EMPOWERING VISION LOSS: A RAPID-RESPONSE SMART STICK FOR SAFE NAVIGATION AND EMERGENCY SUPPORT

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ABSTRACT

*Visually impaired individuals worldwide often rely on others for navigation and daily mobility, which restricts their independence and diminishes quality of life. In Nigeria, this reliance imposes a considerable burden on caregivers, who may forgo personal, educational, and professional opportunities to provide ongoing support. Despite recent advancements in sensing technologies that have enabled the development of electronic travel aids, many existing solutions are constrained by environmental factors, high costs, or insufficient real-time obstacle detection. This study presents the design and development of an intelligent smart walking stick intended to enhance the mobility, safety, and autonomy of visually impaired individuals by providing reliable obstacle detection and emergency alert functions. The proposed system integrates an infrared sensor, an ultrasonic sensor, and a water sensor with an embedded microcontroller and an adaptive buzzer. The ultrasonic sensor identifies obstacles at various distances, the infrared sensor improves short-range object detection, and the water sensor detects wet surfaces and puddles. The buzzer delivers progressively louder warning signals as the user approaches obstacles and emits a repeated "Help" alert during emergencies to attract assistance. The prototype was implemented and experimentally evaluated under diverse environmental conditions to assess response time, obstacle detection performance, and operational reliability. Results indicate that the system demonstrates strong resistance to changes in ambient light and object color, with a rapid response time of approximately **39 ms**, supporting its suitability for real-time navigation. The intelligent walking stick effectively detects obstacles, alerts users to potential hazards, and provides an emergency communication mechanism, thereby improving user safety and reducing caregiver dependence. Future work should incorporate Global Positioning System (GPS) navigation, Internet of Things (IoT)-based remote monitoring, voice guidance, and artificial intelligence techniques to further enhance navigation accuracy, emergency response, and user autonomy.*

Keywords: Arduino UNO R3, buzzer, Visually Impaired, Sensors,

1 INTRODUCTION

The human eye is a critical organ for capturing visual information, which is then transmitted to the brain for processing. It is often described as the organ of sight, responsible for receiving and processing approximately 83% of environmental information [1]. However, many individuals are deprived of this sensory input due to ocular defects, often resulting in blindness. Blindness is defined as the inability to perceive light or having such limited vision that reliance on other senses becomes necessary [2]. The term 'visually impaired' encompasses individuals with complete or partial blindness. The World Health Organisation (WHO) estimates that approximately 285 million people globally experience visual impairments, including 39 million who are blind and 246 million with low vision. Notably, about 90% of these individuals reside in developing countries. Another WHO report estimates that 253 million people live with visual impairment, of whom 36 million are blind, and 217 million have moderate to severe visual impairment [3]. Many individuals experience significant visual impairments that hinder their ability to travel independently. As a result, they must rely on various tools and techniques to assist with mobility. One key resource is an orientation and mobility specialist, who helps train visually impaired and blind individuals to navigate safely on their own using their remaining senses [4]. Another widely used aid is the guide dog, specially trained to assist blind individuals by navigating obstacles and signaling when it's necessary to change direction [5, 6]. However, guide dogs have certain limitations, such as difficulty comprehending complex directions and a relatively short working lifespan of about 5 years. Additionally, the cost of training these dogs is high, and many visually impaired people may find it challenging to provide the necessary care for another living being. A widely recognised tool for blind and visually impaired individuals is the white cane with a red tip, designed to aid safe navigation. Today, various types of canes are available, such as the traditional white cane [7], the smart cane [8], and the laser cane [9]. Despite their usefulness, these canes have several limitations, including their length, difficulty detecting obstacles, and inconvenience in public spaces. Recent advances in signal processing and sensor-based systems have enabled the development of electronic travelling aids (ETAs) for dynamic environments, representing a significant improvement over traditional mobility tool. ETAs are generally classified into sonar input systems and camera-based input systems. Sonar-based systems utilize infrared, laser, or ultrasonic signals [10], while camera-based systems employ mini-CCD cameras [3]. These devices function similarly to radar, using ultrasonic or laser signals to detect the height, direction, and speed of both stationary and moving objects. Obstacle distance is determined by measuring the signal's travel time. Current systems notify users of an object's presence at a specific distance, facilitating navigation. Providing additional information about object characteristics can further enhance spatial awareness and memory for visually impaired individuals. To address existing limitations, this study developed a simple, efficient, and configurable electronic guidance system for blind and visually impaired users, suitable for both indoor and outdoor environments.

