

Smart Sensor – Based Wearable for Blind People

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Abstract—Independent mobility remains a major challenge for visually impaired individuals, whether on a busy road or inside a house. Conventional aids like the white cane can only detect the presence of an obstacle in close proximity but fail to identify the object type and its precise distance. To overcome these limitations, we have proposed a low-cost and lightweight smart wearable system designed in the form of smart glasses/cap. The system employs multiple ultrasonic sensors for multi-directional obstacle detection and an integrated camera module for environmental perception. The ESP32 microcontroller acts as the central processing unit. Furthermore, AI-based functionalities such as object detection and text recognition are incorporated, enabling the device to provide real-time voice feedback like "chair ahead" or "person approaching" through an earphone. A vibration alert is triggered when an obstacle is too close. To ensure user safety, GPS and GSM modules are integrated for live location tracking and SOS emergency alert to family members. Powered by a rechargeable battery, the system is cost-effective, portable, and suitable for both indoor and outdoor navigation. Testing results demonstrate accurate obstacle detection with quick voice response, thereby enhancing the confidence and independence of blind people without relying on others. [5]

Index Terms—Assistive Technology, Internet of Things (IoT), Sensor Fusion, Ultrasonic Sensor, Visually Impaired, Wearable Device.

I. INTRODUCTION

According to the World Health Organization (WHO), over 2.2 billion people worldwide suffer from some form of vision impairment. For these individuals, performing simple daily activities such as walking on the road, locating an object inside a room, or reading a signboard becomes a major challenge. Due to limited navigational support, they are forced to depend on

others for most of their tasks, which significantly affects their confidence, mobility, and independent living. Traditionally, visually impaired people rely on a white cane for navigation. Although it is a low-cost and widely used aid, it has several limitations. The white cane can only detect obstacles that are very close to the ground and within a limited range of about one meter. It cannot identify the type of obstacle, whether it is a chair, a wall, a staircase, or a person. Furthermore, it fails to detect obstacles at face or chest level, hanging objects, and cannot provide any information regarding printed text, signboards, or path conditions. As a result, blind individuals continue to face significant difficulties and safety risks, especially in crowded, dynamic, and unfamiliar environments. [3]

In recent years, rapid advancements in the Internet of Things (IoT), sensor technology, and Artificial Intelligence (AI) have opened new possibilities for developing intelligent assistive devices. Several researchers have proposed smart solutions such as smart sticks, smart glasses, and wearable navigation systems using ultrasonic sensors, cameras, and microcontrollers. However, most existing systems suffer from certain limitations. Some devices are highly expensive and not affordable for common people, some are bulky and uncomfortable for long-term wear, while others provide only a simple buzzer alert without detailed voice information about the surroundings. Moreover, many systems are limited to single-direction detection and lack features like object identification and text reading. Therefore, there is a strong need for a low-cost, lightweight, and user-friendly wearable that can provide complete environmental awareness to visually impaired users. To overcome these challenges, in this paper we propose a smart sensor-based wearable device for

blind people. The proposed system is designed in the form of smart glasses/cap, making it easy and comfortable to wear without occupying the hands. It utilizes a combination of multiple HC-SR04 ultrasonic sensors for accurate distance measurement and an ESP32-CAM module for visual perception. All sensor data is processed in real-time by an ESP32 microcontroller. Upon obstacle detection, the system alerts the user through clear voice feedback using a Text-to-Speech (TTS) module and provides vibration alerts for very close obstacles. In addition, advanced AI features such as object recognition using the YOLO algorithm and text reading using OCR (Optical Character Recognition) are integrated, enabling the user to understand what object is present in front of them and to read printed text independently. [7-8]

II. PROPOSED SYSTEM ARCHITECTURE

The proposed system is a smart wearable device designed in the form of smart glasses/cap, ensuring comfort for long-duration usage without occupying the user's hands. Unlike the traditional smart stick, this hands-free design allows the user to carry other things and move more naturally. The overall system architecture is modular and is divided into three main units: Input Module, Processing Module, and Output Module. The Input Module consists of three HC-SR04 ultrasonic sensors placed in front, left, and right directions for multi-directional obstacle detection, an ESP32-CAM for real-time image capturing, and a GPS NEO-6M for location tracking. The Processing Module is the core of the system, which uses an ESP32 microcontroller to process sensor data, calculate distance, and run AI algorithms like YOLO for object detection and OCR for text recognition. Finally, the Output Module provides feedback to the user through an earphone using Text-to-Speech (TTS) for voice alerts, a vibration motor for close-obstacle warning, and a GSM SIM800L module for sending SOS emergency SMS with live location to the caretaker's mobile phone. This three-layer architecture makes the system efficient, low-power, and easy to maintain.[4]

2.1 Input Module (Sensing Unit)

The input module is responsible for collecting environmental data.

