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Smart Indoor Navigation for the Blind Using Li-Fi and Voice Assistance

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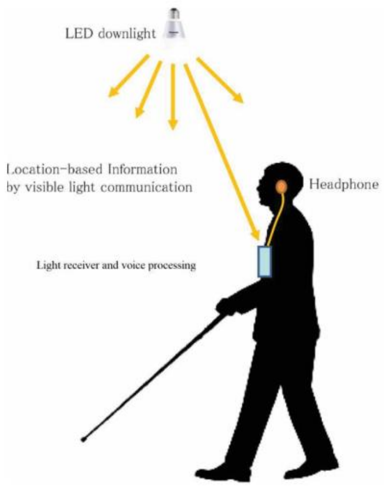
Abstract: Indoor navigation remains a major barrier for visually impaired individuals, especially in unfamiliar environments such as public buildings, offices, and hospitals. Most existing systems depend on Bluetooth beacons or RFID tags, which either lack accuracy or require regular maintenance. This work presents a low-cost, room-accurate indoor navigation and assistance system built using Li-Fi based room identification, sensor-based directional estimation, YOLO-powered object recognition, and emergency SOS support. A 3W LED driven through MOSFET circuitry transmits room IDs using Li-Fi at 2000 baud, while a BPW34 photodiode-based receiver decodes the signal and forwards location and orientation data to a Raspberry Pi 5 over HTTP. The Pi processes navigation commands, captures user speech, and generates voice-based guidance. Additional features include real-time obstacle alerting, object identification using YOLOv8s, and a safety button that sends an emergency telegram message with an image and a 5-second audio clip. Experimental evaluation in a four-room demo environment shows reliable Li-Fi detection up to 30 cm in low-light conditions, 90% object recognition accuracy, and an average navigation response delay of 5 seconds. The system demonstrates a practical and scalable solution for autonomous indoor mobility for visually impaired users.

Keywords: Li-Fi, Indoor Navigation, Visually Impaired, Raspberry Pi, YOLOv8, Object Detection, Assistive Technology

I. INTRODUCTION

Navigating indoor environments without visual cues is a constant challenge for visually impaired individuals. Everyday activities — locating rooms, understanding orientation, identifying objects, and avoiding obstacles — often require dependence on others. Although technologies like Bluetooth beacons, UWB, and RFID offer partial solutions, they come with limitations such as high deployment cost, battery maintenance, signal interference, and limited positional accuracy. Li-Fi (Light Fidelity) provides a simple alternative. Indoor spaces already have lighting infrastructure, and LEDs can be modulated cheaply without affecting illumination. Li-Fi provides room-level precision that RF-based systems struggle to achieve. Combining it with low-cost sensors and onboard processing enables a complete, autonomous navigation framework.

This paper presents a Li-Fi based indoor navigation and assistance system designed specifically for visually impaired users. The system identifies the user's current room using optical signals, determines orientation using a magnetometer, detects nearby obstacles, guides the user towards a chosen destination, recognizes objects using a camera, and sends emergency alerts when needed.