2 LITERATURE REVIEW

Extensive research has been conducted in this area. For instance, [3] equipped a stick with infrared sensors to detect staircases and a series of ultrasonic sensors to identify obstacles within four meters in front of the user. Additionally, it features a water sensor to detect any water on the path. Obstacles are communicated to the user through a buzzer. Furthermore, [12] designed a smart e-stick to assist individuals with visual impairments in navigating their environment more easily. It features an ultrasonic sensor to detect obstacles, as well as light and water sensors that warn users of potential hazards. The data was processed by a microcontroller, which activates a buzzer when obstacles are nearby. Additionally, haptic vibrations alert users to water or potholes, and the stick can determine whether the surroundings are bright or dark. A wireless RF remote helps users locate the stick if misplaced, while the "Speak for me" app on Android generates voice messages to further assist the user. This device enhances mobility and safety for visually impaired individuals. Similarly, [13] examined the future of walking aids, focusing on "Septor," a smart walking stick designed to enhance mobility and safety for individuals with mobility impairments. Septor utilises echolocation technology and incorporates advanced features, including ultrasonic sensors for object detection. A standout feature is its smartphone connectivity, allowing users to sync the stick with a mobile app to monitor walking patterns, receive exercise recommendations, and communicate with healthcare professionals for remote consultations. Unlike existing devices, Septor offers object detection and identification alerts, significantly improving user safety, independence, and convenience. More so, [3] integrate sensors, Artificial Intelligence (AI), and wireless transmission to assist visually impaired individuals. The smart stick features an ultrasonic sensor, camera, and speaker that work together to detect obstacles and provide real-time audio feedback to the user. Additionally, it includes an emergency switch, GSM, and GPS functionality. In emergencies, the user can activate the system to send an SMS with their precise location to a designated contact. This advancement significantly enhances the independence and mobility of visually impaired individuals, empowering them to navigate their environment with greater confidence and self-reliance. The smart blind stick serves not only as a mobility aid but also as a reliable companion for daily challenges. However, this existing system relies on third-party systems such as GSM and GPS to convey the visually impaired's person's location to the designated contact.

Nonetheless, network challenges and the proximity of individuals monitoring the visually impaired under emergency conditions become critical factors, as any delay in information relay or response may be catastrophic. It is therefore expedient to develop a model suitable for guiding the visually impaired amid resource constraints and for drawing the attention of any nearby person in emergency conditions. [14] developed a smart navigational stick that utilises deep learning algorithms for object and face recognition, employs ultrasonic sensors for distance measurement, and provides audio notifications via headphones, significantly aiding blind and visually impaired individuals in navigating their environment with confidence. [15] implemented smart vision technologies that significantly enhance independence for visually impaired individuals through advanced object recognition systems. These systems utilise artificial intelligence and machine learning to provide real-time feedback, enabling users to navigate their environments more effectively. [16] present a YOLOv8-based object detection system for the visually impaired, integrating Google Text-to-Speech for real-time audio feedback, enhancing navigation and independence, and significantly improving the quality of life for over 2 billion individuals with visual impairments. [17] discuss SmartSight, an integrated assistive system utilising image-processing algorithms for real-time object detection, enhancing independence for visually impaired individuals through aural feedback, thereby improving accessibility and visual awareness of their surroundings. [18] proposed that an AI-powered smart vision kit enhances independence for visually impaired individuals by utilising real-time object detection and audio feedback, enabling better environmental awareness and mobility through a portable, low-cost solution with efficient inference capabilities. [19] present an AI-based smart system that enhances independence for visually impaired individuals through accurate object recognition, achieving 94.6% accuracy. It provides real-time feedback via a voice synthesis engine, significantly improving situational awareness and mobility during navigation. [20] *present* a Smart Navigation System utilising AI and the YOLOv8 model for real-time object detection, enhancing independence for visually impaired individuals by providing auditory cues about obstacles, traffic lights, and environmental conditions, significantly improving navigation safety and confidence. [21] proposed an AI-based wearable vision assistance system that enhances independence for visually impaired individuals through real-time object recognition and contextual understanding, enabling them to navigate environments safely and perform daily activities, such as shopping, with greater confidence and autonomy.

