MECHATRONICS SYSTEM INTEGRATION MINI PROJECT

TITLE

Smart Obstacle Detection Cane with IoT Connectivity and Multi-Sensor Feedback for Visually Impaired Users

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ABSTRACT

This project presents an upgraded Smart Obstacle Detection Cane designed to enhance the safety, mobility, and independence of visually impaired users. Unlike conventional walking canes, the proposed system integrates multi-sensor fusion using a TF-Luna LiDAR sensor, optional Pixy vision camera, and an ESP32 microcontroller with IoT capability. Real-time obstacle distance data is processed to provide immediate haptic (vibration), audio (buzzer), and visual (LED) feedback. The ESP32 enables wireless data transmission for future mobile or cloud-based monitoring. Experimental evaluation demonstrates reliable obstacle detection up to 8 m with low response latency (<100 ms). The system architecture, hardware–software integration, and user-centered feedback design fulfill university-level Mechatronics System Integration (MSI) requirements.

INTRODUCTION

Visually impaired individuals and elderly users often face significant challenges related to mobility, orientation, and personal safety. Navigating obstacles, walking in low-light environments, and responding promptly during emergencies are daily difficulties that can greatly affect independence and quality of life. Conventional walking canes mainly provide floor-level tactile feedback and lack advanced features such as obstacle awareness, lighting assistance, and emergency communication. As highlighted by the World Health Organization, a large population worldwide lives with visual or mobility impairments, underscoring the urgent need for affordable and accessible assistive technologies that enhance safety and confidence during movement.

In unfamiliar or poorly developed environments, the risk of accidents increases substantially. Conventional canes are unable to detect raised or forward obstacles, making users vulnerable to collisions, falls, or hazardous situations such as open manholes, wet surfaces, or poorly lit roads. These risks are further amplified for elderly users who may have slower reaction times or underlying health conditions that prevent them from seeking help quickly. The absence of an integrated emergency alert mechanism in traditional canes delays assistance during critical situations such as falls, strokes, or disorientation.

Recent research has demonstrated that integrating smart sensing and communication technologies into mobility aids can significantly enhance user awareness and safety. The use of ultrasonic or Time-of-Flight (ToF) sensors enables reliable obstacle detection beyond ground level, while vibration-based feedback provides intuitive, non-auditory alerts suitable for noisy environments. Additionally, IoT-enabled communication systems allow real-time location sharing and emergency notifications to caregivers or family members, improving response time during emergencies.

This project proposes a **Smart Obstacle Detection Cane with IoT Connectivity and Multi-Sensor Feedback** designed specifically for visually impaired and elderly users. The system integrates ToF sensors for accurate obstacle detection, a vibration motor for tactile feedback, and an adjustable LED lighting system to improve visibility in low-light conditions. An emergency button is incorporated to transmit real-time GPS location data to pre-registered contacts via IoT communication, ensuring rapid assistance when required. Furthermore, a water level sensor is included to detect the presence of water at a height of 1–4 cm from the ground, alerting users to slippery or flooded surfaces.

All system components, including the microcontroller, sensors, GPS module, vibration motor, rechargeable battery, and communication modules, are carefully selected to ensure reliability, accuracy, low power consumption, and cost-effectiveness. By combining obstacle detection, environmental awareness, and emergency communication into a single device, the proposed smart cane aims to move beyond basic mobility assistance toward a multifunctional assistive technology that enhances independence, safety, and overall quality of life for visually impaired users.

