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Design and Implementation of an Ultra-Low-Cost Smart Safety Stick with Multi-Level Obstacle Detection and GPS-Based Emergency Communication for Visually Impaired People in Developing Countries

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Abstract - Visual impairment significantly affects the mobility of visually impaired people and these problems are even higher in developing countries like Bangladesh as they are usually accompanied by undeveloped infrastructure, open drainage systems, risk of uncertain road incidents, etc. Conventional white cane neither provides enough physical feed-back to the user nor it supports emergency communication at remote locations. This study presents an affordable, IoT-enabled Smart Safety Stick designed to support visually impaired people in low-resource settings. The prototype has a listed material cost of BDT 2,323 (approximately USD 18.79). We designed the stick with an ESP32 microcontroller and three ultrasonic sensors for detection of obstacles at different height levels and pothole along the walking path and one resistive water sensor for flood conditions of walking path. It also equips a consolidated GPS and GSM module (NEO-6M and SIM900A) to provide real-time location to track down the disabled and transmit alerts at emergency SMS for predefined mobile contacts. When danger identified the stick instantly produces localized sound from the active buzzer to alert the user and an emergency switch is there which will send its exact coordinates to previously assigned mobile contacts via SMS when pressed. Utilizing a local power distribution network (18650 Li-Ion Battery and AMS1117 Regulator) it has become affordable, highly scalable and easily deployable substitute of high-cost advanced assistive devices. Experimental analysis has shown trustworthy data on detection of obstacle at various angles with promising latency range for transmitting emergency message.

Keywords - Smart Safety Stick, Visually Impaired People, Electronic Travel Aid (ETA), Multi-Level Obstacle Detection, Ultrasonic Sensors, GPS-Based Emergency Communication, Low-Cost Assistive Technology.

I. INTRODUCTION

For visually impaired people, moving independently through unfamiliar surroundings can be challenging. Everyday activities such as crossing roads, walking along footpaths, or avoiding unexpected obstacles require an awareness of the surrounding environment. These difficulties can be more serious in developing countries such as Bangladesh, where uneven roads, open drainage systems, potholes, and waterlogged pathways create additional risks. The conventional white cane is widely used because of its simplicity, affordability, and ease of operation. However, it mainly detects obstacles through physical contact and provides limited information about hazards beyond its reach. To overcome these limitations, researchers designed electronic travel aids (ETAs) that harness sensors and electronic feedback to provide safer and more independent locomotion [1]–[3].

For the past few decades, electronic sensing has played a major role in assistive technologies to aid the visually impaired to navigate more safely. NavBelt by Shoval et al. [1] uses ultrasonic sensors and audio feedback to inform the user of obstacles in the immediate vicinity. Later, Ulrich and Borenstein [2] developed the GuideCane, which employs mobile robotics technology to help users avoid obstacles. These early developments showed the potential of electronic sensing to aid independent mobility.

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More recent work has investigated the use of sensors, microcontrollers and different feedback systems in electronic travel aids. Xu et al. [3], in a review of wearable electronic travel aids, reported that ultrasonic sensors and audio feedback are commonly used for detecting obstacles. But the usefulness of such systems in practice depends not only on the detection of obstacles but also on parameters such as sensing coverage, user comfort, and the ability to distinguish between different types of dangers.

The availability of low-cost microcontrollers and electronic components has also spurred the development of low-cost smart walking sticks. Kazi et al. [4] proposed a smart cane that makes use of ultrasonic sensing to detect obstacles and assist users in navigating their surroundings. Similarly, Ravindran et al. [5] developed a smart stick based on ultrasonic with voice assistance and communication features. These studies show that useful mobility aids can be designed with relatively simple and inexpensive hardware. However, obstacle detection is still an important issue in many existing systems. Other safety issues such as wet surface, ground level hazards and emergency communication are also important. In recent years, a number of studies have explored the fusion of different sensing and communication technologies to address a wider variety of mobility problems. Farooq et al. [6] proposed an IoT enabled smart stick which includes ultrasonic sensors, water detection, camera-based object recognition and GPS/GSM communication. Their work showed the value of combining environmental sensing with location-based help. [7] developed a smart stick navigation system using sensor data and machine learning algorithms. Mai et al. [8] reviewed smart cane technologies based on laser and vision sensing and described how advanced sensors and multi-sensor integration can improve the perception of the environment. These methods provide more functionality but also add complexity to the system and more computation and cost to the system through the use of cameras, complex processing algorithms and advanced sensing hardware.

Location tracking and emergency communication are also important aspects of assistive technology, especially in situations where a visually impaired person is travelling alone and faces an unexpected situation. Helal et al. [9] proposed Drishti, an integrated navigation system for visually impaired users that combined positioning, wireless communication and contextual information. More recently, Abidi et al. [10] reviewed navigational technologies ranging from traditional mobility aids to sensor-based and satellite-navigation systems. These developments show how positioning and communication technologies can extend the capabilities of electronic travel aids beyond simple obstacle detection.

