerts when in distress.

The device provides real-time feedback through auditory and tactile (vibration) signals, enabling users to respond promptly to their surroundings. Extensive testing validated the accuracy, responsiveness, and reliability of the system in both indoor and outdoor environments. User feedback confirmed that the device is user-friendly and effective in enhancing independent mobility.

In summary, the project delivers a cost-effective, reliable, and scalable solution in the domain of assistive technology, filling the gap between traditional mobility aids and more advanced systems, while remaining accessible to a wide user base.

9.2 Future Work

Although the current version of Track Mate meets its core requirements, several enhancements are proposed for future iterations:

- **AI-Based Obstacle Recognition:** Future versions can incorporate machine learning models to recognize and classify obstacles using visual or sensor data.
- **Camera Integration:** Adding a lightweight camera module can enable scene understanding and visual feedback for tasks such as sign recognition or path guidance.
- **Mobile Application:** A companion smartphone app could allow configuration settings, real-time location tracking, and emergency contact management.
- **Indoor Navigation:** Integration with Bluetooth beacons or Wi-Fi positioning systems could facilitate accurate indoor navigation in public buildings.
- **Battery Optimization:** Use of solar charging or advanced power management systems can further increase the device's operational duration.
- **Waterproofing and Rugged Design:** Improving the enclosure for better resistance to water and mechanical shocks will enhance usability in diverse conditions.
- **Voice Assistant Integration:** Adding a basic voice interface for alerts and commands can improve accessibility for users with combined visual and hearing impairments.

These future developments aim to enhance the functionality, adaptability, and user experience of Track Mate, evolving it into a comprehensive mobility solution tailored to the dynamic needs of the visually impaired community.

Bibliography

[1] K. Jivrajani, S. K. Patel, C. Parmar, J. Surve, K. Ahmed, F. M. Bui, and F. A. Al-Zahrani, “AIoT-Based Smart Stick for Visually Impaired Person,” *IEEE Transactions on Instrumentation and Measurement*, vol. 72, 2023, doi:10.1109/TIM.2022.3227988.

[2] M. S. Hossain, M. Ahmed, and M. Kabir, “Belt-Based Navigation System for Blind,” in *Proc. International Conference on Robotics and Automation*, 2011.

[3] M. Ashrafuzzaman, S. Saha, N. Uddin, P. K. Saha, S. Hossen, and K. Nur, “Design and Development of a Low-cost Smart Stick for Visually Impaired People,” in *Int. Conf. on Science & Contemporary Technologies (ICSCT)*, 2021, doi:10.1109/ICSCT53883.2021.9642500.

[4] Y. Sharma and A. Kumar, “Smart Stick for the Blind Using Multiple Sensors,” in *International Conference on Computing, Communication and Automation (ICCCA)*, 2017.

[5] B. H. Kumar, G. Anusha, S. Haritha, and S. U. Sri, “Low-Cost Walking Stick for Obstacle and Stair Detection Using Arduino,” *Science & Technology Development Journal - Engineering and Technology*, vol. 12, no. 5, pp. 614–623, 2023.

[6] B. K. T. P. Wickramasinghe, K. K. V. S. Anjana, G. D. S. T. Ratnasekara, and D. U. Vidanagama, “Smart Cane for Staircase and Water Detection,” Faculty of Computing, General Sir John Kotelawala Defence University, Sri Lanka, 2020.

[7] M. Habib, M. M. Islam, M. N. Kabir, M. B. Mredul, and M. Hasan, “Staircase Detec-

tion to Guide Visually Impaired People: A Hybrid Approach," *Revue d'Intelligence Artificielle*, vol. 33, no. 5, pp. 327–334, 2019, doi:10.18280/ria.330501.