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II. PROPOSED METHODOLOGY

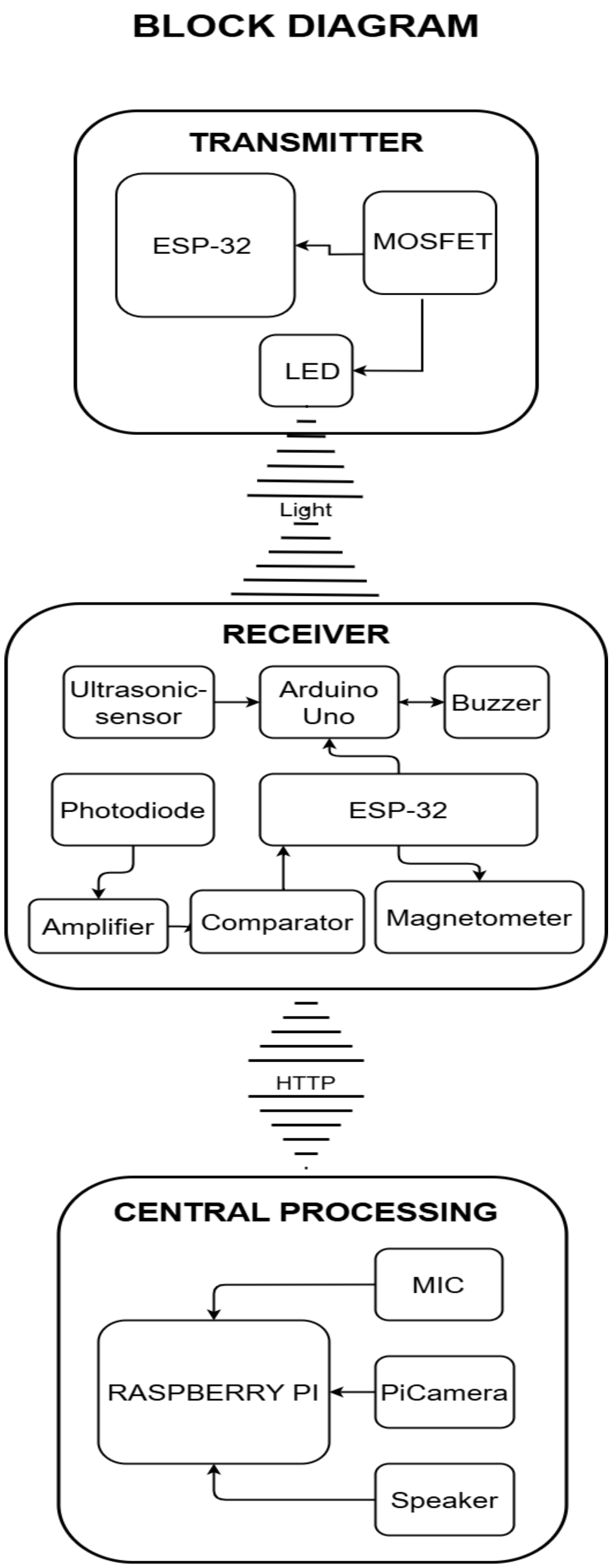

Fig. 2.1 Architecture of the Li-Fi Transmitter and Receiver Modules

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The proposed system follows a layered methodology that combines Li-Fi based room identification, sensor-assisted orientation estimation, path computation, real-time voice guidance, object recognition, and emergency alerting into a single assistive framework for visually impaired users. The method begins by deploying Li-Fi transmitters in each room, where an ESP32 drives a 3W LED through an IRLZ44N MOSFET to broadcast a unique Room ID at a baud rate of 2000. On the user side, a wearable receiver equipped with a BPW34 photodiode, MCP602 amplifier, and LM339 comparator continuously samples incoming light signals. The decoded Room ID, along with directional data from the QMC5883L magnetometer and obstacle distance from the HC-SR04 ultrasonic sensor, is processed by the ESP32 and transmitted to the Raspberry Pi through HTTP. The Raspberry Pi maintains a manually constructed graph of the indoor layout, where each room acts as a node and corridors or doorways form the edges. Once the user presses the navigation button, the system captures the destination through speech recognition and computes the optimal path using the graph. Based on the user's current room, facing direction, and required movement, the Pi generates stepwise voice instructions that guide the user towards the destination. Along the way, the ultrasonic sensor ensures obstacle awareness by triggering a buzzer when an object is dangerously close.

For object recognition, the user can activate a separate mode where the Raspberry Pi uses the Pi Camera V2.1 to capture the surrounding scene. A YOLOv8s model running on TensorFlow 2 processes the image and identifies objects with high confidence, after which the system announces the detected items through audio output. This feature helps the user understand their immediate environment without requiring touch-based exploration. A third mode provides emergency support: pressing the SOS button prompts the Pi to capture the most recent image and record the last 5 seconds of audio, which are then sent to a predefined contact via Telegram along with an alert message. This ensures rapid assistance during critical situations. Throughout all modes, the methodology emphasizes low-cost, reliable components that work together seamlessly, enabling the user to navigate independently, receive real-time object information, and summon help when needed. The system's structure ensures modularity, allowing each function—navigation, sensing, recognition, and emergency response—to operate independently while still contributing to a unified assistive solution.

III. IMPLEMENTATION

The implementation of the proposed system was carried out in three major phases: Li-Fi based room identification, wearable receiver module development, and the central processing system on the Raspberry Pi. The first phase involved setting up Li-Fi transmitters in each room using a 3W star LED, IRLZ44N MOSFET, and an ESP32 Dev Module. Each transmitter was programmed to continuously broadcast a unique Room ID encoded at 2000 baud. The ESP32 modulates the LED without affecting its visible brightness, making the system fully usable as regular indoor lighting while enabling room-level optical communication. This transmitter setup formed the core mechanism to reliably differentiate between rooms and establish the user's location.

