



SAARTHI: AI-Powered Smart Mobility Aid for Visually Challenged Individuals Using Hybrid and Priority-Based Obstacle Detection

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ABSTRACT- Saarthi is an AI-powered smart mobility aid designed to improve safe and independent navigation for visually challenged individuals. The system combines computer vision and ultrasonic sensing within a unified architecture to detect, classify, and prioritize obstacles in real time. Unlike traditional white canes, which detect only ground-level obstacles through physical contact, Saarthi provides intelligent environmental awareness through hybrid and priority-based obstacle detection.

The system performs real-time object detection using the YOLOv8 deep learning model and captures visual input through a Raspberry Pi camera module. Multiple ultrasonic sensors are used to measure obstacle distance and improve close-range hazard detection. A sensor fusion and decision logic module combines object classification with proximity measurements to assign each obstacle a priority level such as High, Medium, or Low. Based on this prioritization, the system generates adaptive audio and vibration alerts to warn the user effectively.

The complete system operates offline on Raspberry Pi 5, ensuring low latency, privacy, and reliable real-time performance. Saarthi transforms assistive mobility from basic obstacle detection into an intelligent, context-aware navigation support system, improving safety, confidence, and independence for visually challenged users.

Keywords: Assistive Technology, Smart Cane, YOLOv8, Raspberry Pi 5, Ultrasonic Sensors, Priority-Based Detection, Sensor Fusion, Visually Challenged, Computer Vision

1. INTRODUCTION

Safe and independent mobility is one of the most important challenges faced by visually challenged individuals in everyday life. Navigating through roads, staircases, uneven surfaces, crowded pathways, and dynamic outdoor environments requires continuous awareness of nearby obstacles and potential hazards. Traditional white canes are useful for basic navigation support, but they are limited in their ability to detect only immediate ground-level obstacles through physical contact.

With the advancement of artificial intelligence and embedded systems, smart assistive technologies are becoming more capable of providing meaningful environmental awareness and real-time safety support. In

particular, the combination of computer vision and sensor-based obstacle detection has created new opportunities for intelligent mobility assistance.

In this context, Saarthi is proposed as an AI-powered smart mobility aid designed to assist visually challenged individuals through hybrid and priority-based obstacle detection. The system combines YOLOv8-based object detection, ultrasonic sensing, and real-time decision logic to detect obstacles, evaluate their danger level, and provide immediate alerts using audio and vibration feedback.

The project aims to improve obstacle awareness, reduce the risk of accidents, and support more confident and independent mobility through an intelligent and practical assistive system.

2. PROBLEM STATEMENT

Over 2 billion people worldwide are affected by visual impairment, and safe navigation remains one of the most critical challenges in their daily lives. Visually challenged individuals often face difficulty while moving through complex environments such as roads, staircases, crowded areas, and uneven terrain, where the risk of collisions, falls, and injuries is significantly high.

Traditional white canes, although widely used, can detect only ground-level obstacles after physical contact. They are unable to detect:

moving obstacles such as vehicles or bicycles elevated obstacles such as hanging boards or branches approaching hazards the type or urgency of nearby obstacles

This limitation reduces environmental awareness and delays user response. Existing electronic mobility aids often rely only on ultrasonic sensors, which can measure distance but cannot identify object type or differentiate between static and dynamic hazards. As a result, users may receive uniform alerts without meaningful prioritization.

Therefore, there is a need for a smart and intelligent mobility aid that can detect both static and dynamic obstacles, recognize object type using AI, evaluate obstacle urgency, and provide immediate and meaningful feedback in real time. Saarthi is developed to address this problem through hybrid sensing and priority-based obstacle detection.

3. OBJECTIVES

The main objective of the Saarthi project is to develop an AI-powered smart mobility aid that improves navigation safety and obstacle awareness for visually challenged individuals.

The specific objectives of the project are as follows:

1. To detect both static and dynamic obstacles

The system is designed to identify nearby environmental hazards such as walls, poles, staircases, vehicles, and pedestrians.

