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Research paper

Intelligent Collaborative Navigation Support for The Visually Impaired

Ashwini Sawant [1] *, Venkata Ramya T. [2], Nilima Warke [2], Vijay Shejwalkar [3], Mahesh Singh [3]

[1] Department of Electronics and Telecommunication Engineering
[2] Department of Automation and Robotics Engineering
[3] Department of Artificial Intelligence and Data Science Engineering, Vivekanand Education Society's Institute of Technology Mumbai University, India
**Corresponding author E-mail: ashwini.sawant@ves.ac.in*

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Abstract

Navigating everyday situations can be difficult for vision impaired people, often limiting their independence Existing assistive technologies frequently fall short in terms of effectiveness and affordability. This study introduces a novel, integrated navigation system designed to enhance safety and autonomy. Combining a smart blind stick, cap, wristband, and smartphone application, the system leverages ultrasonic sensors for obstacle detection, a camera with TensorFlow Lite for real-time object recognition and audio feedback, and vibration feedback for improved spatial awareness. The wristband further integrates GPS and GSM for emergency communication, while the accompanying app offers customizable navigation settings. Early testing indicates this solution is more accurate, reliable, and user-friendly than current technologies, providing an affordable and effective tool for greater independence.

Keywords: *Navigation Aid; Visually Impaired; Assistive Technology; Object Detection System; Independent Navigation.*

1. Introduction

For those with vision impairments (VI), independent mobility is still a big difficulty despite tremendous technical advancements. Frequent tasks like shopping or navigating strange places frequently need for outside help, which reduces independence and self-assurance. Conventional methods, such as memorising routes or using sighted guides, are sometimes unreliable, especially in busy or dynamic environments. These constraints drive the creation of a low-cost, real-time navigation tool that prioritises usability, safety, and minimal infrastructure needs.

This article presents Drishti Sarathi, a multimodal navigation aid that combines proximity sensors, camera-based object identification, wearable gear (wristband, smart cap, and blind stick), and a smartphone interface. Through organised vibration patterns and aural feedback, the system provides real-time guidance, allowing users to identify common objects, identify difficulties, and call emergency assistance. When compared to current solutions, Drishti Sarathi highlights three key features:

1) low-cost deployment appropriate for environments with limited resources.
2) offline capability for both indoor and outdoor use.
3) coordinated haptic–audio input that lessens cognitive load while walking.

1.1. Target users and deployment context

NGOs, rehabilitation facilities, government hospitals, special education schools, and other organisations that assist people with partial or total vision impairment are the target audience for the suggested system. It is appropriate for inclusive education programs and public health facilities because to its inexpensive hardware cost and minimal connectivity needs. Through guided mobility exercises, Drishti Sarathi helps patients adjust to real-world environments in rehabilitation settings, while it aids object recognition training and spatial awareness in educational settings.

1.2. Novelty and contribution

The innovation of this system is the coordinated usage of several wearables with a single feedback mechanism, in contrast to earlier studies that concentrate on a single wearable or primarily rely on cloud services.

A hybrid sensing technique that combines infrared (IR), ultrasonic sensing, and vision-based object recognition for strong obstacle awareness is one of the major contributions.
Using lightweight deep-learning models, offline object identification on a Raspberry Pi eliminates need on constant internet connectivity.
In addition to audible indications, structured vibration feedback patterns are matched to obstacle direction and distance.
A GPS/GSM-based integrated emergency alert system that functions without cell phones in dire circumstances.