Despite these technological advances, affordability is still an important challenge, especially in resource-constrained communities. A household survey conducted in two districts of Bangladesh found high unmet needs for assistive products and indicated the importance of increasing access to these technologies [11]. In addition, Budrionis et al. [12] examined the potential of smartphone-based computer vision systems for assisting travel, as well as the practical issues that are involved in using them. Mohd Romlay et al. [13] reviewed the development and evaluation of electronic travel aids and emphasized the need to consider the needs of visually impaired users in the design of systems. The results suggest that the design of an assistive device should consider not only technical functionality but also affordability, simplicity, portability and practical utility.

In the light of these challenges, this paper proposes an ultra-low-cost Smart Safety Stick to provide visually impaired people with essential mobility assistance and emergency communication. The proposed system uses an ESP32 microcontroller as the central processing unit and has three ultrasonic sensors to detect obstacles in three different positions on the walking path. It uses a resistive water sensor to detect wet or water covered surfaces and an active buzzer to give an instant audible warning when a potential hazard is detected. It also consists of NEO-6M GPS module and SIM900A GSM module for emergency communication based on location. On pressing the emergency button by the user, the system fetches the available GPS coordinates and sends the SMS containing the location information to the pre-defined mobile number. The emergency message function operates over a GSM cellular network as long as there is suitable network coverage, unlike systems that require a constant connection to the internet.

The prototype is expected to cost about BDT 2,323 (approximately USD 18.79) in materials, so affordability is a key design priority. It integrates multiple safety features in one battery-powered device, using cheap, standard electronic components rather than expensive sensors or complex computing. Its main contribution is to combine multi-position obstacle detection, water-hazard detection, audible alerts, GPS-based location tracking and GSM emergency messaging onto a low-cost platform. The paper describes the implementation of these features and the operation of the prototype. It provides a practical starting point for developing accessible mobility aids, especially for people in low-resource settings.

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II. PROPOSED SYSTEM AND METHODOLOGY

A. Overall System Architecture

The Smart Safety Stick is proposed to help visually impaired people by sensing nearby obstacles, detecting water on walking surfaces and providing a communication channel in emergencies. These functionalities are integrated into a single mobile device, using ESP32 microcontroller as a main controller of the system. The design is intended to utilize inexpensive and common electronic components, with a simple operating mechanism. The system comprises three main functional units, environmental sensing, warning generation and emergency communication. The sensing unit consists of three ultrasonic sensors and one resistive water sensor. Ultrasonic sensors detect obstacles at different locations around the walking path and water sensor senses the presence of water on the surface. The ESP32 processes the sensor data and triggers an audible alarm if it detects a potential hazard. The stick includes a NEO-6M GPS module and a SIM900A GSM module for emergency situations. The geographical coordinates are provided by the GPS module and the location information is sent to a predefined mobile number through the GSM module on pressing the emergency button. The system is battery-powered and can operate without a fixed external power connection. The general architecture of the proposed system is shown in Fig. 1.

