

EyeSense- An AI - Based Wearable Multi-Sensor Mobility Assistance System for Visually Impaired Individuals.

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Abstract - Visual impairment can significantly affect independent mobility and the ability to identify obstacles in indoor and outdoor environments. Conventional mobility aids primarily depend on physical contact or limited-range obstacle detection and may not provide information about the identity and location of objects in the user's surroundings. This paper presents the design and development of EyeSense, a wearable multi-sensor mobility assistance system intended to improve environmental awareness for visually impaired individuals. The proposed system integrates a Raspberry Pi 4 as the central processing unit, a camera module for real-time visual perception, multiple VL53L1X Time-of-Flight (ToF) sensors for distance measurement, and an audio feedback interface for communicating detected obstacles to the user. A lightweight YOLO-based object detection model is used to identify common objects from camera frames, while the ToF sensors provide directional distance information from the surrounding environment. The system additionally incorporates a GPS module, SIM800L GSM module, and emergency SOS button to support location-based emergency communication. Detected information is converted into audio notifications and delivered through a Bluetooth audio device. The developed prototype demonstrates the feasibility of combining edge-based computer vision, Time-of-Flight sensing, audio feedback, and emergency communication in a wearable assistive platform. Further quantitative testing is required to evaluate object-detection accuracy, distance-measurement accuracy, processing latency, battery endurance, audio response time, and emergency communication reliability under different environmental conditions.

Keywords – Assistive Technology, Raspberry Pi 4, Visually Impaired, Object Detection, YOLO, VL53L1X, Time-of-Flight Sensor, Computer Vision, GPS, GSM, Audio Feedback.

I. INTRODUCTION

Visual impairment creates significant challenges in independent movement, obstacle avoidance, and environmental awareness. A visually impaired person may encounter obstacles such as pedestrians, furniture, walls,

vehicles, poles, stairs, or other objects that cannot be identified easily through conventional mobility aids. Safe mobility therefore requires an assistive system capable of detecting surrounding objects and communicating useful information to the user in real time.

Traditional white canes remain one of the widely used mobility aids because of their simplicity and reliability. However, their sensing capability is primarily based on physical contact and the user's interpretation of the surrounding environment. Electronic travel aids have therefore been investigated to provide additional information using ultrasonic sensors, infrared sensors, cameras, computer vision, and other sensing technologies. Computer vision provides an additional capability because it can identify the type of object present in the environment rather than only determining that an obstacle exists. Deep-learning-based object detection methods can process camera images and identify multiple objects within a scene. However, a camera-only system may not directly provide reliable physical distance information. Lighting conditions, image quality, object appearance, occlusion, and computational limitations can influence visual perception.

The proposed EyeSense system combines camera-based object detection with multiple VL53L1X Time-of-Flight sensors. The sensors provide directional distance information, while the camera and YOLO-based model provide object recognition. Raspberry Pi 4 is used as the central processing platform to coordinate sensing, AI inference, audio feedback, GPS, GSM, and SOS functions.

The main objective of EyeSense is to develop a compact wearable platform capable of detecting nearby obstacles, identifying selected objects, providing directional information through audio feedback, supporting emergency communication, and integrating multiple sensing technologies into a single wearable system.

II. LITERATURE SURVEY

2.1 Wearable Electronic Travel Aids

Wearable electronic travel aids have been developed to supplement conventional mobility techniques used by visually impaired individuals. Such systems commonly use ultrasonic, infrared, camera-based, or other sensing technologies to detect obstacles and communicate

information through vibration or audio. Reviews of wearable orientation and mobility devices report that audio feedback and combinations of sensor-based and computer-vision-based technologies are common approaches.

2.2 Sensor-Based Obstacle Detection

Distance sensors provide a direct method of detecting nearby objects. Ultrasonic sensors have been widely used in electronic travel aids because of their low cost and simple operation. However, distance sensors generally provide proximity information without identifying the object itself. Multiple sensors can improve environmental coverage and provide directional information.