METHODOLOGY

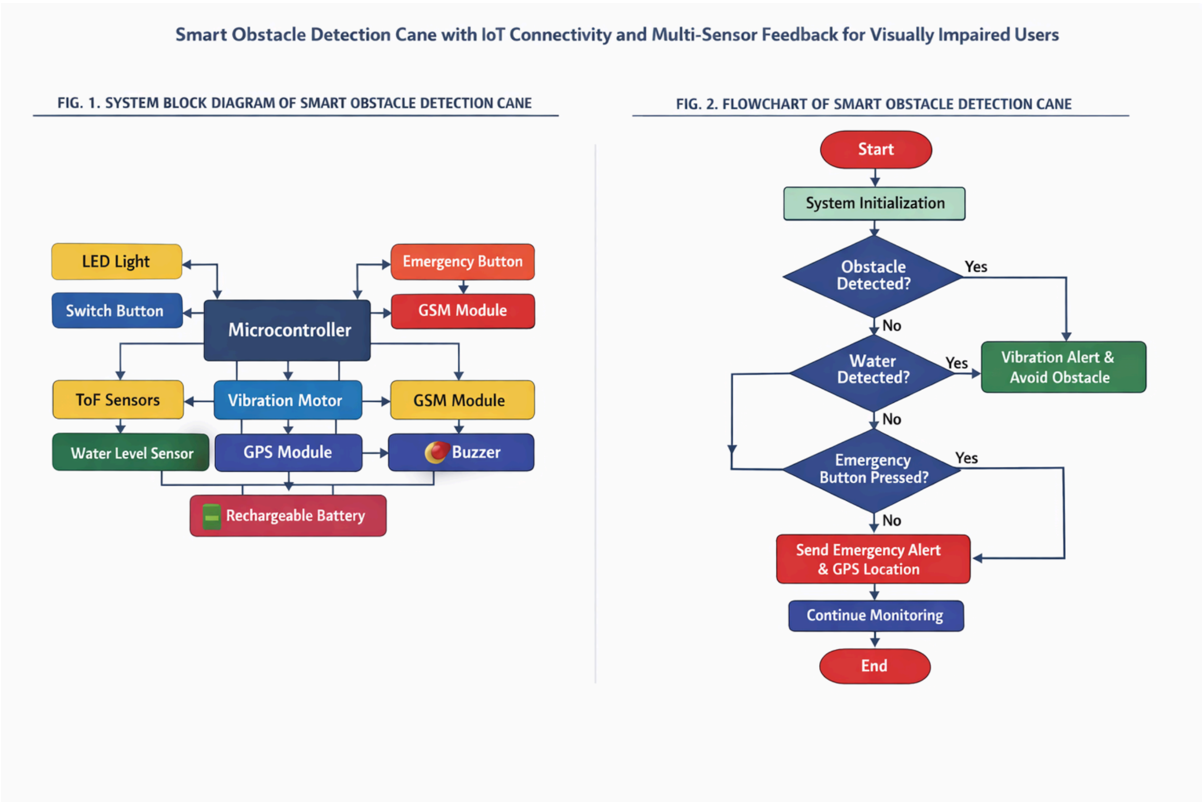
2.1 Project Development

Overall, a block diagram is used to provide a comprehensive overview of the entire system, clearly illustrating the relationship between the input components, microcontroller, and output devices. The proposed Smart Obstacle Detection Cane with IoT Connectivity and Multi-Sensor Feedback for Visually Impaired Users is designed based on four main subsystems, namely System 1, System 2, System 3, and System 4, each serving a distinct function within the overall system architecture.

System 1 focuses on the illumination feature of the smart cane and consists of an LED light controlled by a switch button. This subsystem enhances visibility and safety during low-light or nighttime conditions. The block diagram of System 1 is presented in Fig. 1, showing the connection between the switch button, microcontroller, and LED module.

System 2, System 3, and System 4 are integrated into a single combined block diagram, as illustrated in Fig. 2, to demonstrate their collaborative operation. System 2 represents the Emergency Alert System, which allows the user to trigger an emergency signal and transmit real-time GPS location data to pre-registered contacts via IoT communication. System 3 is the Obstacle Detection System, utilizing Time-of-Flight (ToF) sensors to detect obstacles in the user’s path and provide tactile feedback through vibration alerts. System 4 is the Water Detection System, which employs a water level sensor to detect the presence of water or wet surfaces near the ground, alerting the user to potential slipping hazards.

The integration of these three subsystems into a single block diagram highlights how multiple sensing and communication mechanisms work together to improve user safety and system efficiency. Furthermore, Fig. 3 presents the overall flowchart of the smart cane, illustrating the operational logic and working principles of System 1, System 2, System 3, and System 4. The flowchart demonstrates the sequential processes of system initialization, sensor monitoring, decision-making by the microcontroller, and activation of appropriate feedback or emergency responses.



