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PathBuddy: An IoT-based Smart Cane for Visually Impaired People

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ABSTRACT: Visually impaired individuals face challenges globally, and researchers have developed solutions. However, these solutions struggle with detecting obstacles at certain heights, differentiating moving from stationary objects, and recognizing traffic signals. In this regard, this paper aims to propose "PathBuddy," an IoT-based smart cane for visually impaired individuals. PathBuddy addresses limitations of existing solutions by incorporating features such as the ability to differentiate between moving and stationary objects, an extended range for detecting obstacles at varying distances and heights, and a customized GPS navigation system for reliable guidance. Additionally, PathBuddy includes a camera to detect traffic signals using Machine Learning, enhancing safety during street navigation.

KEYWORDS: PathBuddy, Obstacle detection, Visually impaired person, Moving and static object, Traffic signal detection, Machine learning, Enhanced vertical obstacle detection, Emergency alert

I. INTRODUCTION

Visually impaired individuals encounter several difficulties in their daily lives. Navigating crowded areas or crossing streets can be difficult for them. Recognizing traffic signals, identifying obstacles can be really tough, making these people feel frustrated and dependent. These challenges make it hard for them to do things on their own and be part of social activities. However, some researchers and developers are working to help visually impaired individuals. They have created solutions like smart shoes, smart glasses, and smart cane technologies to assist them.

Traditional canes help visually impaired people navigate and feel independent. They are also easy to use and widely available. However, traditional canes are not equipped with sensors, so they are unable to detect obstacles above waist level, which can lead to difficulties for visually impaired. Smart shoes with sensors help visually impaired people walk safely by detecting changes in the ground and obstacles. Yet, they are expensive and do not perform well in bad weather conditions. They also have limitations in detecting vertical objects. Smart canes for the visually impaired provide advanced features like sensors and GPS (Global Positioning System) for real-time feedback. But, they lack the ability to detect objects above ground level, such as low-hanging branches or sign boards, which could be dangerous for the user. Additionally, they cannot identify muddy surfaces, distinguish between static and moving objects, and are unable to recognize traffic signals.

In spite of having so many technological options there are still some limitations and challenges available in the existing systems. To overcome these issues, we propose a novel and effective solution, PathBuddy, which introduces features, such as, the ability to differentiate between moving and stationary objects, extended range for detecting obstacles at varying distances and heights, ensuring user safety. PathBuddy incorporates customized GPS navigation system, acting as a guide for reliable navigation. Users will be able to input their destination, and the device will guide through the path, making their journey more comfortable. We are installing a camera to detect traffic signals using Machine Learning, making it safer to navigate streets. If the signal is red, the mobile device will sound a notification indicating "Stop, there is a red signal" and when it is green, it will sound a notification indicating "Go, the signal is green". This will ensure users can navigate safely through various conditions.

The subsequent sections of the paper are structured in the following manner: Section 2 shows the related work followed by the proposed system and its architecture in Section 3. Section 4 formally defines the result analysis of our research work. Finally, Section 5 concludes the manuscript.

II. RELATED WORK

Smart navigation system is really important for the visually impaired people for navigation purpose. That is the reason why many researchers have explored this topic as their interest of research. The key findings from [1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12] are discussed in the Table I below:

TABLE I. LITERATURE SURVEY

Citation	Key Findings
[1]	This paper aims to developed an electronic assistive cane for visually impaired individuals by providing real-time contextual information about their surroundings. Utilizing RFID technology embedded within street signs, storefronts, and similar locations, the cane seamlessly retrieves pertinent data and relays it to the user. Additionally, equipped with an ultrasound sensor, it proactively detects obstacles in the user's path. The Smart Cane, featuring an integrated ultrasonic sensor. An audible alert system, positioned on the bag strap, notifies the user of detected obstacles and offers directional guidance for navigation.
[2]	Creating a smart cane with laser sensors to spot obstacles and detect changes in terrain, like downward slopes. When an obstacle is detected, it signals with a high-pitched sound using a microphone. The design of the laser cane is straightforward and easy to understand. However, it only alerts users to obstacles There was only the sound to let them know about obstacles, but no guidance or assistance provided.