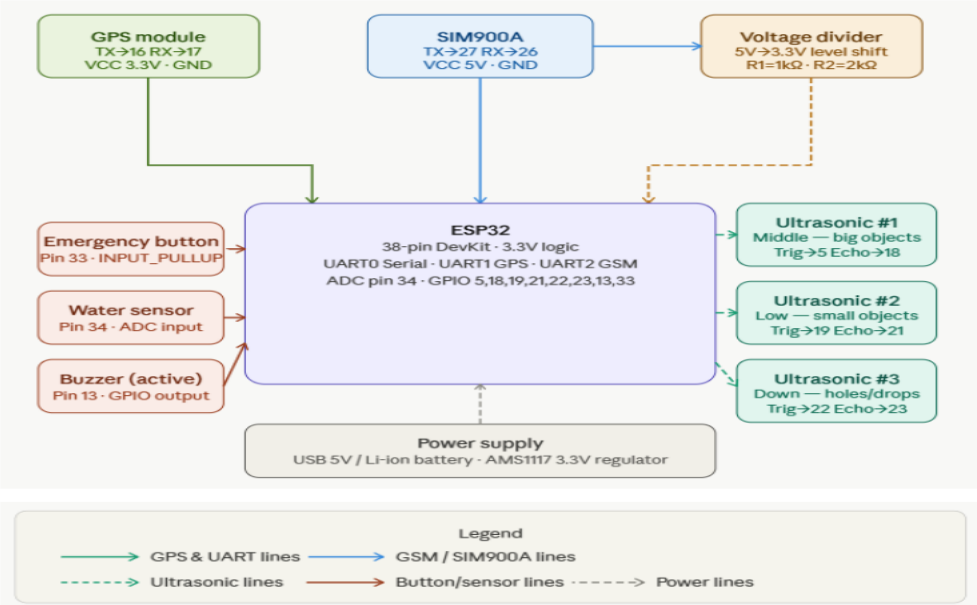


Fig. 1. Functional block diagram of the proposed ESP32-based Smart Safety Stick

B. Hardware Design and Implementation

The hardware was designed using an ESP32S 38 pin development board, three ultrasonic sensors, a water sensor, a NEO-6M GPS module, a SIM900A GSM module, an active buzzer and an emergency push button. The main controller for coordinating the sensing and communication operations is the ESP32. The ESP32 is connected to the ultrasonic sensors using the trigger and echo connections on different digital pins. The sensors are placed to watch for obstacles at various locations around the stick. This configuration is intended to detect obstacles in the forward direction of walking and hazards close to the ground.

The ESP32 is connected to a water sensor to detect wet conditions on the walking surface. When the output of the controller indicates that there is water present, the warning system is activated. Audible feedback is provided by an active buzzer to alert the user without requiring interaction with a display or mobile device.
Emergency communications are provided through the integrated GPS and GSM modules. The NEO-6M module will send location information to the ESP32, and the SIM900A module will send emergency messages over a compatible cellular network. The arrangement of hardware also includes a voltage-dividing circuit of signal-level conversion as needed.

The main components are interconnected according to developed circuit as shown in Fig. 2. The prototype is powered by a battery power supply for portability. The hardware components and their functions are summarized in Table I.

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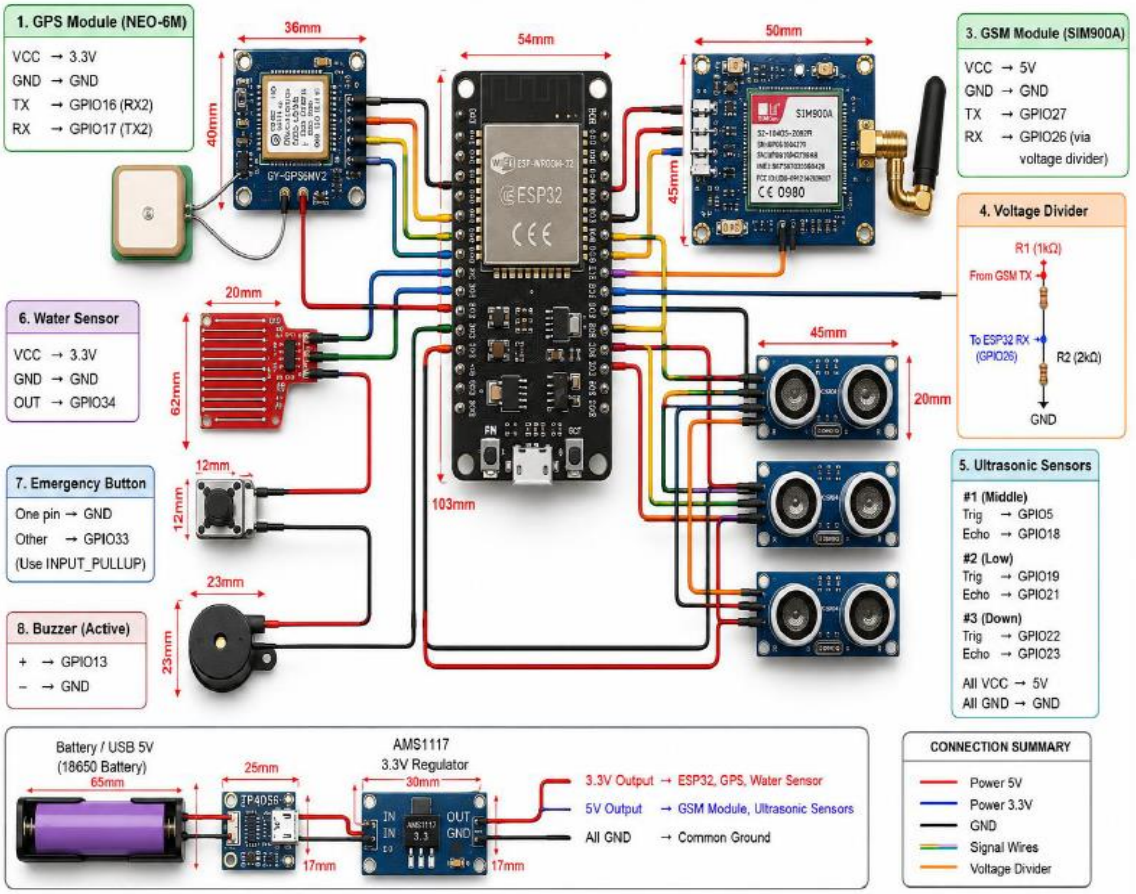


Fig. 2. Pictorial wiring diagram showing the hardware components and their connections to the ESP32