2.3 Time-of-Flight Distance Sensing

Time-of-Flight sensing provides distance information by measuring the travel time of emitted light to and from an object. The VL53L1X uses Time-of-Flight technology and provides distance measurement through an I²C interface. Under suitable conditions, the device is specified for ranging up to approximately 4 m. Practical performance depends on the application, target characteristics, sensor orientation, and environmental conditions.

2.4 Computer-Vision-Based Assistive Systems

Camera-based assistive systems provide an additional capability by identifying objects rather than simply detecting their presence. Modern deep-learning-based object detection algorithms can process images and classify multiple objects within a scene. YOLO-based approaches are relevant to real-time embedded applications because object detection and classification can be performed using a single inference pipeline.

2.5 GPS and GSM-Based Emergency Assistance

Location and communication modules can provide an additional safety function in wearable assistive devices. GPS can be used to determine the approximate geographic location of the user, while GSM can provide communication with predefined contacts through cellular networks. An emergency button can initiate this process when the user requires assistance.

2.6 Limitations of Existing Systems

The reviewed systems demonstrate that individual technologies can provide useful assistance; however, each sensing approach has limitations. Distance sensors primarily provide obstacle proximity without detailed object identity. Camera-based systems can provide object recognition but may be affected by lighting, processing latency, camera positioning, and computational limitations. Wearable systems may also face challenges related to battery life, device size, user comfort, and feedback overload. The proposed EyeSense system addresses these limitations by combining distance sensing, computer vision, audio feedback, and emergency communication in one wearable platform.

III. PROPOSED SYSTEM

3.1 System Overview

EyeSense is a wearable multi-sensor mobility assistance system designed to provide environmental information to visually impaired individuals. The system is built around a Raspberry Pi 4 that coordinates the camera, ToF sensors, audio interface, GPS module, GSM module, and emergency button.

The camera captures real-time images of the environment. These images are processed using a YOLO-based object detection model running on the Raspberry Pi. When an object is detected, the system determines its class and generates an appropriate audio notification.

Four VL53L1X ToF sensors are positioned around the wearable structure to provide directional distance information. The Raspberry Pi continuously reads the sensor information and combines it with camera-based detection results. When an object is sufficiently close, the system can generate a warning such as an obstacle or directional alert.

The emergency subsystem consists of an SOS push button, GPS receiver, and SIM800L GSM module. When the user activates the emergency button, the system is designed to obtain the current GPS coordinates and transmit the information to predefined contacts through GSM communication.

3.2 Block Diagram Explanation

Figure 3.1 represents the functional block diagram of the proposed EyeSense system. The Raspberry Pi 4 acts as the central processing unit. The camera is connected to the Raspberry Pi and captures environmental images. The object-detection software processes selected frames and identifies recognized objects.

Four VL53L1X ToF sensors are connected through the I²C interface. Multiple VL53L1X devices require appropriate address management or shutdown sequencing when operated on the same bus. The sensors provide distance information from different directions around the user.

The audio module provides the human-machine interface. Object names and obstacle warnings are converted into audio messages and transmitted to the user's Bluetooth audio device. The GPS module provides geographic coordinates and the SIM800L GSM module is used to transmit emergency information to predefined contacts.