[3]	The paper introduces an outdoor navigation solution, that incorporating GPS, voice recognition, and ultrasonic sensor technology. This innovative system offers users real-time updates on their current location and delivers spoken directions for reaching a specified destination. However, it lacks functionality in detecting obstacles and issuing corresponding warning alerts.
[4]	The paper aims to developed a navigation system specifically tailored for visually impaired individuals. It utilizes an RGB-D sensor with extended range capabilities. This system employs an affordable RGB-D camera to provide both depth and visual data, facilitating floor segmentation based on distance. Additionally, a lower-cost RGB sensor aids in detecting objects and recognizing colors. The user interface is designed to be accessible through audio instructions and sound-based maps.
[5]	Creating a navigation system that's controlled by both vibration and voice commands, employing ultrasonic sensors to spot obstacles. Because individuals with visual impairments often have heightened hearing and perception, this system delivers alerts through vibrations and voice cues. It's designed to function seamlessly indoors and outdoors, constantly scanning the surroundings for obstacles and providing feedback through vibration and voice prompts. The intensity of the vibration varies depending on how close an obstacle is to the user, enhancing their awareness.

[6]	Introducing a unique location assistance system designed for navigating both indoors and outdoors. This system is centered around a smart walking stick equipped with various technologies including a GSM module for emergency messaging, sonar sensors, and RF transmitter and receiver components. For indoor localization, RFID technology is employed, while outdoor positioning relies on GPS. By incorporating GPS into the walking stick, the need for extensive RFID tag installations outdoors is circumvented, reducing both complexity and cost.
[7]	This paper introduces a navigation aid system, combining hardware and a mobile app. Using ultrasonic sensors and vibrators, it detects obstacles and guides users accordingly. Bluetooth and GPS enable precise location tracking, with SMS alerts for emergencies. Additionally, a color sensor detects red colors, ensuring users stay within safe parameters.
[8]	Creating a navigation system, using a camera, AI, controller, and voice alerts. Its main goal is to detect obstacles and notify users through voice alerts. AI improves obstacle recognition, and a voice assistant aids users in private spaces. With indoor and outdoor image capture, the system enhances safety for visually impaired individuals.
[9]	This paper highlights a prototype model and system, comprising a Raspberry Pi, ultrasonic sensor, GPS module, and USB microphone, aims to provide comprehensive object detection, human detection, and real-time assistance. Mounted onto a shoe, this Electronic Travelling Aid kit assists blind individuals in navigating obstacle-free paths. When objects or individuals are detected near the shoe, the system alerts the user through voice commands, and for added functionality through headphones with voice recorder and replay capabilities.

[10]	This paper aims to develop a highly efficient and accurate system for wearable devices, specializing in real-time three-dimensional object detection within a set distance. It utilizes a text-to-voice Google API to relay obstacle notifications via voice messages. The goal is to seamlessly integrate precise object detection with voice notifications into everyday wearables.
[11]	This paper introduces a system where an ultrasonic sensor is employed to measure the distance of obstacles from the user. This distance measurement serves as a reference point to determine whether the user can proceed safely or not. Ultrasonic sensors operate by emitting sound waves, which travel forward from the sensors towards potential obstacles. These sensors are capable of detecting distances up to 12 feet with resolution of 0.3cm.
[12]	This paper describes a system that uses a Raspberry Pi to gather information. It has a buzzer to warn of obstacles before a camera identifies objects. A speaker tells the user what's detected. It also includes a GPS module updates the user's location, while fire and water sensors detect nearby hazards and resources. A light sensor assists users in discerning day from night.

We discussed the previous studies on navigation system of visually impaired people. However, these papers didn't cover some important aspects as discussed in Section I. On contrary, in this paper, we introduce new features such as horizontal and vertical object detection, muddy area detection, traffic signal detection, GPS and emergency alert feature. In the next section, we will discuss our proposed system.

III. PROPOSED SYSTEM

A. System Block Diagram

We have used IoT to design PathBuddy. By connecting different electronic components and creating a circuit, we have brought it into a working condition and attempted to create a prototype. The components required for this and their interconnections are shown in Fig 1.