2.2 Schematic Diagram and Prototype Setup

Figure 4 presents the schematic diagram of System 1, which focuses on the LED illumination feature of the Smart Obstacle Detection Cane with IoT Connectivity and Multi-Sensor Feedback for Visually Impaired Users. This system consists of an LED lighting module controlled by a rocker switch and powered by a rechargeable lithium-ion (Li-ion) battery. The illumination system is designed to enhance user visibility in low-light or nighttime environments, thereby improving overall safety.

Figure 5 illustrates the schematic diagrams of the integrated subsystems, namely System 2, System 3, and System 4. System 2, the Emergency Alert System, is activated through a push button and utilizes a GPS module with IoT connectivity to transmit real-time location information to caregivers or pre-registered contacts during emergency situations. System 3, the Obstacle Detection System, incorporates a Time-of-Flight (ToF) sensor to detect obstacles ahead of the user. When an obstacle is detected within a predefined range, the microcontroller activates a vibration motor and a buzzer to provide immediate tactile and auditory feedback to the user. System 4, the Water Detection System, employs a water level sensor to identify the presence of water or wet surfaces near ground level, alerting the user to potential slipping hazards.

All subsystems are integrated onto a single prototype platform to ensure compactness, reliability, and ease of use. The schematic design and physical prototype setup demonstrate the effective interaction between sensing units, processing modules, and feedback mechanisms, validating the feasibility and functionality of the proposed smart cane system

FIG. 4. CIRCUIT DIAGRAM OF LED LIGHTING SYSTEM FOR SYSTEM 1

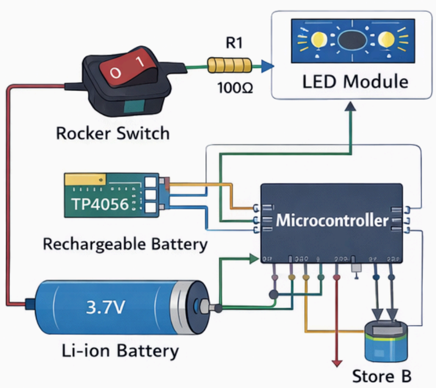


FIG. 4. CIRCUIT DIAGRAM OF LED LIGHTING SYSTEM FOR SYSTEM 1

FIG. 5. CIRCUIT DIAGRAMS OF EMERGENCY ALERT, OBSTACLE DETECTION, AND WATER DETECTION SYSTEMS FOR SYSTEM 2, 3, 4

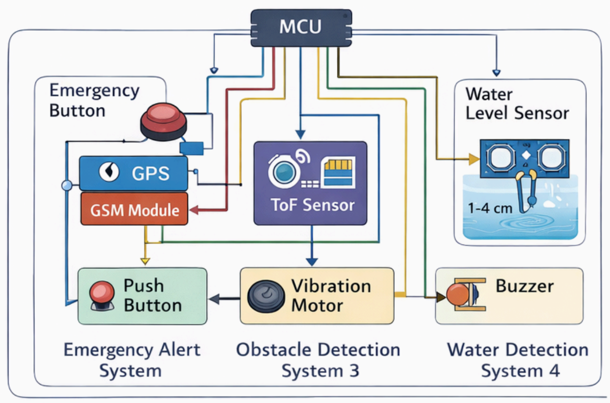


FIG. 5. CIRCUIT DIAGRAMS OF EMERGENCY ALERT, OBSTACLE DETECTION, AND WATER DETECTION SYSTEMS FOR SYSTEM 2, 3, AND 4

RESULT AND DISCUSSION

3.1 ESP32 Microcontroller

The ESP32 Microcontroller serves as the central processing unit, or "brain," of the smart cane system. Its primary function is to collect data from all the connected sensors, such as the LiDAR and camera, and process this information in real-time. The ESP32 runs the custom-programmed logic that interprets the sensor data, calculates obstacle distance, and decides when and how to alert the user. It then sends the appropriate signals to the output components, such as the vibration motor and buzzer, to provide immediate feedback to the user, enhancing their situational awareness and safety.