1.3. Related work

The proposed solution caters to a wide range of customers. Many of these clients are government and non-governmental organisations that work with blind individuals or children, such the Ashish Foundation. NGOs working in the areas of disability assistance, inclusive education, and assistive technology would find this product helpful in empowering those with visual impairments. The device will also be used in government hospitals and public health facilities for rehabilitation centres or assistive clinics for people who are blind or have low eyesight. This system is suitable for deployment in resource-constrained areas due to its low cost and minimal infrastructure needs. By incorporating auditory cues into occupational therapy or visual rehabilitation programs, hospitals can use the proposed method to assist patients in acclimating to their surroundings. In order to promote teaching practices that use voice-assisted identification and let students interact with real-world items, schools with blind students can integrate Drishti Sarathi into special education. It enables greater engagement, item recognition training, and increased spatial awareness.
An accelerometer and a network of infrared sensors were utilised by the device, which was controlled by a single microcontroller, to detect obstacles and help the user navigate. The audio output is provided by buzzers [1]. In terms of navigation, the TensorFlow-lite system guarantees both effectiveness and enhanced user safety with a 96.48 percent accuracy rate and 120 frames per second [2]. The technology, which provided real-time verbal instructions for boarding and disembarking buses, was 97.6% effective. Compared to GPS-based solutions, it operated indoors and offline and proved to be reliable and user-friendly for commuters with visual impairments [3].
In both indoor and outdoor environments, a smart blind stick with 87.24% detection accuracy that was enabled by IoT and ANN enhanced user autonomy [4]. Assistance walking device had voice-command control, emergency location sharing, and a buzzer function to aid locate the stick if it was misplaced [5]. A camera connected to a Raspberry Pi and machine learning models were used to create a system that generated real-time audio descriptions of commonplace objects [6].
An AI-powered smart stick with a computer vision foundation offered GPS tracking, emergency alerts, and auditory feedback for identifying faces, objects, and colours [7]. A review highlighted advancements in assistive technologies for the blind and VI that facilitate navigation and obstacle detection with haptic and auditory input [8]. A smartphone-based approach enabled autonomous navigation for those with visual impairments by utilising image recognition, obstacle detection, and collision avoidance [9].
A software system capable of text-to-speech and speech-to-text conversion using a mobile application enabled voice commands to be used for conversation by visually impaired individuals [10]. An HD webcam-equipped smart headpiece provided audio feedback from captured images and has a 128 GB SD card to prevent memory problems [11]. The traffic signal detection system using ESP32-CAM and ANN proved less practical in remote locations because of its dependence on cloud services and challenges in low light [12].
Although BLE beacons made it easier for people to use public transport, they were more costly and complex, and in crowded places, their signals were more likely to be disrupted [13–16]. Wearable technology, including a smart blind stick, helmet, and wristband, was able to detect obstacles and give feedback by vibrating or sending out sounds with the aid of a smartphone app [17–19].
The investigation detailed an SSD and YOLO-based real-time object recognition system that makes use of a Raspberry Pi and a Neural Compute Stick. Its cloud connectivity and modular architecture ensured real-world adaptability, while vibrations and audio alerts enhanced spatial awareness for blind and deaf users [20]. Deep learning is used by a Raspberry Pi garbage classification model to automatically sort rubbish and accurately identify various waste types. It provided a cost-effective substitute for traditional trash management because of its real-time processing, compact form factor, and ingenious environmentally friendly design [21]. OpenCV and Python face recognition on a Raspberry Pi enables real-time identification with minimal resource usage. By leveraging the Raspberry Pi's technology for effective data processing, the method offers a feasible means of integrating machine learning models into embedded security applications [22].
The investigation presents low-cost smart glasses for the blind and VI that employ Raspberry Pi technology to detect obstacles in real time. The gadget offers a low-cost method of boosting mobility and independence while lowering costs [23]. Deep learning, IoT, and Smart Cap technologies are all integrated into the system to assist those with visual impairments. Its real-time face and text recognition, powered by a Raspberry Pi, enables users to read text and identify faces. Features like OCR and news scraping enhance daily life and independence even more [24].
According to recent studies, navigation aids that use infrared or ultrasonic sensors to detect obstacles can achieve detection accuracy of about 85–90% in controlled conditions. On Raspberry Pi platforms, vision-based systems using CNNs, YOLO, or SSD models show great recognition accuracy (>95%) and real-time performance, although they frequently rely on cloud services or consume a lot of power. Though they usually lack coordinated multimodal feedback and offline capacity, wearable solutions like smart sticks, hats, or spectacles offer either haptic or aural feedback. Although BLE beacon-based and GPS-centric solutions work well in controlled settings, they must deal with interior signal interference and more expensive deployment.
Although these methods show significant advancements, there are still issues with low-cost offline operation, integrated multimodal input, and realistic deployment in a variety of settings. Drishti Sarathi uses optimised on-device processing and a single wearable ecosystem to fill these gaps.

1.4. Objectives

The main goal is to improve visually impaired users' independent mobility by providing a dependable and user-friendly navigational assistance. Specific objectives comprise:
Object and Obstacle Detection: Use sensor fusion and vision-based techniques to identify common objects and identify barriers in the vicinity.
Wearable Interface Design: Create wearables that are portable, pleasant, and offer clear haptic and audible feedback for prolonged use.
Navigation and Safety Support: To facilitate safe navigation in both known and new settings, provide real-time guidance and emergency notifications.

2. Materials and Methods

2.1. System architecture

A Raspberry Pi for image processing and object detection, an ESP32 microcontroller for sensor management, and wearable modules (blind stick, cap, wristband) comprise the system architecture. While vibration motors and audio output (text-to-speech) provide user feedback, cameras, infrared, and ultrasonic sensors gather ambient data. Emergency communication is made possible with a GPS/GSM module, which transmits the user's location to designated contacts.