2. To implement real-time object detection using YOLOv8

The project aims to use AI-based visual recognition for accurate obstacle identification.

3. To integrate ultrasonic sensing for distance measurement

The system uses multiple ultrasonic sensors to estimate obstacle proximity and improve close-range awareness.

4. To implement priority-based obstacle detection

The system aims to classify obstacles based on object type, distance, and motion behavior, so that critical hazards receive higher priority.

5. To generate adaptive user alerts

The project provides audio alerts and vibration feedback based on the assigned priority level.

6. To ensure offline real-time operation

The system is designed to operate entirely on-device without requiring internet connectivity.

7. To improve safety, confidence, and independent mobility

The overall objective is to create a practical assistive solution that enhances user confidence and safe movement in real-world conditions.

4. LITERATURE REVIEW

Several assistive mobility systems have been developed to support visually challenged individuals using different sensing and detection approaches. These systems generally rely on ultrasonic sensing, computer vision, or a combination of both. However, many existing solutions still face limitations in real-world usability, accuracy, and intelligent decision-making.

1. Ultrasonic Sensor-Based Systems

Many traditional smart cane systems are based on ultrasonic sensors for obstacle detection. These systems measure the distance of nearby obstacles and provide basic alerts to the user. While they are effective for short-range detection, they are unable to identify the type of obstacle or distinguish between static and dynamic hazards. As a result, users receive uniform alerts without meaningful contextual information.

2. Computer Vision-Based Systems

Recent advancements in artificial intelligence have enabled the use of computer vision models for assistive navigation. Object detection models such as YOLO allow systems to identify obstacles like pedestrians, vehicles, and barriers in real time. These systems improve environmental awareness but may struggle with accurate distance estimation and real-time reliability when used alone.

3. Hybrid Detection Systems

To overcome the limitations of individual approaches, some systems combine computer vision with ultrasonic sensing. This hybrid approach improves detection accuracy by combining object recognition with distance measurement. However, many existing hybrid systems still lack intelligent decision-making and often provide multiple alerts without prioritizing urgency.

4. Limitations of Existing Systems

From the study of existing solutions, the following key limitations are observed:

lack of object classification in sensor-only systems

absence of distance validation in vision-only systems

no prioritization of detected obstacles

generation of excessive or irrelevant alerts

5. Proposed Approach in Saarthi

The Saarthi addresses these limitations by integrating:

YOLOv8-based real-time object detection

ultrasonic sensor-based distance measurement

sensor fusion for improved accuracy

priority-based obstacle classification

adaptive audio and vibration feedback

This combination enables Saarthi to provide more meaningful, accurate, and user-friendly assistive navigation compared to existing systems.

Table I COMPARISON OF EXISTING ASSISTIVE MOBILITY SYSTEMS AND PROPOSED SAARTHI SYSTEM

System	Features	Limitations
Traditional White Cane	Simple, low cost	Detects only after contact
Ultrasonic Smart Cane	Distance-based obstacle detection	No object identification
Vision-Based Systems	Object recognition	No accurate distance estimation
WeWALK Smart Cane	Navigation support, voice guidance	No priority-based obstacle detection
Existing Hybrid Systems	Better obstacle detection	No intelligent alert prioritization
Saarthi	YOLOv8 + ultrasonic + camera + priority alerts	Improved real-time assistive support

5. PROPOSED SYSTEM

Saarthi is designed as an intelligent assistive mobility system that improves traditional obstacle detection through a hybrid sensing architecture and priority-based decision-making mechanism. The system not only detects obstacles but also evaluates their danger level before generating alerts.