TABLE I. COMPONENTS USED IN THE PROPOSED SYSTEM

Component	Quantity	Function
ESP32S development board	1	Central processing and control
Ultrasonic sensor	3	Detection of obstacles
Resistive water sensor	1	Detection of water on walking surfaces
NEO-6M GPS module	1	Acquisition of geographical coordinates
SIM900A GSM module	1	Emergency SMS transmission
Active buzzer	1	Audible warning
Emergency push button	1	Manual emergency activation
Battery	2	Portable power supply
Battery case	1	Battery mounting
Voltage-divider circuit	1	Signal-level conversion
SIM card	1	Cellular network communication
Jumper wires	1 set	Electrical interconnections

C. Obstacle Detection Mechanism

Obstacle detection is one of the main functions of the proposed system. The objects are detected by three ultrasonic sensors which are used to detect objects in the sensing ranges. In contrast, a normal walking stick is mostly about physical contact to get information. Ultrasonic sensors can get information about nearby objects before physical contact.

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Each ultrasonic sensor works by transmitting a short ultrasonic pulse and measuring the time required for the reflected signal to return. The ESP32 uses this time interval to calculate the distance between the sensor and the detected object. The relationship can be expressed as

$$d = \frac{v \times t}{2}$$

where d represents the distance between the sensor and the obstacle, v is the speed of sound in air, and t is the round-trip travel time of the ultrasonic pulse.

During operation, the ESP32 receives the measured distances and compares them with the programmed detection thresholds. When an object is detected within the selected range, the controller activates the buzzer to warn the user.

Using three ultrasonic sensors allows the stick to monitor more than one sensing direction. The arrangement is intended to improve the coverage of nearby obstacles, including objects that may be encountered at different heights. However, the detection capability depends on the position of the sensors, the shape and orientation of an obstacle, and the programmed distance limits.

D. Water Detection Mechanism

Visually impaired pedestrians may also find it more difficult to navigate where pathways are covered in water, particularly in areas where there has been rain or where drainage is inadequate. To overcome this problem, the proposed system has a resistive water sensor. The water sensor operates by detecting changes in the electrical conductivity between its sensing electrodes when they come into contact with water. The sensor output is read by the ESP32, and is evaluated in accordance with the programd detection condition.

The controller actuates the buzzer for audible warning when water is detected. This allows the stick to sense another type of environmental hazard that may not be sensed by ultrasonic distance measurements alone. The water detection function is meant to complement, not replace, obstacle detection. It works depending on the contact of the sensing surface with the water and the electrical properties of the water and the threshold of the detection that you set .

E. GPS and GSM-Based Emergency Communication

The Smart Safety Stick has an emergency communication feature to assist the user in calling for help when needed. The system uses a NEO-6M GPS module for location acquisition and SIM900A GSM module to send emergency message. The GPS module receives signals from the satellites and gives the geographical coordinates in the form of latitude and longitude. The coordinates are sent to the ESP32 through a serial communication interface. The user can manually start the communication process via an emergency push button. When the button is pressed, the ESP32 reads the current GPS location data and creates an emergency message including the coordinates. The SIM900A GSM module then forwards the message to a predefined mobile number via the cellular network.

The emergency communication sequence can be represented as: Emergency Button → ESP32 → GPS Coordinates → GSM Module → Emergency SMS

This arrangement allows the user to send location information without requiring a smartphone application or a continuous internet connection. However, successful SMS transmission depends on the availability of a compatible cellular network, while the location information depends on adequate GPS satellite reception.

F. Software Development and Working Algorithm

The ESP32 was programd with the Arduino Integrated Development Environment (Arduino IDE). The embedded program takes care of sensor readings, obstacle detection, water detection, buzzer activation and emergency communication.

On powering up the device, the ESP32 initialises the attached sensors and communication modules. After the initialisation, the

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controller starts to check the ultrasonic sensors for any obstacles. The measured distances are compared with the programd limits and the buzzer is activated if an obstacle is detected within the selected range. The controller also monitors the water level sensor. When the sensor detects water, the ESP32 will turn on the warning system. In normal operation these sensing operations are performed repeatedly so that the device can respond to changes in its surroundings.

The ESP32 checks the emergency push button in addition to the sensing functions. Pressing the button will start the emergency communication procedure on the controller. The available GPS coordinates are taken and sent to the predefined contact through the GSM module. After the necessary operations are performed the controller keeps observing the attached sensors. The operational sequence is outlined in Fig. 3.