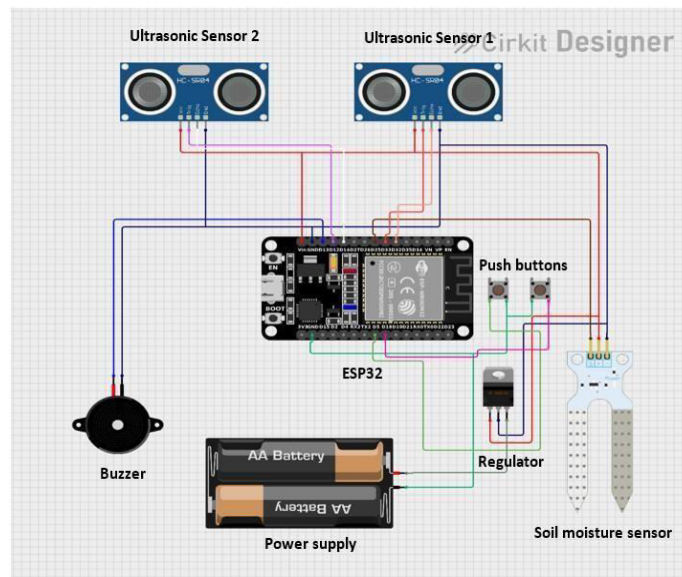


Fig. 1 Block Diagram of Proposed System

Fig.1 shows the interconnections between various components that work together seamlessly to enable real-time navigation and obstacle detection. The main component of our diagram is ESP32 microcontroller, which acts as the central processing unit. We have added two HC-SR04 ultrasonic sensors, one at the bottom and one at the top of the cane for obstacle detection, covering both ground-level and higher level obstacles. There is also a soil moisture sensor which will detect wet or muddy surfaces to prevent slips or falls. Moreover, our cane includes a push button. If pressed, it sends an emergency alert to the user's chosen contacts for help. There is also a switch button that makes it easy to turn the device on or off. A buzzer provides auditory alerts to inform users of their surroundings. A LM7805 regulator ensures stable power supply to all components, optimizing performance and reliability. The diagram shows how the smart cane detects obstacles and gives instant feedback to users. By using the ESP32 microcontroller and sensors, it quickly identifies objects and wet areas, improving navigation for visually impaired people.

Block diagram provides a visual representation of our system's structure and components. Each component plays a crucial role in fulfilling our system.

1. *ESP32*: The ESP32 microcontroller is used due to its powerful processing capabilities, built-in Wi-Fi and Bluetooth connectivity, low power consumption, compact size and affordability.
2. *HC-SR04 Ultrasonic Sensors*: We used ultrasonic sensors to help the smart cane detect obstacles. By placing sensors both at the bottom and the top of the cane, we cover different heights, ensuring it spots obstacles well. Ultrasonic sensors are great because they are accurate and not too expensive.
3. *Soil Moisture Sensor*: We added a soil moisture sensor to our smart cane to help users understand ground conditions better. This sensor detects how wet or dry the ground is, which is useful for avoiding slippery or muddy areas.
4. *Power Source*: We included a power source, through two rechargeable AA type batteries, to ensure all the electronic parts of the smart cane have stable power. This ensures that the device operates smoothly and consistently.
5. *Buzzer*: We added a buzzer to give users important alerts through sound. It alerts users to stay aware of obstacles while using the smart cane.
6. *Push Buttons*: After pressing the push button, the smart cane will quickly send an SOS message to the contacts you have chosen for help in emergencies, ensuring user's safety.

A. Modular View of System

- Horizontal Object Detection:** Horizontal Object Detection, addresses the common challenge faced by visually impaired individuals while walking. Navigating obstacles on the ground that can lead to trips and falls. This module employs an ultrasonic sensor strategically positioned to measure the distance of obstacles near ground level. When the sensor detects an object within a range of less than 100 cm, it triggers the activation of a buzzer. As the obstacle approaches closer to the sensor, the buzzer emits a louder sound, serving as an intuitive warning system for the user. This functionality equips individuals with visual impairments with the capability to detect ground-level obstacles in real-time, enabling them to navigate safely and avoid potential accidents.
- Vertical Object Detection:** Vertical Object Detection, addresses the challenge faced by visually impaired individuals who may not notice obstacles above the ground, such as low-hanging branches or sign boards, which can pose risks. This module incorporates an ultrasonic sensor positioned at the top of the smart cane, facing upwards to detect overhead obstacles. When the sensor detects an object within a range of less than 100 cm above, it activates a buzzer. The buzzer continues to sound until the object is no longer detected. This feature significantly enhances safety by alerting the user to obstacles above ground level, enabling them to navigate with greater awareness and avoid potential hazards.
- Muddy or Water Surface Detection:** Muddy or Water Surface Detection, helps visually impaired individuals avoid accidentally stepping into wet or muddy areas, which can lead to slips and falls. This module includes a soil moisture sensor positioned on the smart cane, close to the ground where it can touch the soil. As the cane moves, the sensor continuously checks the ground for moisture. If it detects wet or muddy conditions, it sends a signal to the cane's system. In response, the cane emits a sound at regular 1-second intervals to alert the user. This simple yet effective feature provides early detection of potentially hazardous surfaces, enabling visually impaired individuals to navigate safely and reducing the risk of accidents.

