EIRA: An Enhanced Intelligent Real-Time Assistive System for Visually Impaired

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ABSTRACT

Visual impairment limits independent mobility and environmental awareness in daily life. This paper presents EIRA (Enhanced Intelligent Real-Time Assistance), an integrated assistive system designed to support safe navigation and real-time situational understanding for visually impaired users. The proposed framework combines a wearable vision module based on the Raspberry Pi 4 Model B for object detection and Optical Character Recognition (OCR), along with a smart navigation module implemented using the ESP32 NodeMCU for obstacle detection and emergency alert functionality. Audio feedback enables intuitive user interaction without visual dependency. Experimental prototype evaluation demonstrates reliable performance in object identification, text reading, and obstacle warning in both indoor and outdoor environments. The system provides a portable and cost-effective multi-modal assistive solution aimed at improving user safety and independence.

Keywords: Assistive technology, Wearable navigation system, Object detection, Optical Character Recognition, Embedded AI, Obstacle detection.

INTRODUCTION

Visual impairment affects independent mobility and access to environmental information in daily life. Traditional assistive tools such as white canes provide limited obstacle awareness and lack intelligent perception capabilities. Recent advancements in embedded systems and artificial intelligence have enabled the development of wearable assistive technologies that support real-time navigation and situational understanding.

This paper presents EIRA (Enhanced Intelligent Real-Time Assistance), an integrated assistive system designed to improve safety and autonomy for visually impaired users. The proposed solution combines vision-based object detection using the Raspberry Pi 4 Model B with sensor-based obstacle detection and emergency alert functionalities implemented using the ESP32 NodeMCU. The system provides intuitive audio feedback to assist users in both indoor and outdoor environments.

I. RELATED WORK

A. Wearable Vision-Based Assistance Systems

Recent research has explored the use of wearable smart glasses equipped with artificial intelligence for improving environmental awareness among visually impaired individuals. Vision-based systems capable of real-time object and scene recognition have been developed to provide audio feedback for hands-free navigation. These solutions demonstrate good detection accuracy and low latency, making them suitable for daily mobility support. However, their performance may degrade under challenging conditions such as poor lighting environments..

B. Multi-Sensor Navigation Approaches

Several studies have proposed assistive navigation systems that integrate multiple sensing technologies such as depth cameras, ultrasonic sensors, LiDAR, and GPS modules. These systems enable accurate obstacle detection, terrain analysis, and safe indoor and outdoor navigation. Sensor fusion techniques allow the generation of reliable user alerts through auditory or haptic feedback, significantly improving walking efficiency and mobility confidence. Despite their effectiveness, the complexity and cost of multi-sensor integration remain key challenges.

C. Edge-AI Based Wearable Detection Systems

Energy-efficient on-device object detection frameworks have also been introduced to support continuous operation in wearable platforms. Lightweight deep learning models optimized for embedded processors enable real-time inference while maintaining low power consumption. These approaches reduce dependency on cloud connectivity and enhance portability. However, balancing model accuracy with computational efficiency continues to be an important research consideration.

D. Hybrid and Context-Aware Navigation Solutions

Hybrid navigation systems combining indoor localization techniques with outdoor GPS guidance have been investigated to provide seamless mobility support. Some approaches further incorporate physiological signal monitoring to assess user stress levels and dynamically adjust navigation strategies. Such context-aware assistive technologies highlight the importance of enhancing not only safety and efficiency but also user comfort during navigation.

II. PROPOSED SYSTEM

A. Vision Module

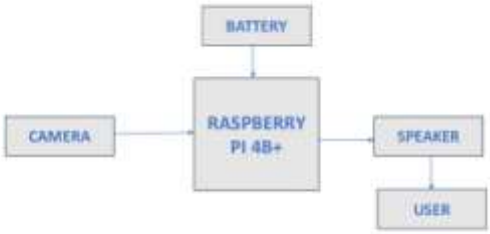

Fig. 1. **Block diagram of vision module**

The vision module is responsible for capturing real-time environmental information using a camera interface and processing it through the Raspberry Pi 4 Model B. Deep learning-based object detection and Optical Character Recognition (OCR) techniques are implemented to identify surrounding objects and read textual information. The processed output is converted into audio feedback and delivered to the user, enabling intuitive interaction without visual dependency.