3 DEVELOPED SYSTEM

The proposed system comprises the Arduino Uno R3, water sensor, ultrasonic sensor, jumper wires, USB cable, buzzer, voltage regulator, infrared sensor, operational amplifier, and system casing. To facilitate effective communication between the sensors and the environment, Arduino code was developed using the Arduino IDE installed on the Department of Computer Engineering's workstation at Edo State Unversity, Iyamho. The following sections provide a detailed description of the hardware components utilized in this research.

3.1 Arduino Uno

The Arduino Uno R3 uses the Atmel Atmega328 microcontroller with a clock speed of 16 MHz. Different sensors can be attached to the board as it has fourteen (14) digital input and output (I/O) pins, six (6) analogue inputs, a USB connection, an ICSP reset button, and a power jack, as shown in Figure 1, [22]. The Arduino UNO is the brain of the smart walking stick. It processes inputs from different sensors and uses programmed logic to make decisions before sending signals to actuators, such as buzzers and LEDs, as feedback to the user [23]. During the development stage, the USB cable was connected to the USB plug shown in Figure 1, and its other end to the Laboratory workstation. This enabled serial communication between the workstation and the Arduino Uno R3 for code upload and during the developmental phase.

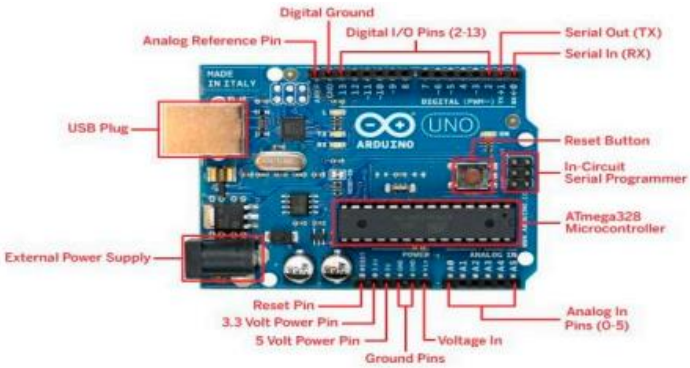

Figure 1. Arduino Uno R3

3.2 Ultrasonic Sensor (HC-SR04)

The ultrasonic sensor used as a proximity sensor was adopted as an object detector. It is a four-pin module with Ground, Vcc, Trigger, and Echo pins. The sensor was configured to detect objects from 2cm to 400cm and send the detected information to the microcontroller, which drives the buzzer to guide the visually impaired in the necessary actions.

3.3 Infrared Sensor (A 215/450)

The infrared (IR) sensor module consists of an IR Receiver and Transmitter, a variable resistor (Trimmer pot), an op-amp, and an LED outlet. The IR LED emits light at a wide range of infrared frequencies that are invisible to humans. The reason is its wavelength (700 nm–1 mm), which is much higher than that of visible light. Infrared LEDs typically have an optical illumination angle ranging from approximately 20 to 60 degrees and can transmit light over distances from a few inches to several feet, depending on the specific type and manufacturer of the IR transmitter. Some transmitters are capable of operating over distances of several miles. IR LEDs, as shown in Figure 2, are generally white or transparent, allowing for high-intensity output [24].

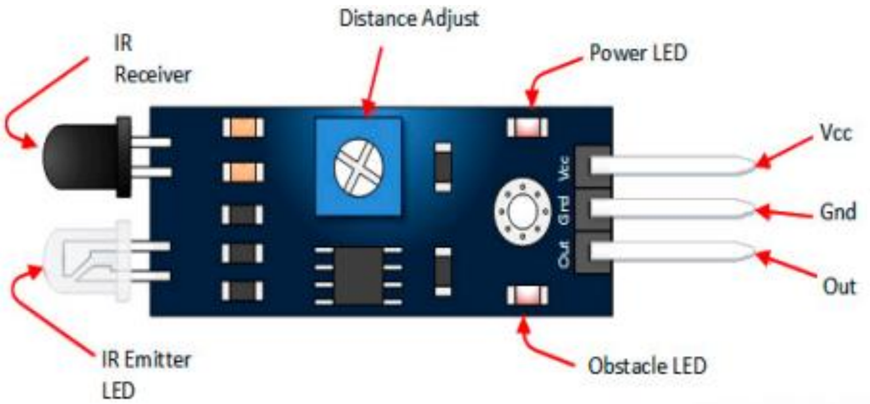

Figure 2. Infrared Sensor (A 215/450)

3.4 Water Level Detector

The water sensor brick is designed for versatile water detection applications, such as rainfall monitoring, leak detection, and water level monitoring. It has three major components: a 1 MΩ resistor, an electronic brick connector and several rows of exposed wires. This sensor functions using exposed conductive tracks connected to the ground. When water comes into contact with these tracks, the 1 MΩ resistor pulls the sensor's value high until the water drops, completing the circuit. The sensor was used with the Arduino analogue pins to measure water-induced connections between the sensor tracks and the ground. This design enables the sensor to evaluate water levels by measuring the presence or size of water through interconnected strings. It effectively converts the amount of water detected into an analogue signal, which is integrated into a system to enable easier detection of water level along the path of the visually impaired [25].