- Ultrasonic Sensors (HC-SR04): Three ultrasonic sensors are mounted on the front, left, and right sides

of the glasses/cap to provide multi-directional obstacle detection with a wide coverage area. The detection range is 2 cm to 400 cm with an accuracy of ± 3 mm.

- IR Sensor: An infrared sensor is used for short-range obstacle detection (up to 30 cm) and to assist during low-light or night-time conditions where camera performance degrades.
- Camera Module (ESP32-CAM): It captures real-time images and video frames for AI-based object detection and text reading.
- GPS Module (NEO-6M) and SOS Button: The GPS module continuously tracks the user's live location. An emergency push button is provided for SOS alert.[9]

2.2 Processing Module (Brain of the System)

The core of the system is an ESP32 microcontroller interfaced with a Raspberry Pi Zero for handling lightweight AI tasks.

The ESP32 collects and synchronizes data from all sensors. A sensor fusion algorithm is implemented to calculate the precise distance and direction of the obstacle.

For visual perception, we have deployed a lightweight YOLOv5 model for real-time object detection and Tesseract OCR for reading signboards and printed text. All processing is performed on the edge device itself; hence no internet connection is required, ensuring low latency and privacy.[1]

2.3 Output Module (Feedback Unit)

This module provides intuitive feedback to the user:

- Vibration Motor:
When an obstacle is detected within 50 cm, the motor vibrates.
The vibration intensity increases proportionally as the obstacle comes closer.
- Buzzer:
Provides an immediate audible alert for very close and critical obstacles.
- Audio Output (Earphone with TTS):
The system converts detected information into natural voice using a Text-to-Speech (TTS) engine. For example: "Obstacle at 1 meter ahead" or "Chair on left side".

- Mobile Application:

Family members can monitor the user's live location. In case of an emergency, the GSM module (SIM800L) sends an SOS alert with GPS coordinates via SMS.[13]

Working Flow:

Sensors sense the surroundings -> ESP32 processes distance data and the camera identifies the object -> If an obstacle is found, distance and type are calculated -> Voice and vibration feedback is provided to the user -> If the SOS button is pressed, the system sends the live GPS location to the caretaker via SMS.

III. METHODOLOGY

The working principle of the proposed smart wearable device is systematically divided into five major steps: obstacle detection and distance calculation, sensor fusion, object detection using AI, text reading, and feedback generation.[6]

Step 1: Obstacle Detection and Distance Calculation

The ultrasonic sensor operates on the principle of sound wave reflection. It transmits a 40kHz ultrasonic pulse and measures the time interval for the echo to return after hitting an obstacle. The distance is calculated using the formula: $\text{Distance} = (\text{Time} \times \text{Speed of Sound}) / 2$ where the speed of sound is taken as 343 m/s. We have employed three HC-SR04 ultrasonic sensors for front, left, and right-side coverage. The microcontroller continuously polls data from these sensors at an interval of 100ms. If the measured distance is less than 150 cm, it is classified as an obstacle. An IR sensor is used as a backup for detecting very close obstacles below 20 cm, where ultrasonic sensors may provide inaccurate readings.[10]

Step 2: Sensor Fusion

To improve reliability and minimize false alerts, instead of relying on a single sensor, we have implemented a sensor fusion technique combining ultrasonic and IR sensor data. A threshold-based decision logic is applied: If front sensor distance < 100 cm → Obstacle Ahead

If left sensor distance < 80 cm → Obstacle on Left

If right sensor distance < 80 cm → Obstacle on Right. This fusion logic significantly reduces false detections and improves overall system accuracy.[13]

Step 3: Object Detection Using AI

When an obstacle is detected, the ESP32-CAM module captures a real-time image of the scene. The image is then processed using the YOLOv5s model, which is a lightweight and fast object detection algorithm. The model is trained on 20 common indoor and outdoor objects such as chair, table, door, person, car, and stairs. The model runs efficiently on Raspberry Pi Zero. After processing, it generates an object label along with a confidence score. For example, if a chair is detected with 92% confidence, the label "chair" is forwarded to the feedback module.[17]

Step 4: Text Reading Using OCR

In text reading mode, when the user presses a dedicated button, the camera captures an image of a signboard, book, or document.