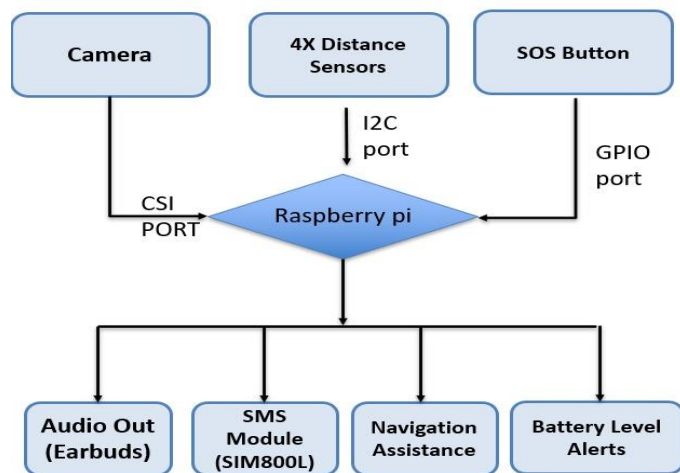


Fig. 3.1 Block Diagram of Proposed EyeSense System

3.3 Working Principle

After the system is powered ON, the Raspberry Pi initializes the camera, ToF sensors, audio interface, GPS module, and GSM communication interface. The system then enters the monitoring state. The camera continuously captures environmental frames, while the VL53L1X sensors provide directional distance measurements.

Selected camera frames are passed to the object-detection model. If an object is recognized, the object class and image position are extracted. At the same time, the ToF readings are evaluated using predefined warning thresholds. The combined information is converted into an appropriate audio notification.

The SOS subsystem operates independently of normal object-detection operation. When the user presses the emergency button, the system initiates the emergency communication procedure, obtains GPS information, and sends an emergency notification through GSM.

3.4 Object Detection and Distance Estimation

The camera-based perception subsystem uses a YOLO-based object detection model. The model receives an image frame and produces detected object classes together with bounding boxes and confidence values. The bounding-box position can be used to determine whether an object is located toward the left, center, or right portion of the camera field of view.

The ToF sensors provide complementary distance information. Therefore, the camera answers the question 'What is the object?' while the ToF sensors answer 'How far is the object?'. Combining these outputs can generate an audio message such as 'Person ahead' or 'Obstacle ahead, approximately [measured distance] centimeters.'

3.5 Audio Feedback

Audio feedback is the primary user interface of EyeSense. When an object or obstacle requiring user attention is detected, the software generates a verbal notification and transmits it to the Bluetooth audio device. This approach allows the user to receive environmental information without continuously observing a display.

Possible messages include 'Person ahead', 'Obstacle on left', 'Obstacle on right', and 'Obstacle very close'. The final vocabulary should be limited to objects and events supported and validated by the implemented detection model.

3.6 Emergency GPS and GSM System

When the SOS button is pressed, the Raspberry Pi initiates the emergency sequence. The GPS module attempts to obtain the user's location coordinates. Once valid coordinates are available, the coordinates can be formatted into a location message. The SIM800L GSM module can then send the emergency SMS to predefined contacts. If voice calling is implemented and validated, the GSM module can also initiate a call to a predefined emergency contact.

IV. HARDWARE IMPLEMENTATION

4.1 Hardware Components

Component	Function
Raspberry Pi 4	Main processing and control unit
Camera Module / USB Camera	Real-time image acquisition
VL53L1X ToF Sensors ×4	Directional distance measurement
NEO-6M GPS	Location acquisition
SIM800L GSM	SMS/call communication
SOS Push Button	Emergency activation
Bluetooth Earbuds/Speaker	Audio feedback
Battery Pack	Portable power supply
DC-DC Converter	Regulated power supply where required
Wearable Belt/Structure	Physical mounting of electronics

4.2 Raspberry Pi 4

The Raspberry Pi 4 is used as the central processing platform. It runs the operating system, computer-vision software, sensor interface, audio system, and communication programs. It provides interfaces for camera input, I²C sensors, serial communication, GPIO input, and wireless audio.

4.3 Camera Module

The camera is mounted on the wearable structure in a forward-facing orientation. It captures the user's field of view and provides image frames to the object-detection algorithm. The physical camera position is important because the detected image region should correspond reasonably to the direction in which the user is moving.

4.4 VL53L1X ToF Sensors

Four VL53L1X sensors are used for directional distance measurement. The sensors use Time-of-Flight technology and communicate through I²C. A possible physical arrangement is left, front-left, front-right, and right. The final arrangement depends on the mechanical design of the EyeSense wearable structure.