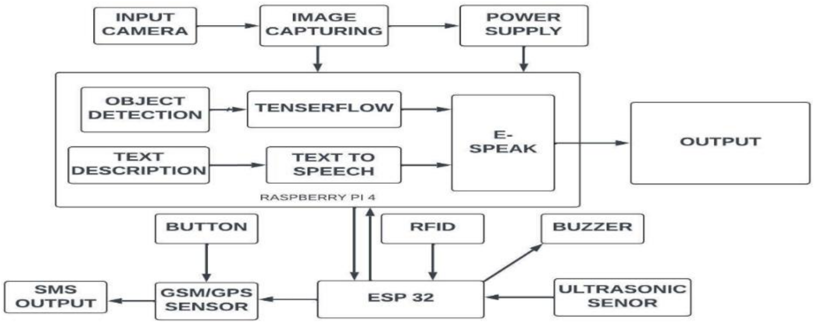

Fig. 1: Block Diagram of Proposed System.

The system provides visually impaired people with dependable navigation assistance by combining several hardware and software components. By identifying barriers, identifying items, and providing instant feedback, it assists children in walking securely and independently. To enhance mobility and spatial awareness, wearable technology—such as a smart blind stick, headgear, and wristband—is combined with technologies including ultrasonic sensors, cameras, and microcontrollers. Several technologies, including cameras, sensors, microcontrollers, and voice output systems, collaborate to help people with visual impairments navigate their surroundings. The primary objectives are to provide aural feedback and real-time obstacle and object recognition so that users can travel freely and safely.
The block diagram in Figure 1 illustrates the role of each system component. The main processing unit is the Raspberry Pi, which can also interpret camera images, identify objects, and produce noises using the eSpeak library. The Raspberry Pi and ESP32 microprocessor facilitate smooth system operation. Cameras and ultrasonic sensors can direct the user by using vibration or sound signals to identify barriers and their surroundings. An additional degree of security is provided in the event of an emergency by the GPS/GSM module and emergency button communicating position information. system's real-time object detection and clear feedback, users may easily explore both familiar and unfamiliar environments. The system is a useful tool for everyday living and safety since wearable technology, sensors, and microcontrollers work together to enhance mobility and freedom. In addition to making navigation simpler, this technique assists users in avoiding obstructions, resulting in safer travel. Because of its easy-to-use design, blind or visually impaired people can better regulate their environment.

2.2. Flowcharts

Three flowcharts, each of which represents a crucial operational function, are used to depict the system workflow:
Obstacle Detection (Smart Blind Stick): Threshold-based vibration and auditory alerts are followed by continuous distance measuring utilising infrared and ultrasonic sensors.
Emergency Alert Mechanism: GPS and GSM modules are activated when a button is pressed, location coordinates are obtained, and SMS messages are sent to designated contacts.
Object Detection and Audio Feedback: video frame capture, preprocessing, YOLO-based deep learning models for object detection, and speech output from discovered objects.

a). Working Mechanism of Blind Stick. **b). Working Process of GSM and GPS Sensor.** **c). Object detection model.**