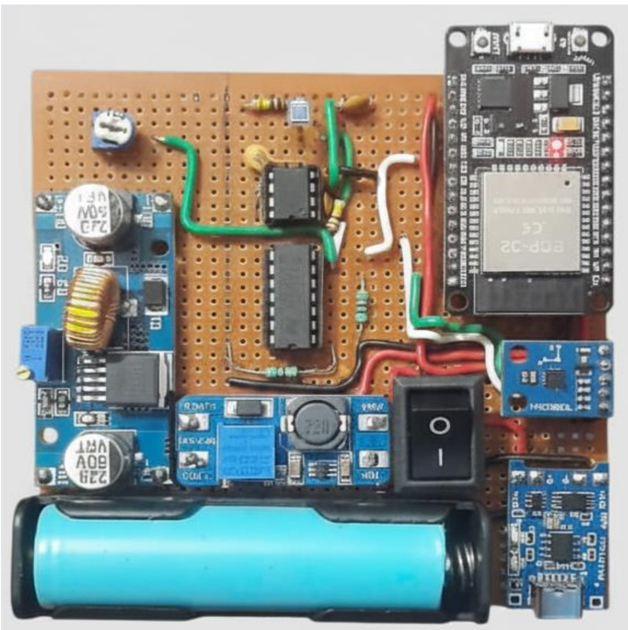

Figure 3.1 Receiver

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The second phase focused on building the wearable receiver unit. The receiver uses a BPW34 photodiode to sense the modulated light signal from the transmitters. Since the raw photodiode output is weak and susceptible to noise, an analog front-end was built using an MCP602 amplifier followed by an LM339 comparator for clean digital recovery of the Li-Fi signal. An ESP32 module decodes the Room ID, reads the orientation from the QMC5883L magnetometer, and detects obstacles using the HC-SR04 ultrasonic sensor. Whenever the ultrasonic sensor detects an object within a predefined threshold, the piezo buzzer immediately alerts the user. The ESP32 then packages the decoded Room ID, the user's facing direction, and obstacle information, and sends it to the Raspberry Pi through an HTTP request over the local Wi-Fi network. This ensures low-latency communication without complex networking protocols.

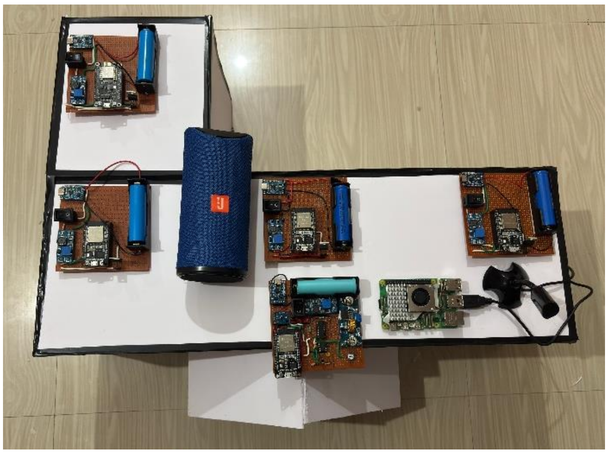

Figure 3.2 Model

The third phase dealt with implementing the processing and decision-making logic on the Raspberry Pi 5. A Python program was developed to maintain a graph-based model of the indoor environment, where rooms and connections are represented as nodes and edges. When the receiver transmits a new location and orientation update, the Raspberry Pi combines this data with the user's spoken destination, captured through a microphone using the Speech Recognition library and Google Speech API. The system computes the optimal navigation path and generates clear voice instructions guiding the user in the correct direction. For object recognition, the Pi Camera V2.1 captures an image when the second button on the receiver is pressed. The image is processed using a YOLOv8s model running on TensorFlow 2, and the detected object is announced to the user through audio feedback.