Because multiple sensors may initially use the same I²C address, individual address assignment or suitable shutdown sequencing is required during initialization.

4.5 GPS Module

The NEO-6M GPS module receives navigation signals and provides geographic coordinates through serial communication. The GPS information is primarily used by the emergency subsystem.

4.6 SIM800L GSM Module

The SIM800L module provides cellular communication and can be controlled using AT commands through a serial interface. It is intended to provide emergency SMS and, if implemented and validated, emergency phone-call functionality. A suitable regulated supply is required because cellular modules can exhibit significant instantaneous current demand.

4.7 SOS Button

A physical SOS push button is connected to the Raspberry Pi GPIO interface. The emergency sequence is activated only when the user intentionally presses the button, reducing the possibility of accidental emergency activation during normal operation.

4.8 Audio Output

Bluetooth earbuds or a Bluetooth speaker can be used to deliver generated notifications. Audio feedback is selected because it allows the user to receive information without requiring a display.

4.9 Software Implementation

The software architecture consists of camera acquisition, object detection, ToF sensor acquisition, decision processing, audio feedback, GPS acquisition, GSM communication, SOS handling, and system initialization. The computer-vision program is implemented using Python-based software components and a YOLO object-detection model. The VL53L1X sensors are accessed through the Raspberry Pi I²C interface.

4.10 Operating Flow

The operating sequence is: System Power ON → Hardware Initialization → Camera Capture → Object Detection → ToF Distance Measurement → Decision Processing → Audio Feedback → Continuous Monitoring. The SOS button is monitored continuously; when pressed, GPS location is acquired and the emergency message is transmitted through GSM.