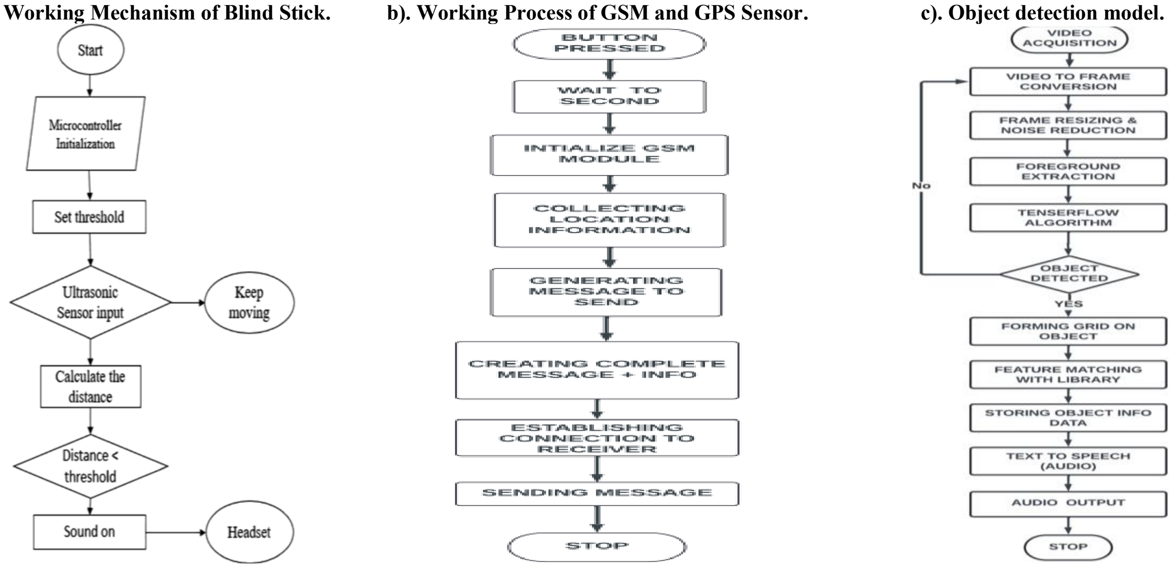

Fig. 2: Workflow of the System.

The first flowchart displayed in Figure 2(a) illustrates the precise operation of the smart blind stick, which aids blind people in identifying impediments in their route. It provides a thorough explanation of every step of the procedure, from configuring the microcontroller to using an ultrasonic sensor to continuously monitor the environment. The device will sound a buzzer as an auditory alert if it finds an impediment within the predetermined safety level. This system's real-time obstacle recognition features enable users to safely travel and steer clear of any dangers. The ultrasonic sensor continuously transmits and receives ultrasonic waves in order to look for impediments in its surroundings. The system uses an audio headset to notify the user if an obstruction is found within the predetermined threshold, as shown in Fig. 2(a). Safe navigation is made possible with real-time obstacle recognition, which gives users instant feedback to prevent collisions.

When the emergency button is pressed, the system waits a short while before activating the GPS and GSM modules, as seen in Fig. 2(b). The GPS module prepares to send a message to the GSM module after obtaining the user's current location. By merging these, an emergency notice is generated. The system then forwards the message to the user's designated contact to ensure timely assistance. After the message is sent, the procedure is finished.

The suggested navigation tool for individuals with vision problems uses a multi-step object detection algorithm. The system's first action is to capture video from the camera and turn it into frames. These frames are magnified and any extraneous noise is removed to make them legible, as seen in Fig. 2(c). The main objects in the frames are then identified using the TensorFlow approach. Once the object has been found, a grid is added around it to enhance recognition. When the object is compared to a library of stored data, details are kept. The user can hear real-time environmental updates thanks to a text-to-speech technology that converts this data into audio. Secure navigation and precise object detection are guaranteed by this procedure. Users' mobility and safety are increased via real-time updates and aural feedback that keep them aware of their surroundings.

2.3. Hardware implementation

2.3.1. Smart blind stick

The blind stick uses infrared and ultrasonic sensors to identify obstructions on the ground and in front of it, depicted in Figure 3. The ultrasonic sensor enhances short-range measurements up to about 3 m under regulated circumstances, while the infrared sensor offers dependable detection in the 10–80 cm range. Vibration feedback patterns are mapped as follows: continuous vibration for immediate risks, longer pulses for mid-range obstacles (0.5–1.5 m), and short pulses for nearby obstacles (<0.5 m). When distance data are unchanged, feedback is reduced to lessen alert fatigue.

Fig. 3: Smart Blind Stick for Obstacle Detection.

Fig. 4: Smart Cap for Obstacle Detection in Line of Sight.

Fig. 5: Smart Wrist-Band for Emergency Communication.

2.3.2. Smart cap

The smart cap, demonstrated in Figure 4, combines a camera and infrared sensor on the front to identify obstructions at the head and upper body levels. An audio buzzer alerts the user when an obstruction is found. To improve comfort and utility during continuous navigation, the buzzer output is automatically reduced if the same barrier remains at a set distance.

2.3.3. Smart wristband

A push button coupled to a NodeMCU microcontroller makes up the smart wristband. The SIM800L GSM module uses the mobile network to deliver an emergency message to designated contacts when it is turned on. The Neo-6M GPS module provides the wristband with location data, depicted in Figure 5, allowing for precise position sharing and quick help in an emergency.
Results and discussion
The design and development of the navigation aid for the blind is covered in this section. Numerous elements of the system are discussed in detail, including the object detecting system, headgear, wristband, and blind stick. Simplifying how the system helps blind people navigate their surroundings safely and easily is the main goal.

3.1. Experimental evaluation metrics

The system was assessed using the metrics listed below:
The accuracy of obstacle detection in mixed indoor environments is 86.2% for ultrasonic sensors and 90.8% for infrared sensors.
The accuracy of object recognition using YOLO-based detection on a Raspberry Pi is 95.6%.
Latency: Object-to-audio feedback has an average end-to-end reaction time of 240 ms, whereas obstacle alarms have an average of 180 ms.
During real-time object detection, the frame rate (FPS) is between 18 and 22 FPS.
Battery Usage: A 5000 mAh power bank can run continuously for about eight to ten hours.
These outcomes show that the system is energy-efficient for everyday use while still meeting real-time requirements.