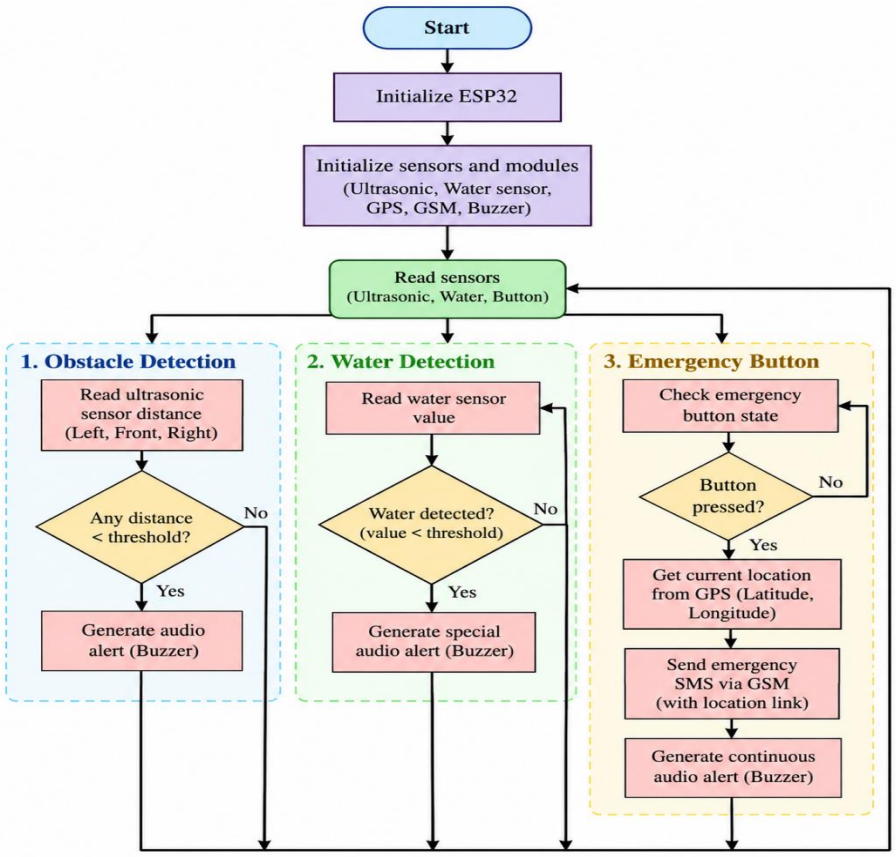


Fig. 3. Software control flowchart of the proposed Smart Safety Stick showing ultrasonic obstacle detection, water-hazard detection, audible warnings, and GPS/GSM-based emergency communication

G. Power Supply and System Integration

Since it runs on batteries, the Smart Safety Stick is portable. The power arrangement provides electrical connections for the ESP32, sensing components, warning unit and communication modules. The hardware design incorporates the necessary supply connections and a voltage-divider circuit for signal-level compatibility. All interconnected modules share a common electrical reference to enable communication and control. After the hardware assembly, the sensing, warning and communication units were integrated through the ESP32. In normal operation the ultrasonic sensors detect the presence of obstacles in the vicinity and the water sensor monitors the presence of water in the walking surface. The ESP32 processes the respective signals and if it detects a possible hazard, it triggers the buzzer. In the event of an emergency, the user may press the emergency button to start location-based communication. The proposed stick combines local hazard warning and remote emergency messaging in one battery-powered unit. Figure 4 presents the physical realisation of the developed system.