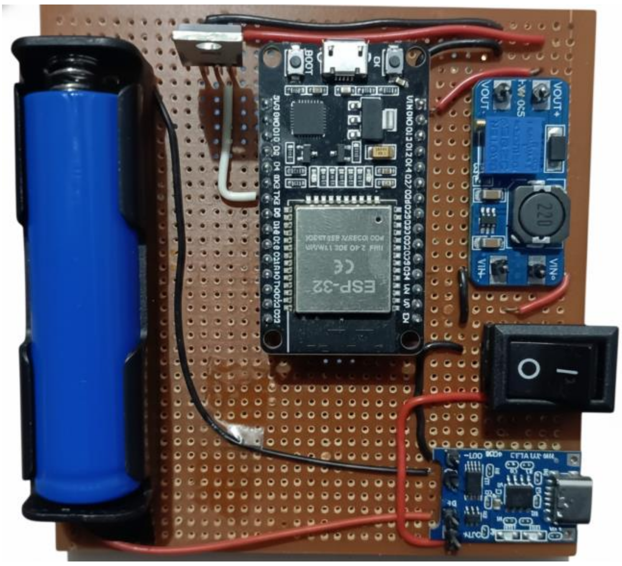

Figure 3.3 Transmitter

The system also includes an emergency assistance mechanism, implemented as part of the Raspberry Pi's GPIO handling logic. When the user presses the SOS button, the Pi automatically captures the latest image from the camera, records the last 5 seconds of audio, and forwards both along with an emergency message to a pre-configured Telegram account. This

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ensures immediate notification of caregivers or family members. Throughout the implementation, the focus was on maintaining low cost, reliability, and real-time responsiveness. The final integrated system successfully combined Li-Fi communication, sensor data processing, AI-based object detection, and cloud-based emergency alerts into a single, coherent solution tailored for visually impaired users.

Figure3.4 Central Processor

IV. RESULTS AND DISCUSSION

The proposed system was tested in a controlled indoor environment consisting of four rooms, each equipped with a Li-Fi transmitter. The primary focus of the evaluation was to measure the accuracy of room detection, the responsiveness of the navigation module, the performance of object recognition, and the reliability of the SOS alert mechanism. The Li-Fi based room identification worked consistently within the expected operating range. During low-light and nighttime conditions, the BPW34 photodiode was able to decode the modulated Room ID from a distance of up to 30 cm. In daytime tests with stronger ambient lighting, the usable range reduced to around 15 cm, which is expected due to interference from background illumination. Despite this limitation, the system still maintained room-level accuracy because users generally point the receiver upward while walking indoors. The clean digital output from the MCP602 and LM339 circuitry helped in minimizing noise, allowing stable detection in most lighting conditions.

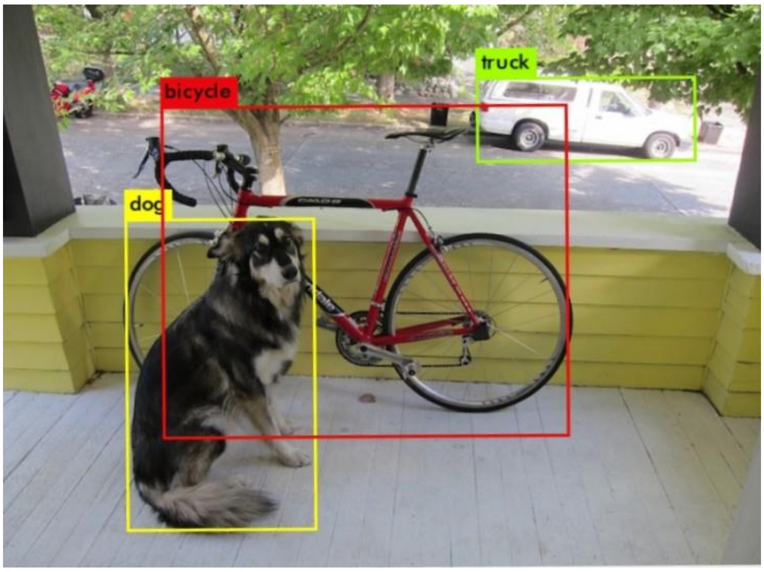

Figure 4.1 Direction Instructions

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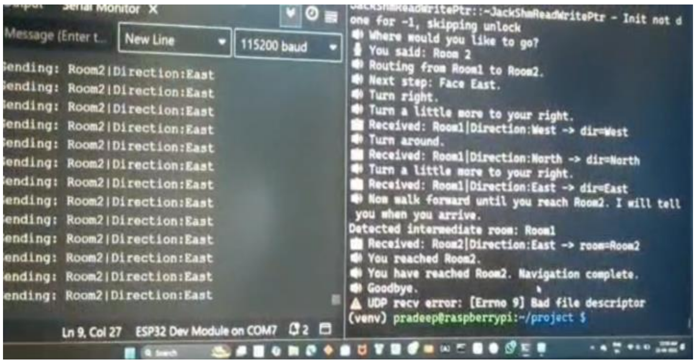

Figure 4.2 Object Identification

Navigation performance was evaluated by repeatedly guiding users from one room to another using different starting orientations. The Raspberry Pi took an average of 5 seconds from receiving the user's voice input to generating the first navigational instruction. This delay mainly came from online speech recognition using the Google API. Once the initial command was processed, the real-time updates based on orientation and location were stable, and the instructions matched the graph-defined floor plan accurately. The integrated obstacle detection system using the HC-SR04 sensor triggered alerts instantly when objects were within the threshold distance. This ensured that users were warned before walking into obstacles, enhancing the system's safety features.