The proposed system consists of:

Raspberry Pi camera module for visual input

4 Ultrasonic Sensors for multi-directional distance sensing

Raspberry Pi 5 for local AI processing and decision-making

PAM8403 Amplifier + Audio Exciter for audio alerts

Coin Vibration Motors for tactile feedback

3S Li-ion Battery Pack + buck converter + rocker switch for power supply

The camera module captures real-time frames of the surrounding environment, which are processed using the YOLOv8 model for object detection. Simultaneously, ultrasonic sensors measure the distance of nearby obstacles from multiple directions. The system then combines object classification and distance data through a sensor fusion module.

A major feature of Saarthi is its priority-based obstacle detection mechanism, where detected obstacles are classified into High, Medium, or Low Priority depending on:

object type

distance from the user

and motion behavior

Based on this analysis, the system generates adaptive alerts through audio and vibration feedback. This approach helps reduce unnecessary warnings and ensures that critical hazards are communicated to the user immediately.

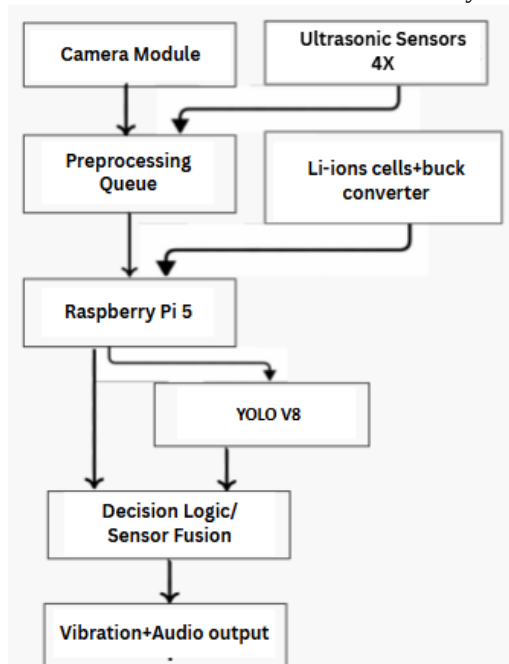


Figure. 1. Workflow of SAARTHI

6. OVERALL ARCHITECTURE

The Saarthi system follows a three-layer hybrid architecture consisting of:

1. Input Layer (Sensing Layer)

This layer includes:

Raspberry Pi camera module

4 Ultrasonic Sensors

The camera module captures real-time visual frames, while ultrasonic sensors provide distance measurements in multiple directions.

2. Processing Layer

This layer is handled by Raspberry Pi 5 and includes:

YOLOv8 Object Detection Module

Sensor Fusion Module

Priority-Based Decision Logic

This layer performs obstacle detection, validation, and risk prioritization.

3. Output Layer

This layer includes:

Audio Alert System

Vibration Feedback System

Based on the assigned priority, the system generates suitable multimodal alerts for the user.

This architecture improves reliability, modularity, and real-time assistive performance.

7. HARDWARE REQUIREMENTS AND COMPONENTS

1. Raspberry Pi 5

The Raspberry Pi 5 acts as the central processing unit of the system. It handles:

AI inference,

sensor interfacing,

decision logic,

and feedback control.

It enables on-device real-time processing and offline operation.

2. Raspberry Pi camera module

The camera module captures real-time visual frames of the surrounding environment and provides high-resolution image input for YOLOv8-based object detection.

3. Ultrasonic Sensors (4x)

Four ultrasonic sensors are used to measure obstacle distance and provide multi-directional coverage, including:

front,

left,

right,

down.

4. Speaker / Audio Output System

The audio output system provides voice-based alerts describing detected obstacles.

5. PAM8403 Amplifier Module

The PAM8403 module amplifies the audio signal so that alerts remain clearly audible in practical environments.

6. Coin Vibration Motors

The vibration motors provide tactile feedback and help users receive alerts quickly, especially in noisy surroundings.

7. Rocker Switch

A rocker switch is used to switch on and off the Saarthi based on user preference.

8. Rechargeable Li-ion cells

The Saarthi system is powered using a Li-ion battery pack, which provides portable and reliable energy for the complete hardware setup. The battery pack supplies the required power to Raspberry Pi 5, sensors, and output modules, enabling the system to operate independently without a direct external power source. The use of Li-ion batteries makes the system compact, rechargeable, and suitable for practical assistive mobility applications.