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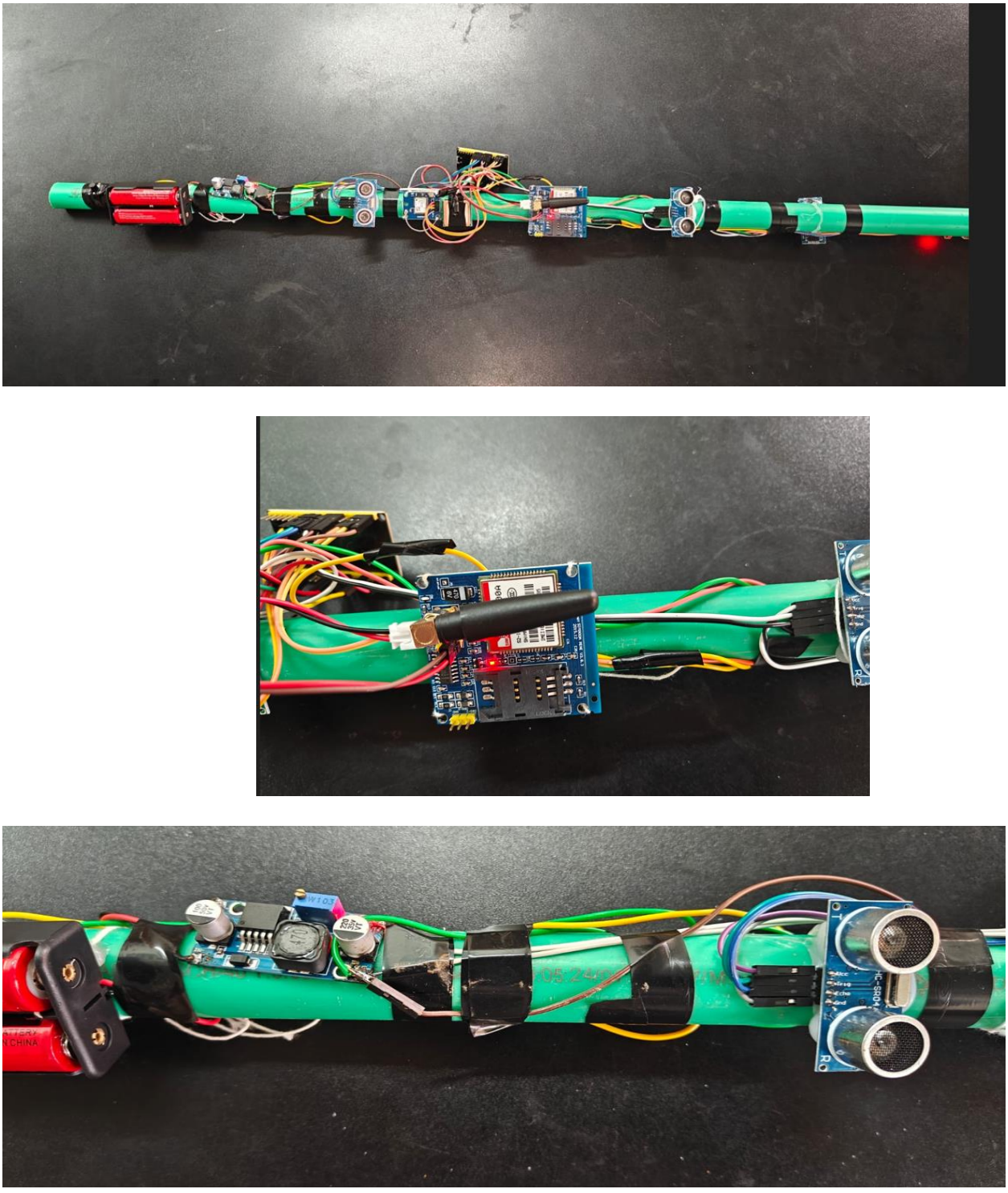


Fig.3. Photographs of the assembled Smart Safety Stick

III. EXPERIMENTAL RESULTS AND DISCUSSION

A. Functional Evaluation of the Prototype

The proposed Smart Safety Stick is an embedded system that integrates obstacle detection, water detection, audible warnings and emergency communication in one device. The project implementation explains how the ESP32 microcontroller coordinates these functions. It works by constantly checking the inputs from the ultrasonic sensor and water sensor, and then making an audible alarm

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if the conditions that have been programmed as hazards are met. Emergency communication is done separately through the push button where the user can ask for help by sending GPS location information via the GSM module.

The major functions of the prototype are given in Table II. The table explains how they are designed to work based on the design that has been built. Their detection accuracy, response time and reliability must be determined by quantitative measurements and repeated experimental trials.

TABLE II. FUNCTIONAL CHARACTERISTICS OF THE PROPOSED SYSTEM

Functional unit	**Implemented approach**	**Intended response**
Obstacle detection	Three ultrasonic sensors	Detection of nearby objects
Water detection	Resistive water sensor	Identification of water contact
Warning system	ESP32-controlled active buzzer	Audible warning when a hazard is detected
Location acquisition	NEO-6M GPS module	Latitude and longitude information
Emergency communication	Push button and SIM900A GSM module	SMS containing location information
Power supply	Battery-powered circuit	Portable operation

B. Obstacle Detection Performance

Three ultrasonic sensors are integrated to detect obstacles at various positions along the walking path. Each sensor measures the distance to a nearby object by timing the travel of an ultrasonic pulse.

TABLE III. FUNCTIONAL EVALUATION OF THE PROPOSED SMART SAFETY STICK

Test Case	**Test Condition**	**Expected Response**	**Observed Result**
1	Obstacle detected in the forward walking path	Ultrasonic sensor activates the buzzer	Successful
2	Obstacle detected near ground level	Ultrasonic sensor activates the buzzer	Successful
3	Water contacts the sensing electrodes	Water sensor activates the buzzer	Successful
4	Emergency button is pressed	GPS coordinates are sent through GSM via SMS	Successful
5	No obstacle or water is detected	Buzzer remains OFF	Successful
6	Device operates using battery power	ESP32 and connected modules operate without external power	Successful

The functional performance of the developed Smart Safety Stick was tested under six operating conditions as shown in Table III. The system detected obstacles in the forward walking path and in the near ground level and activated the buzzer to alert the user. The water sensor also responded to the presence of water and produced a loud alarm. Emergency tests confirmed that the emergency button could trigger the transmission of GPS location information successfully through the GSM module. When no hazard was detected the buzzer was not activated and the system was powered by the battery supply. These observations show the successful integration of the sensing, warning and emergency communication functions in the proposed prototype.