The object recognition module using YOLOv8s performed reliably during testing. In indoor lighting conditions, the model achieved approximately 90% accuracy on clear images captured by the Pi Camera V2.1. Detection accuracy dropped slightly for very small objects or objects with low contrast against the background, but the overall performance was strong enough for practical use. The recognition speed was also acceptable, with the system taking only a couple of seconds to capture, process, and announce the detected object. This feature added an extra layer of environmental awareness for visually impaired users.

The SOS emergency mechanism was tested multiple times to check consistency. Whenever the SOS button was pressed, the system successfully sent a Telegram message containing the emergency text, the latest captured image, and a 5-second audio clip. The alerts were delivered almost instantly, demonstrating that the communication pipeline between the Raspberry Pi and the Telegram API was reliable. This feature gives the system a practical safety backup in case the user encounters an emergency situation.

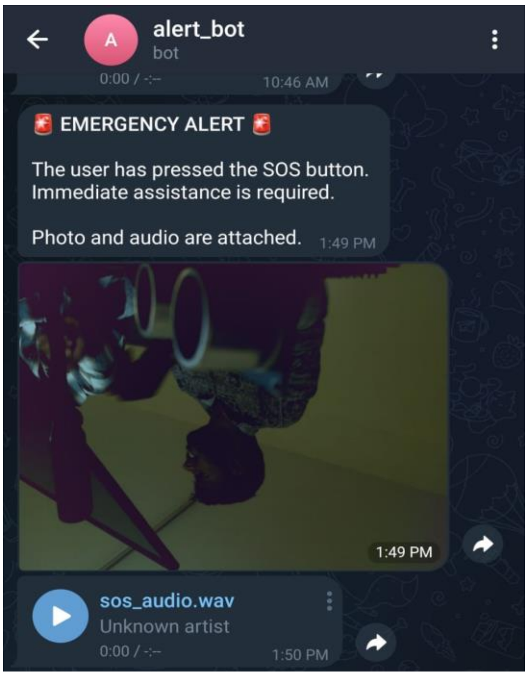

Figure 4.3 SOS Alert

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Overall, the results show that combining Li-Fi based room identification with sensor-assisted navigation and AI-based object recognition can create a functional and dependable indoor assistance tool for visually impaired individuals. While Li-Fi range is influenced by lighting conditions and the speech recognition delay is noticeable, the system still performs well enough for real-world scenarios. The discussion highlights that the chosen hardware components and algorithms worked cohesively to deliver accurate, responsive, and user-friendly assistance. With further refinements—especially offline speech recognition and improved Li-Fi range—the system has strong potential for scaling into larger environments and more advanced assistive applications.

V. CONCLUSION

This paper presented the design and implementation of a Li-Fi based indoor navigation and assistance system intended to enhance independent mobility for visually impaired individuals. By integrating Li-Fi based room identification, real-time orientation sensing using a magnetometer, obstacle detection with ultrasonic sensors, voice-guided navigation, AI-based object recognition, and an SOS emergency alert mechanism, the system delivers a complete and practical indoor assistance solution. The use of visible light communication enables accurate room-level localization with low infrastructure cost and minimal maintenance.

Experimental results obtained from a four-room prototype environment demonstrate that the system performs reliably under varying lighting conditions, achieves approximately 90% object detection accuracy using YOLOv8s, and provides timely navigation guidance with an average response delay of about five seconds. The SOS feature further strengthens user safety by enabling immediate communication with caregivers through image and audio alerts.

Overall, the proposed system proves that combining Li-Fi communication with embedded sensors and artificial intelligence can significantly reduce dependency on others and improve situational awareness for visually impaired users. With future improvements such as offline speech recognition, extended Li-Fi range, and large-scale deployment, the system has strong potential for real-world adoption in public and private indoor environments.

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