9. Buck Converter

A buck converter module is used to regulate and step down the battery voltage to the required operating level for different components of the system. This ensures a stable and safe power supply for Raspberry Pi 5 and other connected modules. The buck converter helps improve power efficiency and protects the hardware from voltage fluctuations.

10. Walking Stick Base

The stick serves as the main mechanical structure for mounting all components while maintaining portability and usability.

8. SOFTWARE REQUIREMENTS AND IMPLEMENTATION

1. Raspberry Pi OS

The Saarthi system is developed and executed on Raspberry Pi OS, which serves as the operating environment for all software modules. It supports hardware interfacing, camera input, sensor communication, and execution of the object detection model on Raspberry Pi 5. The operating system provides a stable platform for embedded AI and real-time processing.

2. Python Programming Language

The complete software implementation of Saarthi is carried out using Python. Python was selected because of its simplicity, readability, and wide support for AI, computer vision, and hardware interfacing libraries. It allows smooth integration of object detection, ultrasonic sensing, and user feedback modules within a single embedded system.

3. YOLOv8 Framework

The YOLOv8 framework is used for real-time object detection in the Saarthi system. This framework enables the model to identify surrounding obstacles such as vehicles, pedestrians, poles, and barriers with high speed and good accuracy. It is suitable for embedded applications because it supports efficient inference and real-time visual processing.

4. OpenCV Library

The OpenCV library is used for image capture, frame handling, and preprocessing of visual data before object detection. It helps in acquiring continuous frames from the camera module and preparing them for YOLOv8 inference. OpenCV plays an important role in the vision pipeline of the system.

5. GPIO Interface Libraries

GPIO interface libraries are used to establish communication between Raspberry Pi 5 and the connected hardware components such as ultrasonic sensors, vibration motors, toggle switch, and audio output system. These libraries allow the software to send and receive control signals for proper hardware operation.

6. Object Detection Module

The object detection module is one of the most important software components of Saarthi. It continuously receives video frames from the camera module and processes them using the YOLOv8 model. The system identifies surrounding obstacles and extracts useful information such as object class, location, and confidence score. Only valid detections are considered for further analysis to improve system reliability.

7. Ultrasonic Sensor Interface

The ultrasonic sensor interface is used to collect real-time distance measurements from the ultrasonic sensors mounted on the stick. The software sends trigger signals, receives echo responses, and calculates the distance of nearby obstacles. This data is then passed to the decision-making module for obstacle validation and proximity analysis.

8. Sensor Fusion Module

The sensor fusion module combines the outputs of the object detection system and ultrasonic sensors. This integration helps the system validate detected obstacles more accurately and reduces the chances of false alerts. By combining object recognition and distance measurement, Saarthi is able to provide more meaningful obstacle awareness.

9. Priority-Based Decision Logic

The priority-based decision logic is a key software feature of Saarthi. It analyzes each detected obstacle based on its type, distance, and risk level, and assigns a suitable priority such as High, Medium, or Low. This ensures that the system does not treat every detected object equally and instead focuses more on hazards that require immediate attention.

10. Alert Generation Module

The alert generation module is responsible for converting the obstacle analysis into user-understandable warnings. Based on the assigned priority level, the system generates suitable audio alerts and vibration feedback. High-priority obstacles trigger stronger and more immediate alerts, while lower-priority obstacles generate softer warnings.

11. Offline Processing Capability

One of the major strengths of the Saarthi software system is its offline operation. All image processing, object detection, sensor analysis, and alert generation are performed locally on Raspberry Pi 5 without requiring internet connectivity. This improves privacy, reduces latency, and makes the system more practical for real-world assistive use.

9. IMPLEMENTATION

1. Physical Integration

The Saarthi system is physically integrated on the walking stick in a compact and functional arrangement. Each component is placed according to its purpose so that sensing, processing, and user feedback can work together efficiently. This arrangement supports portability, proper balance, and ease of use during navigation.