3.5 Operational Amplifier (LM358)

The LM358 is an operational amplifier (Op-Amp) utilised as a voltage comparator in infrared (IR) sensor applications. In this configuration, the comparator compares the voltage at pin 2, which serves as the threshold, with the voltage drop across the photodiode's series resistor connected to pin 3. If the voltage drop across the photodiode's resistor exceeds the threshold voltage, the Op-Amp outputs a high signal. Conversely, if the voltage drop is below the threshold, the output will be low. When the Op-Amp output is high, the LED connected to the output terminal illuminates, indicating that an object has been detected [26].

3.6 Voltage Regulator (LM7808)

The LM7808 is a three-terminal positive voltage regulator housed in a TO-220 package. It provides a stable output voltage, making it suitable for a variety of applications. Each unit features built-in current limiting, thermal shutdown, and protection mechanisms, ensuring reliable operation. Under appropriate thermal conditions, it can deliver over 1A of output current. While designed primarily for fixed-voltage regulation, it can be configured with external components to support adjustable voltages and currents, as illustrated in Figure 3 [27]. One of its key benefits is its ability to maintain a constant output voltage despite input fluctuations; however, the input voltage must always be at least 2 to 3 volts higher than the desired output voltage. For a stable 8V output, the input should be maintained at a minimum of 10V. The LM7808 operates on a DC input, and to achieve 1.5A at the output, the input current should be at least 2A.

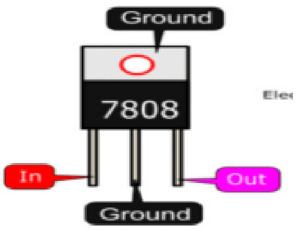

Figure 3. Voltage Regulator Diagram

3.7 Photodiode Receiver

The photodiode functions as an infrared (IR) receiver, activating when light strikes its surface. It is a semiconductor device with a P-N junction that operates in reverse bias; this means it conducts current in the reverse direction when exposed to light, with the current intensity proportional to the light level. This characteristic makes it particularly effective for IR detection. The photodiode resembles an LED, featuring a black outer casing that maximises light absorption [28].

3.8 Buzzer

The buzzer is a compact yet powerful component for integrating audio feedback into systems. It features two pins, facilitating easy integration onto breadboards, perf boards, and PCBs, which makes it a popular choice in many electronic projects. There are two common types of buzzers: a simple buzzer that produces a continuous beep when activated, and a more complex buzzer with an internal oscillating circuit that emits a "Beep. Beep. Beep." sound. The simpler buzzer is widely preferred and adopted in this design owing to its flexibility for customization within projects. It operates on a DC power supply ranging from 4V to 9V, with 5V or 6V recommended for optimal performance. A standard 9V battery can also be used. Typically, the buzzer is controlled by a switch to turn it on or off as needed. The circuit of the developed system is shown in Figure 4 [29]. As illustrated in Figure 4, initially simulated in Proteus prior to physical implementation. The final implementation. Then the final implementation. Then the customised circuit was transferred to a Vero board, and a custom casing was designed for final packaging.

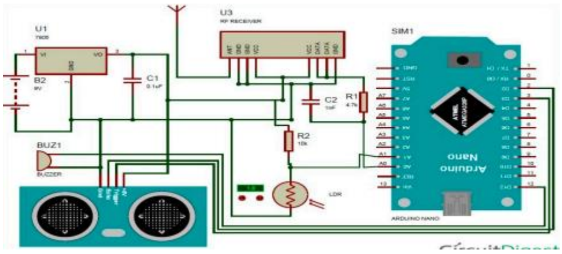

Figure 4. Project Circuit Diagram

3.9 Packaging

A portable wooden casing covered with leather was used in packaging the implemented circuit. The reason for a wooden casing was its poor conductivity of heat and electricity, and its ability to retain the heat generated by the bulls. The dimensions of 31.5cm and 26.5 cm were adopted for the length, while 14cm for the height after an optimal evaluation of the width and length of the Vero board, and the battery location as shown in Figure 5 [30].