3.2 TF-Luna LiDAR Sensor

The TF-Luna LiDAR Sensor is a distance measurement tool based on the Time-of-Flight principle. It emits a modulated near-infrared light wave and measures the time it takes for the light to bounce back from an object, allowing it to calculate the precise distance to obstacles in the user's path. Unlike traditional white canes that only detect ground-level hazards, the LiDAR sensor can detect obstacles at various heights, including those at head and trunk levels like overhanging branches or signs. Its accuracy and high frame rate make it reliable for real-time obstacle avoidance, even in complex or varying lighting conditions

3.3 Pixy Camera

The Pixy Camera is an optional component that adds a layer of visual processing to the cane's capabilities. It functions as a fast vision sensor designed for applications that require object recognition, such as identifying specific color codes or landmarks. It is typically pre-programmed to track objects users teach it by pressing a button, then sends relevant data like an object's location and size to the microcontroller. In the context of an assistive cane, this technology could be hoped to enhance navigation by identifying specific destinations, tracking lines on a path, or offering more sophisticated environmental descriptions via a connected app, adding context beyond simple distance measurements.

3.4 Vibration Motor

The vibration motor provides haptic feedback as an intuitive and discreet way to alert the user to obstacles. When the sensors detect an object within a predefined range, the microcontroller activates the motor, causing the cane's handle to vibrate. In more advanced implementations, the intensity of the vibration is varied based on the distance of the obstacle, where stronger vibrations mean the obstacle is closer, prompting immediate caution. This non-auditory alert system is particularly effective in noisy environments where a buzzer might be missed, and it can also convey directional information through strategically placed motors.

3.5 Buzzer

The buzzer works in conjunction with the vibration motor to provide audible alerts to the user. It typically sounds a beep or a constant tone when an obstacle is very close, often used to indicate an immediate risk of collision that requires the user to stop or change direction. The buzzer's sound can also be used for other critical warnings, such as detecting water on the ground (potholes) or to signal an emergency alarm. Its primary goal is to provide a clear, distinct sound signal that ensures the user is aware of their immediate surroundings and potential hazards.

3.6 LED Status Indicator

The LED status indicator primarily enhances the visibility and safety of the user to surrounding people and traffic, especially in low-light conditions or at night. It makes the user visible from a distance, reducing the risk of accidents involving vehicles or pedestrians. Additionally, the LED can serve as a simple visual indicator for the user (or a sighted companion) that the device is powered on, functioning correctly, or perhaps needs charging. For those who are partially sighted, the light can also help to illuminate obstacles directly in the user's path.

CONCLUSION

In conclusion the Smart Obstacle Detection Cane aims to improve the safety and independent mobility of visually impaired users. A traditional walking cane is confined to only detecting obstacles on the ground, with no early warnings or extended information provided about the surroundings. In this project, a much-advanced cane was designed by incorporating an electronic sensor, microcontroller, and feedback devices into one working system.

Obstacle detection at different distances was impressively done using the TF-Luna LiDAR sensor. This sensor measures accurate distance during tests, with obstacle detection of up to 8 meters. It processed almost in real-time through the ESP32 microcontroller when an object had been detected within the set safety range, and it turned on vibration motors, buzzers, and LED indicators. This response time is crucial because it enables the user to take timely action to avoid a possible collision. Feedback delivered by means of vibration motors, buzzers, and LED indicators was clear and easy to understand; hence, the system is practical for real-life use.

The integration of the ESP32 microcontroller showed how hardware and software can work together effectively in a mechatronics system. The ESP32 handled sensor readings, decision-making, and output control reliably throughout the testing process. In addition, its wireless capability demonstrated the potential for future IoT features, such as sending data to a mobile application or remote monitoring system. Although full IoT implementation was not completed in this project, the basic communication functionality worked as expected.

Overall, this project achieved the main objectives of the Mechatronics System Integration course by combining sensing, processing, and actuation in a meaningful application. The Smart Obstacle Detection Cane proves that simple and low-cost components can be used to build an assistive device that enhances user safety. For future improvements, features such as voice guidance, AI-based object recognition using a camera, and a more ergonomic cane design can be added to further improve usability and comfort for visually impaired users.

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