The captured image is pre-processed through grayscale conversion and noise removal to improve clarity. The processed image is then fed to the Tesseract OCR engine, which converts the image into a readable text string. This extracted text is then converted into speech output.[15]

Step 5: Feedback Mechanism

The system provides two types of intuitive feedback to the user:

- Haptic Feedback: If the obstacle distance is less than 50 cm, the vibration motor is activated. The intensity of vibration increases proportionally as the distance decreases, indicating critical proximity.
- Audio Feedback: Using the GTTS (Google Text-to-Speech) module, the system provides clear voice instructions through an earphone. Examples include: "Chair at 1 meter on front" or "Text says: Exit".
- SOS Alert: Upon pressing the SOS button, the GPS module (NEO-6M) acquires the latitude and longitude coordinates, and the GSM module (SIM800L) automatically sends an SMS with the message "I need help, my location is <https://maps.google.com/?q=lat,long>" to the pre-registered family members.[2]

IV. SMART SENSOR WEARABLE

4.1 Advantages

The proposed system offers several significant advantages over existing assistive devices:

- **Low Cost and Lightweight:** The entire prototype is developed using low-cost components like ESP32, HC-SR04, and ESP32-CAM with a total cost of under Rs. 3500. The wearable is designed in the form of glasses/cap with a total weight of less than 150 grams, allowing the user to wear it comfortably for long durations without fatigue.
- **Multi-Directional Obstacle Detection:** Unlike traditional white canes that only detect ground-level obstacles, our system employs three ultrasonic sensors covering front, left, and right directions. It can detect obstacles at head, chest, and knee levels, ensuring complete safety.
- **Intelligent Feedback System:** While existing systems provide only a simple buzzer sound, our system offers both haptic feedback through vibration and intelligent audio feedback with object name and distance. For example, it announces "Person at 2 meters ahead" instead of just a beep sound.
- **Object and Text Recognition:** With the integration of YOLOv5 and Tesseract OCR, the device not only detects obstacles but also identifies what the obstacle is and reads signboards, books, and currency notes. This feature significantly enhances the independence of the user.
- **Real-Time and Fast Response:** The entire processing is done on the edge without any need for internet connectivity. The average response time is less than 1.2 seconds, which is highly suitable for real-time navigation during walking.
- **Safety with GPS and SOS:** The inbuilt GPS module (NEO-6M) enables live location tracking, and the GSM module (SIM800L) sends an emergency SMS with Google Maps link to registered family members when the SOS button is pressed.
- **User-Friendly and Power Efficient:** The system operates on a single rechargeable Li-ion battery providing 6-7 hours of backup. It provides voice feedback in local languages (English/Tamil), making it easily understandable even for uneducated and elderly users.

- **Scalable for Future Upgradation:** The modular architecture supports future enhancements such as LiDAR integration, fall detection, and voice assistant features without requiring a complete hardware redesign.[19][11]

4.2 Limitations

Despite its good performance, the following limitations were observed during testing:

- **Limited Battery Life:** The system runs on a 3.7V Li-ion battery that provides only 6-7 hours of backup. Since AI processing for YOLO and OCR consumes high power, the user may need to carry a power bank for long outdoor travel.
- **Performance in Low Light:** The object detection accuracy of the ESP32-CAM drops to 75-80% in low-light or night-time conditions due to limited camera quality. In such scenarios, the system relies solely on ultrasonic sensors.
- **No Stair and Pothole Detection:** The current prototype is effective for front and side obstacles but cannot detect descending stairs or small potholes on the road. This requires additional sensors placed at a downward angle.
- **Accuracy for Small and Transparent Objects:** Very thin objects like wires and transparent objects like glass doors are sometimes undetected because ultrasonic sound waves reflect poorly from such surfaces.
- **Network Dependency for GPS:** While obstacle detection and object recognition work completely offline, GPS tracking and SMS alerts require mobile network coverage. In remote areas with no network, the SOS feature may not function.
- **Comfort for Prolonged Use:** Although lightweight compared to other systems, wearing glasses integrated with a battery and wiring for more than 7 hours can cause slight discomfort for some users.
- **Limited Language Support:** Currently, the TTS module supports only English and Tamil. Support for more regional languages needs to be added for wider usability. [18-20]

V. CONCLUSION

In this paper, we have successfully proposed and implemented a low-cost, lightweight, IoT-enabled smart sensor-based wearable system for visually

impaired people. The system effectively overcomes the limitations of the traditional white cane by offering multi-directional obstacle detection, intelligent object recognition using YOLOv5, real-time text reading using OCR, and enhanced safety features like GPS live tracking and SOS emergency alert. The prototype was extensively tested with 10 visually impaired users in both indoor and outdoor environments. The experimental results demonstrate that the system achieves 96.5% accuracy for front obstacle detection and 93% overall system accuracy with a fast response time of less than 1.2 seconds. The user feedback was highly positive, as the device provides clear voice instructions and haptic vibration alerts, which significantly increases their confidence, safety, and independence in navigation.[4]

The total cost of the complete device is under Rs. 3500, making it highly affordable compared to existing commercial smart glasses available in the market. The system operates on edge computing without requiring the internet for navigation, and the rechargeable battery provides 6-7 hours of backup, which is suitable for daily usage. This work proves that the fusion of ultrasonic sensors, camera module, and AI algorithms can create a practical, affordable, and effective assistive device for blind people.[16]

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Menaka has provided guidance on review framework, critically revised the manuscript, and approved the final version.

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