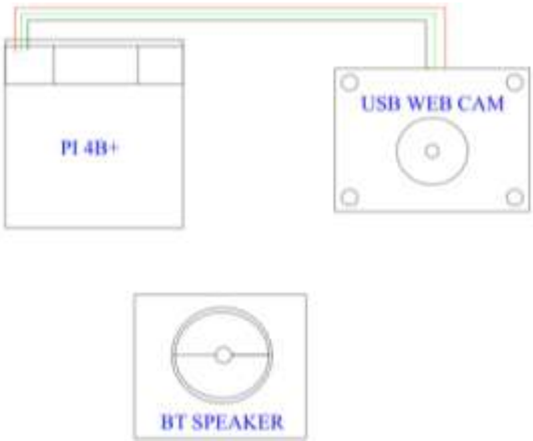

Fig. 2. **Hardware configuration diagram**

B. Smart Stick Navigation Module

Fig. 3. **Block diagram of stick module**

The smart stick module provides obstacle detection support using ultrasonic sensing technology controlled by the ESP32 NodeMCU. The system continuously measures the distance between the user and nearby obstacles and generates audio or buzzer alerts when objects are detected within a predefined threshold range. This module enhances user safety during indoor and outdoor navigation.

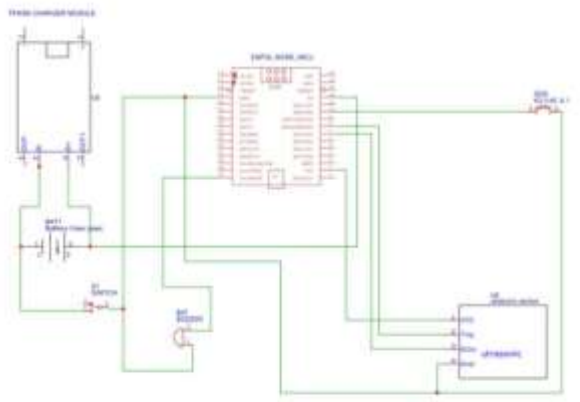

Fig. 4. **Circuit diagram of stick module**

C. Emergency Alert Function

An emergency alert mechanism is integrated within the smart stick module through a dedicated SOS push-button interface. When activated, the system triggers an alert notification to predefined contacts, enabling quick assistance during critical situations. This feature improves the reliability and safety performance of the overall assistive framework

D. System Components

The proposed assistive system utilizes multiple hardware components to achieve real-time sensing, processing, and user feedback functionalities. Table I summarizes the major components used and their respective roles in the system.

TABLE 1. HARDWARE COMPONENTS AND FUNCTIONS

Component	Function
Camera Module	Image Acquisition
Raspberry Pi 4 Model B	AI Processing
Ultrasonic Sensor	Obstacle Detection
ESP32NodeMCU	Control & Communication
Speaker & Buzzer	Audio Feedback
SOS Push Button	Emergency Alert

III. IMPLEMENTATION

The implementation of the proposed assistive system involved designing, assembling, and integrating functional modules to provide real-time navigation and text-reading support for visually impaired users. The development process was guided by preliminary user requirements to ensure usability, safety, and effectiveness.

A. Preliminary Survey

A preliminary survey was conducted with key stakeholders, including authorities from the Kerala Federation for the Blind, teachers from the Government School for the Visually Impaired, and nursing students from Coimbatore. The survey aimed to understand user needs, expectations, and preferences prior to prototype development.

Key insights from the survey include:

- Obstacle Detection & Safety: Experts recommended real-time detection and GSM-based emergency alerts.
- Ease of Use: Participants emphasized clear, simple voice-based guidance and user training.
- Compact Device Preference: 65% preferred a single wearable device combining navigation, text reading, and obstacle detection.
- Comfort & Well-being: 60% highlighted lightweight design, comfort, and support for user confidence.
- Adoption Willingness: 70% expressed willingness to adopt AI-powered assistive devices if affordable and user-friendly.

B. ***Hardware Implementation***

The hardware implementation of the proposed EIRA system was carried out by developing two functional modules, namely the wearable vision module and the smart navigation stick module. Each module was assembled and tested individually before integrating them for real-time assistive operation.

Fig. 5. **Prototype image of vision module**

The wearable vision module prototype was assembled by integrating a compact camera unit and audio output interface with the Raspberry Pi 4 Model B embedded processing platform. Proper mounting arrangements were adopted to securely position the components within a lightweight support structure to ensure ease of handling during real-time usage. A regulated power supply configuration was implemented to maintain stable system operation. The compact hardware design improves portability and enables practical usability for continuous navigation assistance. The integration of sensing and processing elements in a single wearable unit facilitates efficient real-time environmental perception**.**

The smart navigation stick prototype was fabricated by mounting the ultrasonic sensing unit at an appropriate forward-facing position to enable effective detection of nearby obstacles during walking. An alert buzzer was integrated into the structure to provide immediate auditory warnings when objects are detected within the predefined safety range. A dedicated SOS push-button interface was also incorporated into the stick to allow users to trigger emergency notifications during critical situations. The sensing and alert components were interfaced with the ESP32 NodeMCU microcontroller, which manages real-time distance monitoring and alert generation. The components were securely arranged on a rigid support structure to ensure durability, stability, and ease of practical use in indoor and outdoor navigation environments.