B. System Architecture

Our proposed system, PathBuddy introduces features often overlooked by current navigation solutions. We are focusing on integrating advanced capabilities such as traffic signal detection using cameras, GPS navigation, and emergency alerts. With PathBuddy, our aim is to enhance user safety and navigation accuracy. By detecting traffic signals and providing real-time alerts, users can confidently and safely navigate their surroundings. To achieve this, we have designed the architecture of our system.

Fig. 2, illustrates the structure of the software modules of the Pathbuddy, which comprises multiple models integrated with a comprehensive database system. In the subsequent sections, we will provide a detailed breakdown of its various components.

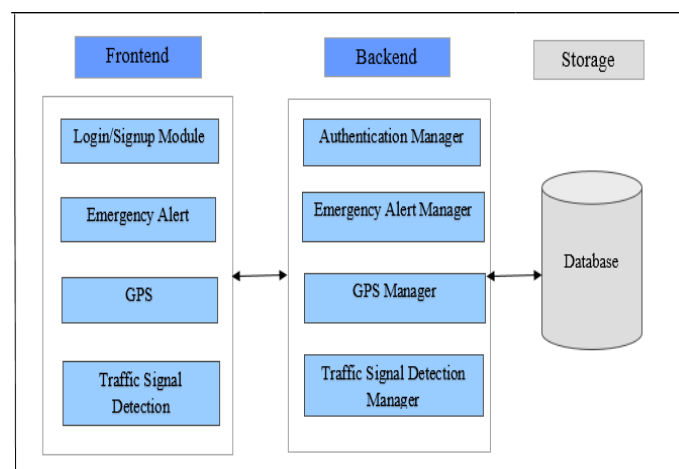


Fig. 2 Architecture of Proposed System

1. *Login/Signup Module and Authentication Manager*: The authentication manager handles user authentication and credential management in the backend, using Firebase. Frontend module for login or signup allow users to interact with the system. Users input their credentials in the login module, which are verified by the backend. The signup module collects user details, sends them to the backend for processing, and registers the user. This facilitates the registration process for parents to set up the application on behalf of the visually impaired user.
2. *Emergency Alert and Emergency Alert Manager*: The emergency alert manager in the application for visually impaired individuals ensures quick assistance when they encounter difficulty. Through the frontend interface, users activate the alert by pressing a button on their stick, confirming their distress signal. This action triggers real-time updates on the frontend. On the backend, the emergency alert manager promptly sends pre-set urgent messages to chosen contacts, such as parents, containing important details. This collaborative approach ensures swift assistance while providing vital information to emergency contacts, thereby enhancing user safety.
3. *GPS and GPS Manager*: The GPS feature in the application for visually impaired users seamlessly integrates frontend and backend components to facilitate navigation through voice guidance. On the frontend, users verbally request their location, initiating a query to the GPS manager backend. The GPS manager retrieves the user's current location from the GPS system and processes it to generate clear and precise directions. These instructions are then relayed back to the frontend interface through voice guidance, enabling users to navigate effectively.
4. *Traffic Signal Detection and Traffic Signal Detection Manager*: The frontend traffic signal detection feature in the application for visually impaired users seamlessly interfaces with the backend manager to aid in recognizing traffic signals. Utilizing the device's camera, the frontend component continuously scans the surroundings in real-time. When a traffic signal is detected, the backend traffic signal detection manager is activated, leveraging machine learning algorithms to accurately identify the signal's color. Once identified, the backend manager generate auditory cues.
5. Indicating the backend manager generates auditory cues indicating the signal status, such as red, green. This integrated approach between the frontend and backend ensures that visually impaired users receive timely and accurate information about traffic signals.