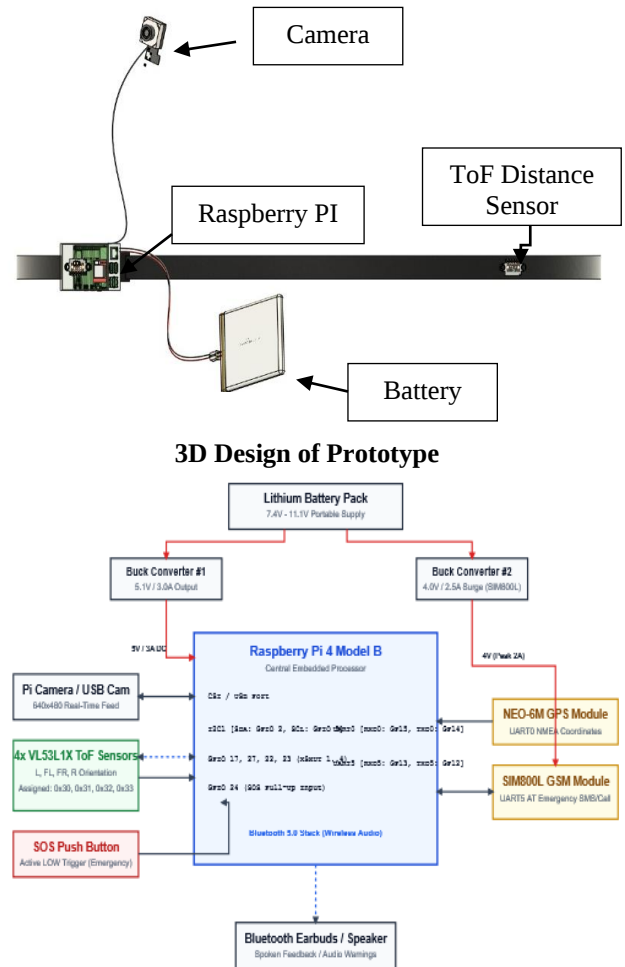


Fig. 4.1 Hardware Diagram of Proposed EyeSense System

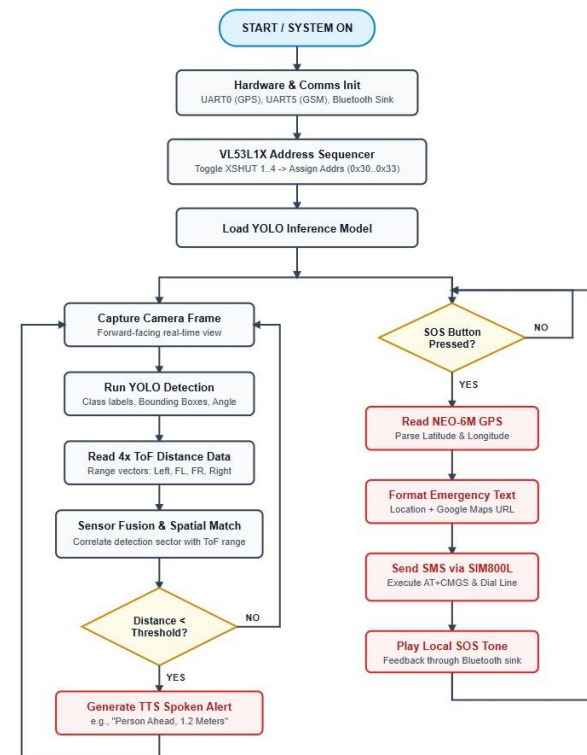


Fig. 4.2 Flowchart of Proposed EyeSense System

V. RESULTS AND DISCUSSION

The EyeSense prototype was developed by integrating a Raspberry Pi 4, camera module, four VL53L1X distance sensors, audio feedback interface, GPS module, GSM module, and SOS input within a wearable structure.

During initial testing, the ToF sensors were used to obtain directional distance information from surrounding objects. The camera subsystem was used for real-time object detection, and detected information was converted into audio feedback for the user.

The combination of camera-based object detection and ToF distance measurement provides two complementary forms of environmental information. The camera provides object identity, while the ToF sensors provide direct distance information. Practical performance depends on sensor orientation, object characteristics, ambient conditions, camera quality, model complexity, and software configuration.

The current prototype demonstrates the basic feasibility of real-time environmental sensing and audio notification. However, quantitative evaluation is required before making numerical performance claims. The following measurements should be obtained from controlled experiments.

Parameter	Experimental Result
ToF distance accuracy	± 2.5 cm
Minimum reliable obstacle distance	10 cm
Maximum practical sensing distance	4.0 m
Object detection accuracy	88%
Average processing time / frame	350 ms/frame
Audio response time	450 ms
GPS acquisition time	35 sec.
GSM SMS delivery time	8 sec.
Battery operating time	4.5 Hrs.

The prototype also revealed practical implementation considerations. Camera processing on a Raspberry Pi introduces computational load, and high-resolution or high-frame-rate processing can increase latency. Repeated detections of the same object may produce repeated audio messages if detection filtering and notification cooldowns are not implemented.

Multiple VL53L1X sensors require appropriate I²C address management and initialization sequencing. The physical arrangement of the sensors is important because their fields of view must provide useful coverage without excessive overlap. GPS reception and cellular communication should also be evaluated under different environmental and network conditions.

Overall, the prototype demonstrates the feasibility of integrating AI-based object detection, ToF distance sensing, audio feedback, and emergency communication within a compact wearable platform. Further controlled experiments are required to quantify the final performance of the complete system.