C. GPS Location and Emergency SMS Performance

The GPS and GSM modules also provide an extra safety feature which is that the user can share the location information in case of an emergency. In accordance with the designed operation procedure, pressing the emergency button will start location acquisition and SMS transmission to a predetermined contact.

The emergency communication function can be assessed by recording the time at which the button is pressed and the time at which the SMS is received. The message delivery delay can be expressed as

$$T_{\text{sms}} = T_{\text{r}} - T_{\text{p}}$$

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where T_{sms} represents the SMS delivery delay, T_r is the message reception time, and T_p is the time of button activation.

For repeated trials, the average delivery delay can be calculated using

$$T_{avg} = (\Sigma T_{sms,i}) / N$$

where N represents the number of successful message delivery trials.

The emergency message should also be checked to confirm that it contains valid location information. GPS coordinates can be compared with a reference location to assess positioning performance.

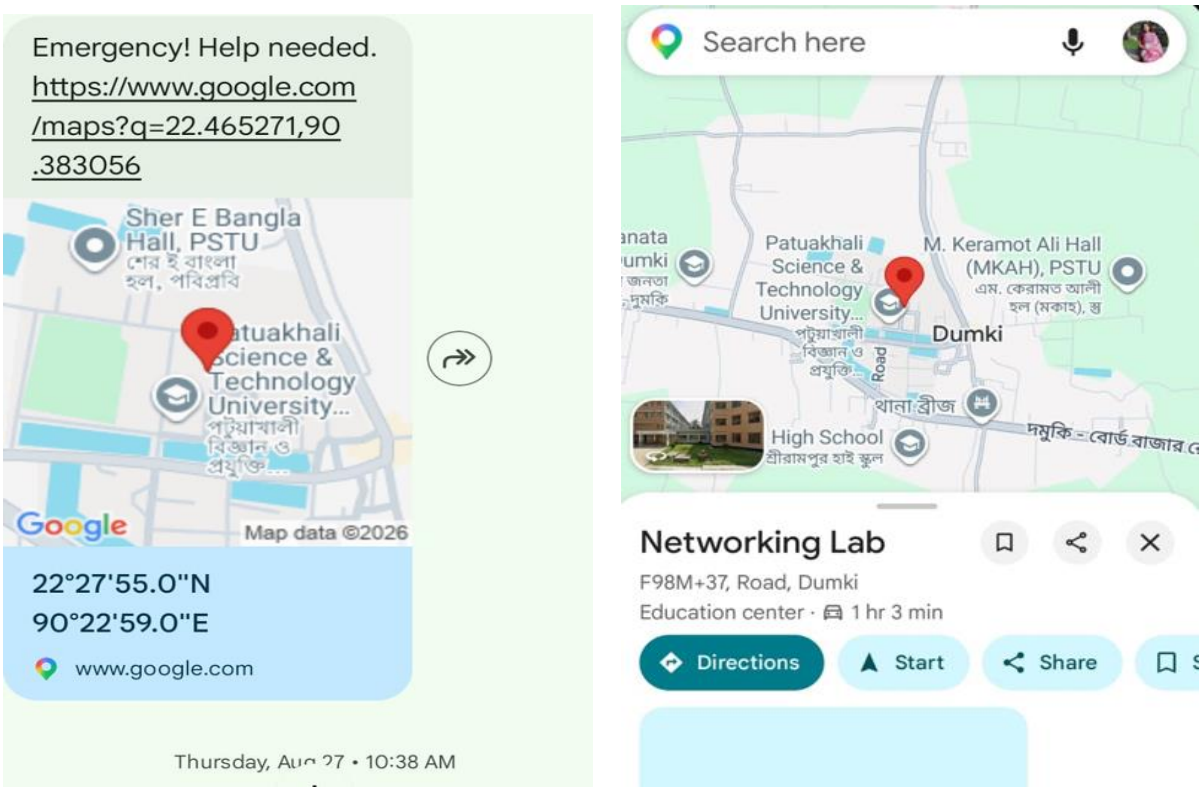


Fig. 4. Screenshot of an emergency SMS containing the GPS location and exact location in Google Maps

TABLE V. EMERGENCY SMS DELIVERY PERFORMANCE OF THE PROPOSED SMART SAFETY STICK

Trial No.	Emergency Button	SMS Delivery Status	Delivery Time (s)
1	Pressed	Successful	32
2	Pressed	Successful	38
3	Pressed	Successful	45
4	Pressed	Successful	36
5	Pressed	Successful	42
6	Pressed	Successful	40
7	Pressed	Successful	35
8	Pressed	Successful	47
9	Pressed	Successful	39
10	Pressed	Successful	47
Average	—	—	**40.1**

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The GSM-based approach avoids dependence on an active internet connection, which is useful for a low-cost assistive device. Nevertheless, SMS delivery can be affected by network coverage, signal strength, and operator availability. Similarly, GPS positioning may be less reliable in locations with obstructed satellite reception.