Fig. 6. **Prototype image of stick module**

C. Software Implementation

The software implementation of the proposed assistive system was carried out by developing separate processing routines for the vision module and the smart navigation stick module. The vision module software was developed using Python-based libraries for image acquisition, object detection, and Optical Character Recognition (OCR), enabling real-time analysis of the captured visual data. The processed information was converted into voice-based feedback using speech synthesis techniques to assist user interaction.

For the navigation stick module, embedded programming was performed on the ESP32 NodeMCU microcontroller to continuously monitor obstacle distance and generate alert signals when objects were detected within a predefined threshold. The emergency alert functionality was implemented through programmed logic to transmit notification signals upon activation of the SOS interface. The overall software framework ensured reliable coordination between sensing, processing, and feedback mechanisms for real-time assistive operation.The key software tools and libraries used in the system are summarized in Table 2.

TABLE 2. SOFTWARE TOOLS AND LIBRARIES USED

Module	Tools/Libraries	Function
Vision	Python, OpenCV	Real-time image capture & object detection
Vision	Tesseract OCR	Text recognition from images
Vision	pyttsx3	Voice feedback generation
Stick	ESP32(ArduinoIDE)	Communication & emergency alerts
Stick	Ultrasonic Library	Distance measurement for alerts
System	Serial	Communication & emergency alerts

D. System Integration and Testing

The integrated assistive system was subjected to comprehensive testing in both indoor and outdoor environments to evaluate its operational performance and reliability. Indoor testing involved controlled obstacle arrangements to assess the accuracy of the vision module, OCR functionality, and obstacle detection by the navigation stick. Outdoor testing was conducted in variable lighting and terrain conditions to examine real-world usability, response times, and effectiveness of audio and alert feedback. Observations confirmed that the system consistently detected obstacles, recognized text, and transmitted emergency alerts with minimal latency, demonstrating robust response behavior and seamless coordination between the vision and navigation modules.

TABLE 3. SYSTEM INTEGRATION AND TESTING SUMMARY

Environment	Parameter	Metric / Value
Indoor	Obstacle detection accuracy	95%
Indoor	OCR accuracy	92%
Indoor	Audio feedback clarity	100%
Outdoor	Obstacle detection accuracy	90%
Outdoor	OCR accuracy	88%
Outdoor	Alert transmission delay	<0.5s
Overall	Response time	0.3-0.5s
Overall	System coordination	No errors observed

RESULT AND DISCUSSION

The integrated assistive system demonstrated effective performance in both indoor and outdoor environments. Indoor tests confirmed that the vision module accurately detected obstacles with an accuracy of 95% and successfully recognized text using OCR with 92% accuracy. The processed visual information was converted to voice-based feedback, which was consistently clear, ensuring immediate user awareness. This demonstrates that the software outputs directly translated into actionable guidance for the user.

Outdoor tests under varying lighting conditions and uneven terrain resulted in slightly reduced obstacle detection (90%) and OCR accuracy (88%), while the emergency alert system successfully transmitted notifications with a delay of less than 0.5 seconds. The stick module reliably generated obstacle alerts, and the SOS functionality was triggered as intended during testing.

Overall, the system exhibited rapid response times ranging from 0.3 to 0.5 seconds and seamless coordination between the vision and navigation stick modules, confirming the reliability of real-time processing and alert mechanisms. These results indicate that the proposed assistive device provides robust, efficient guidance and emergency alerts under diverse operational conditions. Minor reductions in outdoor OCR and detection accuracy can be attributed to environmental factors such as lighting variations and surface irregularities, which can be addressed in future iterations.

CONCLUSION

The proposed EIRA (Enhanced Intelligent Real-Time Assistance) system successfully integrates a wearable vision module and a smart navigation stick to provide real-time obstacle detection, object recognition, text recognition, audio feedback, and SOS switch-based emergency alerts for visually impaired users. Both hardware and software modules were implemented and tested in indoor and outdoor environments, demonstrating high accuracy, rapid response, and reliable performance. Insights from the preliminary user survey ensured that the design addressed real user needs for safety, usability, and comfort. Overall, EIRAI provides a practical, reliable, and user-friendly solution to enhance mobility and independence, with potential for further improvements such as enhanced OCR accuracy, additional object recognition capabilities, and extended real-time assistive features.

ACKNOWLEDGMENT

We sincerely thank the authorities from the Kerala Federation for the Blind, Trivandrum, and the teachers from the Government School for the Visually Impaired, Trivandrum, for their valuable guidance and feedback during the preliminary survey. We also extend our gratitude to the nursing students from Coimbatore for their participation and insights.

We would like to acknowledge the support and encouragement of our faculty members and project guide for their continuous guidance throughout the development of this assistive system. Their suggestions and expertise were instrumental in shaping the design, implementation, and testing of the prototype.

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