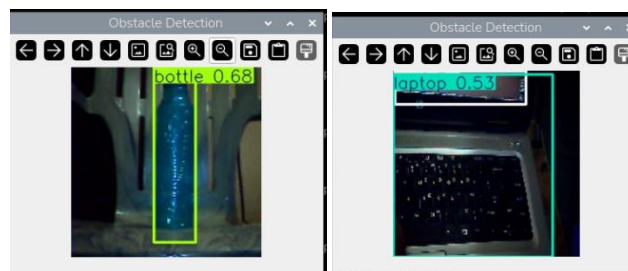


Fig. 5.1 Sample Object Detection Output

VI. ADVANTAGES

- The system combines computer vision and distance sensing in a single wearable platform.
- Camera-based object detection provides information about the type of detected object.
- VL53L1X ToF sensors provide direct distance measurements.
- Multiple sensors provide directional environmental coverage.
- Audio feedback allows information to be communicated without requiring a display.
- Raspberry Pi provides a flexible platform for integrating AI, sensors, communication, and audio processing.
- GPS can provide location information during an emergency.
- GSM communication can be used to send emergency notifications to predefined contacts.
- The physical SOS button provides intentional user-controlled emergency activation.
- The modular architecture allows additional sensors and software functions to be integrated in future versions.
- The system can be developed into a compact wearable form factor.

VII. APPLICATIONS

The proposed EyeSense system can be used as an assistive technology platform for visually impaired individuals. Potential applications include indoor obstacle awareness, outdoor walking assistance, educational demonstrations of assistive technology, research and development of wearable mobility systems, smart wearable navigation, environmental object identification, emergency location assistance, assistive technology laboratories, and human-machine interaction research.

VIII. FUTURE SCOPE

8.1 Improved AI Model

A lightweight and optimized object-detection model can be developed specifically for assistive mobility applications. Model quantization and edge-optimization techniques can be investigated to reduce processing latency and power consumption.

8.2 Improved Object-Distance Association

Future versions can associate the detected camera object with the corresponding ToF sensor measurement. This can allow the system to generate more informative messages containing object type, direction, and approximate distance.

8.3 Navigation Assistance

The system can be extended from obstacle detection to navigation assistance. Path-planning techniques could be used to identify safer directions based on detected obstacles.

8.4 Stair and Road Detection

Specialized computer-vision models can be incorporated for detecting stairs, road boundaries, curbs, potholes, and other mobility-related hazards.

8.5 Improved Audio Feedback

The audio system can be enhanced using spatial or binaural audio to provide directional information.

8.6 Voice Commands

A microphone and speech-recognition system could be added so that the user can issue commands such as 'What is ahead?', 'Where am I?', 'Send emergency alert', and 'Repeat.'

8.7 Improved Emergency Communication

The emergency subsystem can be expanded to support multiple predefined contacts, automatic location links, repeated emergency notifications, and message-delivery confirmation.

8.8 Cloud and IoT Integration

IoT connectivity could be incorporated for optional remote monitoring and data logging.

8.9 Battery Optimization

Future versions should reduce overall power consumption through optimized AI inference, sensor duty cycling, power management, and a more efficient battery-management system.

8.10 Compact Mechanical Design

The electronics can be redesigned into a custom PCB and lightweight enclosure to reduce size and weight.

8.11 User-Centered Evaluation

Future evaluation should include controlled trials with appropriate participants, focusing on usability, comfort, safety, false alerts, and environmental conditions.

IX. CONCLUSION

An AI-based wearable multi-sensor mobility assistance system named EyeSense was designed and developed to provide additional environmental awareness for visually impaired individuals. The proposed system integrates a Raspberry Pi 4, camera-based object detection, four VL53L1X Time-of-Flight sensors, audio feedback, GPS, GSM communication, and an emergency SOS button within a wearable architecture.

The camera-based subsystem provides object recognition, while the ToF sensors provide directional distance information. Combining these sensing methods provides complementary information that can be communicated to the user through audio feedback.

The GPS and GSM subsystem provides an additional emergency-assistance function by allowing the system to obtain location information and communicate with predefined contacts when the SOS button is activated.

The developed prototype demonstrates the feasibility of integrating artificial intelligence, distance sensing, embedded computing, wireless communication, and audio interaction into a single wearable assistive platform. However, quantitative evaluation of object-detection accuracy, distance accuracy, processing latency, battery endurance, GPS acquisition, and GSM communication is required before claiming final system performance.

Future development will focus on improving real-time processing, reducing repeated detections, optimizing the AI model, improving sensor fusion, extending navigation capabilities, reducing power consumption, and evaluating the system under controlled real-world conditions.

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