D. Cost Analysis

One of the main objectives of the proposed design is to provide essential mobility assistance at a low hardware cost. The system uses commonly available electronic components rather than expensive imaging systems or specialized processing platforms.

The total material cost can be determined using

$$C_{\text{total}} = \Sigma (Q_i \times C_i)$$

where Q_i represents the quantity of each component and C_i is its corresponding unit price.

TABLE VI. BILL OF MATERIALS AND COST ANALYSIS OF THE PROPOSED SMART SAFETY STICK

Component	Quantity (Q_i)	Unit Cost (C_i) (BDT)	Total Cost ($Q_i \times C_i$) (BDT)	Total Cost (USD)
ESP32S (38-pin)	1	493	493	3.99
SIM900L Mini GSM Module	1	750	750	6.07
NEO-6M GPS Module	1	430	430	3.48
Ultrasonic Sensor	3	110	330	2.67
Water Sensor	1	50	50	0.40
Buzzer and Battery Accessories	1 set	70	70	0.57
Emergency Switch	1	10	10	0.08
Battery	1	190	190	1.54
Total Cost			**2,323**	**18.79**

[Note: USD values were calculated using an exchange rate of 1 USD = BDT 123.65 as of October 20, 2026. Individual values are rounded to two decimal places, while the total USD cost is calculated from the unrounded values.]

The affordability of the proposed system is an important design consideration, particularly for users in low-resource communities. However, a complete cost evaluation should also consider expenses associated with assembly, the walking-stick structure, batteries, and future maintenance.

E. Overall Discussion and Limitations

The proposed Smart Safety Stick integrates several functions for the support of daily mobility of visually impaired people. Three ultrasonic sensors are used to detect obstacles at different positions on the walking path and a resistive water sensor to detect contact with water. If a potential hazard is sensed, the user will be warned with an audible signal. The emergency button is an additional safety feature that allows the user to send location information to a pre-defined contact by using GPS and GSM. The design is a practical starting point for developing affordable assistive technology in resource-constrained settings by combining these functions into a single device built around an ESP32 microcontroller and commonly available electronic components.

Another advantage of the system is that it is able to share emergency location information via SMS, without the need for an internet connection. This feature relies on the availability of GPS signals and cellular network coverage. The performance of the ultrasonic sensors may also be influenced by the angle, shape and surface of an obstacle as well as the location of the sensors and the conditions of the environment. Likewise, the water sensor is a physical contact sensor and may not recognize all wet or slippery surfaces. The simple audible warning may also restrict the information available to the user, particularly in terms of differentiating between types of hazards or their direction.

Preliminary functional tests show the co-operation of the main components under test conditions. These tests do not measure how accurate, reliable and effective the system is in everyday use. Other assessments are required to check the obstacle detection performance at different distances and angles, the reliability of water detection, the accuracy of GPS positioning, the delivery time of SMS and the battery endurance. It would be good to test the system in different environmental conditions and with different cellular network strengths to see if it works as expected or not.

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Another important factor is the experience of the intended users. A device can be a technical marvel, but still feel clunky or awkward for everyday use. Trials with visually impaired participants are thus needed to evaluate the stick's portability, comfort, warning signals and practical usefulness. Their feedback can help inform whether the design works for users and what changes might be worth making before wider use.

IV. CONCLUSION AND FUTURE WORK

This paper discusses the design and implementation of a low-cost Smart Safety Stick to help visually impaired people in their day-to-day movement. The proposed system has an ESP32 microcontroller, three ultrasonic sensors, a resistive water sensor, an active buzzer, GPS and GSM communication. It includes multiple obstacle detection points, water detection, audible warnings and an emergency location sharing button that is operated by the user.

The main advantage of the presented design is that it integrates a set of useful safety functions into a portable device made of relatively inexpensive and readily available electronic components. Its simple design and low cost make it a promising candidate for the development of assistive mobility devices in resource constrained settings. However, the practical usefulness and reliability of the proposed system need to be verified by quantitative performance data and testing with visually impaired users. The future work will focus on evaluation of the accuracy of obstacle detection, water detection performance, GPS positioning accuracy, GSM message sending, system response time and battery life under various operating conditions. Tests will also be conducted with visually impaired users to evaluate the comfort and ease of use of the device and the efficiency of the warning system. Voice guidance, vibration feedback, fall detection and a mobile application to track location are some of the additional enhancements. Depending on cost, computation and power consumption, camera-based object recognition and LiDAR sensing for better environmental awareness might also be looked into. The developed prototype provides a basis for further research on affordable electronic mobility aids in general. Further rigorous technical testing and evaluation with visually impaired users will be needed to establish its appropriateness for daily use and to guide the design of a more robust and accessible device.

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