IV. RESULT ANALYSIS

A. Simulation Environment

Hardware Components:

- ESP32 microcontroller
- HC-SR04 Ultrasonic sensor
- Soil moisture sensor
- Buzzer
- Push button
- Switch button
- Vibration motor AA type battery

Software Components:

- Arduino IDE: Used for coding the ESP32 microcontroller in C++.
- Flutter: Used to create the user interface of the Android application.
- Visual Studio Code: VSCode Primary coding environment used for developing PathBuddy's Android application.
- Google Collab: We have used Google Colab, a cloud-based platform for Python, to train the YOLO model for traffic signal detection, which provides temporary access to a 12 GB GPU for training.

B. Simulation Result

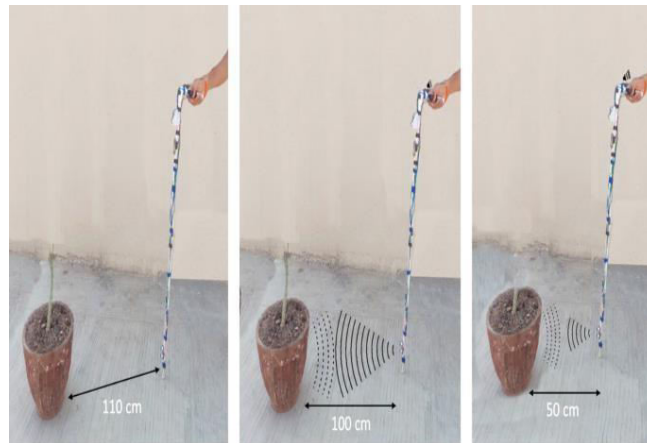


Fig. 3 Horizontal Object Detection

In Fig. 3, a visually impaired individual is walking with the assistance of a smart cane. As they move closer to an obstacle in their path, located approximately 100cm away, vibrations activate to alert them. As the person gets closer to the obstacle, around 75cm away, the intensity of the vibrations increases. This helps the visually impaired know about the obstacle, ensuring they can navigate safely.



Fig. 4 Vertical Object Detection

In Fig. 4, a visually impaired individual is walking with the assistance of a smart cane. There is an open window in front of them, positioned 150cm above the ground. As the person gets closer to the open window, reaching a distance of 100cm, vibrations activate to alert them. Even when the person gets closer, reaching a distance of 75cm, the vibrations keep going to ensure continuous alertness until the window is no longer detected. This helps the visually impaired know about the obstacles at higher levels.



Fig. 5 Emergency alert

Fig. 5, shows the emergency alert feature. When the user encounters trouble, they press the button on the stick, activating the integrated application. This application then automatically dials the pre-set emergency contact number, enabling communication for the visually impaired individual.

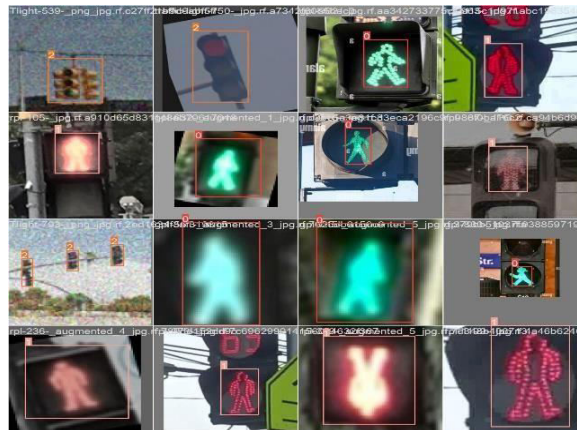


Fig. 6 Traffic Light Detection

Fig. 6, represents the traffic light detection. It captures both the green and red phases of the traffic signal.

V. CONCLUSION AND FUTURE SCOPE

In conclusion, our paper, addresses the ongoing challenges faced by visually impaired individuals in navigating their surroundings. Even with the wide range of technological options available, existing systems frequently fail to deliver complete solutions. Recognizing these limitations, we have developed PathBuddy, a smart cane equipped with different features to improve user safety and independence. By differentiating between moving and stationary objects and offering an extended range for obstacle detection, PathBuddy ensures users can navigate with confidence, even in dynamic environments. Moreover, PathBuddy is equipped with a customized GPS navigation system, serving as a reliable guide for navigation. Users will be able to input their destination, and the device will guide through the path, making their journey more comfortable. Additionally, our implementation of machine learning-based traffic signal detection further improves safety by alerting users to traffic signals in real-time. In the future, we're committed to making PathBuddy even better, so it's easier for visually impaired individuals to use. Our goal is to help them feel more

confident and independent when navigating their surroundings, making their lives happier.

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