3.2. Smart blind stick

IR and ultrasonic sensors are compared in Table 1. The IR sensor is appropriate for continuous obstacle detection because it provides quicker reaction times, greater accuracy, and reduced battery consumption. For redundancy and short-range verification, ultrasonic detection is still helpful.

Table 1: Comparison between Traditional Blind Stick & Project Blind Stick

Parameters	Traditional Blind Stick	Proposed Blind Stick
Customizability	No	Yes
Object detection Range	1-3 meter	0-1 meter
Portability	Heavy, & Difficult to use	Lightweight & easy to use
Response Time	Slow	Fast
Power Consumption	Low	High

Table 2: Comparison between Ultrasonic Sensor & IR Sensor

Parameters	Ultrasonic Sensors	IR Sensor
Accuracy	Lesser than IR Sensor	Highly Accurate
Range	100 cm	500-600 cm
Surface Requirement	Smooth & Plain surface	Surface doesn’t matter
Response Time	Slow	Fast
Power Consumption	High	Low

Table 2 illustrates that the blind stick's infrared sensor outperforms the ultrasonic sensor in terms of distance, accuracy, and response time. Integration is made easier by its lower size, which also keeps the device light and portable. The ultrasonic sensor is helpful for differentiating close objects, while having a lesser precision and a shorter range. Overall, the infrared sensor is the best option for quick and accurate obstacle notifications.

3.3. Smart cap for object detection

As demonstrated in Figure 6, the smart headgear uses a Raspberry Pi coupled to a front-facing camera. In order to reduce noise, captured video is pre-processed using OpenCV and transformed into frames. Figure 7 shows how YOLOv3 is used for object recognition. A text-to-speech engine is used to name detected objects and translate them into spoken output, which is then sent to the user via Bluetooth earphones. Safer navigation and real-time environmental awareness are made possible by this procedure.

Fig. 6: Camera Module Placed on Cap for Object Detection.

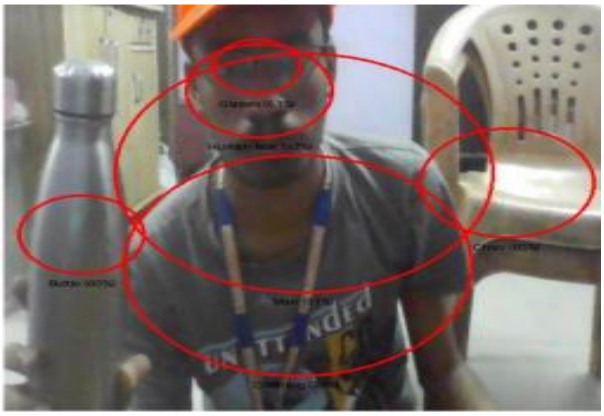

Fig. 7: Object Detection in Camera Module.

3.4. System limitations and environmental constraints

Despite its advantages, the system has drawbacks. The performance of infrared sensors deteriorates under direct sunshine or on shiny surfaces. Low light and occlusions hinder camera-based object recognition. Long-term camera use may shorten the battery life, even though it is sufficient. Energy optimisation, enhanced low-light vision models, and adaptive sensor calibration will be the main topics of future research.

3.5. Discussion

According to the trial findings, Drishti Sarathi offers dependable, real-time support with manageable latency and power consumption. Vibration and acoustic feedback are used in tandem to improve situational awareness without overpowering the user. The suggested method provides visually impaired people with a more complete and useful navigational help than current single-device alternatives.

3. Conclusions

In order to improve visually impaired people's independent mobility, this effort presented a complete and reasonably priced navigation aid system. The system offers dependable real-time support by combining hybrid sensing, camera-based object identification, and multimodal audio–vibration feedback with a smart blind stick, smart cap, and smart wristband.

Effective obstacle detection, precise object recognition, reasonable response latency, and energy-efficient operation appropriate for every-day use are all demonstrated by experimental evaluation. The suggested approach greatly increases safety in dire circumstances by sup-porting offline processing and integrating a GPS/GSM-based emergency alert mechanism, in contrast to many current solutions. The device works well in normal indoor and semi-outdoor settings, while performance may deteriorate in extremely bright illumination. All things considered, the suggested technique is a workable and scalable step towards safer and more inclusive navigation for users with visual impairments. Future research will concentrate on strengthening robustness and conducting more extensive real-world testing.

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