Figure 5. Circuit Design Packaging

Figure 5 demonstrates that the battery compartment, located at the bottom of the case, is smaller than the Vero board section. The battery was securely fastened to the base, followed by the installation of the power section of the circuit board. Adequate spacing was maintained between each mounted component to prevent overcrowding. The Vero board was positioned on the upper side of the case, with resistors, transistors, and other components mounted accordingly. All accessories were firmly secured to prevent movement during operation. The mounting arrangement is depicted in Figure 6. Figure 6 clearly shows how the basic components were arranged in the constructed package box [30].

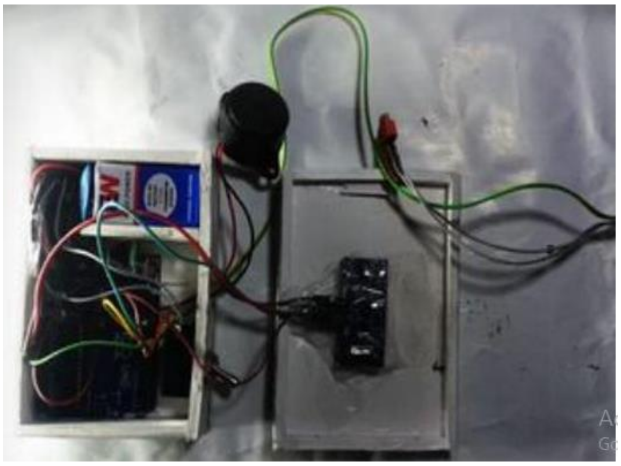

Figure 6. Developed System Packaging

4 RESULTS AND DISCUSSION

The well-packaged circuit was attached to a well-carved stick to make it smart for the visually impaired, as shown in Figure 7.

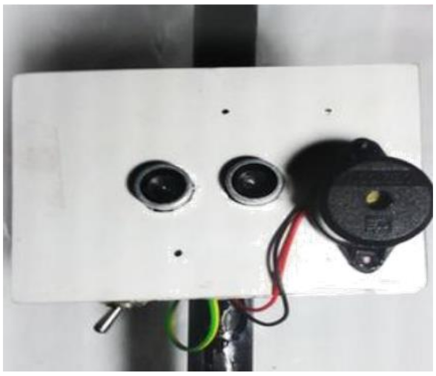

Figure 7. Implemented system

For effective evaluation of the implemented system, the designed smart stick was tested under different scenarios, recording the output as a function of proximity to various obstacles. Also, the critical scenario where the blind or visually impaired seek nearby help was tested. This was done by switching the emergency help button attached to the hand of the smart stick to the "ON" position, as shown in Figure 8 [30]. System implementation demonstrated that the buzzer emitted an audible, echoing "help help help" signal, effectively attracting the attention of nearby individuals. The smart stick utilizes sensory inputs to detect obstacles up to 400 cm away. Both ultrasonic and water sensors collect real-time data, which is transmitted to a compact controller. Upon receiving this data, the microcontroller activates the buzzer. The water sensor identifies water beneath the device, and the system operates on battery power. The design exhibits high resistance to ambient light and object color, with a rapid response time of approximately 39 ms. Overall, the proposed solution offers significant assistance to visually impaired individuals by effectively detecting obstacles through integrated components [30].

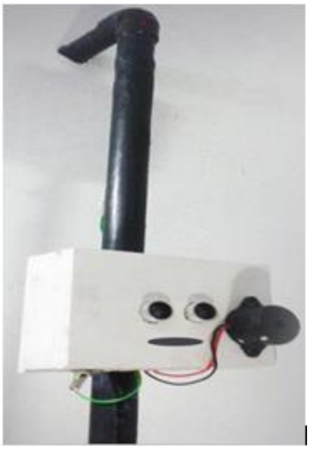

Figure 8. Smart Stick

5 CONCLUSIONS

This study presents the design of an intelligent walking stick intended to serve as a mobility aid for visually impaired individuals. The development was motivated by the challenges faced by this population in performing daily activities. The smart stick incorporates low-cost, low-power components, making it a practical assistive device for future applications. Distinct output signals from the buzzer enhance usability and provide alerts in critical situations requiring immediate assistance. While the system has achieved its primary objectives, future work will focus on integrating obstacle recognition and descriptive feedback via the buzzer, enabling users to better understand the nature of encountered obstacles.

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