2. Handle Section

The handle section contains the main user feedback components of the system. It includes the coin vibration motors and audio exciter, which are placed close to the user so that alerts can be received quickly and effectively. This placement improves both tactile and audio communication during movement.

3. Camera Placement

The Raspberry Pi camera module is mounted in the upper section of the stick in a forward-facing position. It is slightly tilted downward so that it can capture the user's walking path more effectively. This placement helps the object detection system monitor the environment ahead in real time.

4. Ultrasonic Sensor Placement

The ultrasonic sensors are placed at different positions on the stick to provide multi-directional obstacle awareness. Their placement helps the system monitor frontal, side, and lower regions of the user's path. This improves the detection of close-range obstacles and sudden ground-level hazards.

5. Central Electronics Integration

The main electronics, including Raspberry Pi 5, battery pack, and voltage regulation module, are integrated in the central section of the system. This section acts as the core processing and power unit and ensures stable operation of the complete assistive system.

6. Hardware-Software Coordination

The final implementation of Saarthi depends on smooth coordination between hardware and software modules. The camera captures visual data, ultrasonic sensors measure distance, Raspberry Pi processes both inputs, and the alert system generates appropriate feedback. This complete

integration enables the smart cane to function as a unified assistive device.

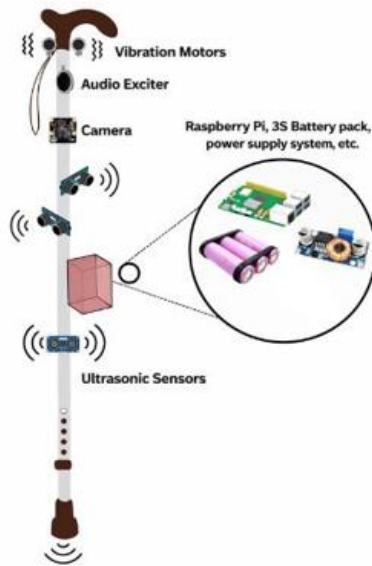


Figure.2.Physical Implementation Layout of the Saarthi Smart Cane

10. RESULTS AND PERFORMANCE ANALYSIS

The Saarthi prototype was tested under different practical conditions to evaluate its real-time performance, obstacle detection capability, and user alert effectiveness. The testing process was focused on analyzing how accurately and reliably the system could identify obstacles, measure their distance, assign priority, and provide timely feedback to the user.

1. Testing Environment

The Saarthi prototype was tested under different real-world and controlled conditions to evaluate its performance. Testing was carried out in indoor corridors, outdoor pathways, roadside environments, uneven surfaces, and staircase-related areas. These conditions were selected to observe the system's behavior under practical mobility scenarios.

2. Object Detection Performance

The object detection system successfully identified various surrounding obstacles in real time using YOLOv8. During testing, the system was able to recognize common hazards such as pedestrians, vehicles, poles, and barriers. This improved the user's environmental awareness beyond basic proximity sensing.

3. Distance Detection Performance

The ultrasonic sensing system effectively measured the proximity of nearby obstacles. It helped the system determine how close an obstacle was and improved the reliability of close-range warnings. This was particularly useful for immediate hazard awareness.

4. Priority-Based Detection Performance

One of the most important outcomes of the system was the successful implementation of priority-based obstacle classification. Obstacles that posed greater danger were assigned higher priority and triggered stronger warnings. This reduced unnecessary alerts and made the system more user-friendly and practical.

5. Alert Generation Performance

The system successfully generated audio alerts and vibration feedback according to obstacle priority. High-priority obstacles produced stronger and more immediate

feedback, while lower-priority obstacles generated softer warnings. This adaptive feedback mechanism improved usability and safety.

6. Response Time

The Saarthi system demonstrated real-time performance during testing. The complete cycle of image capture, object detection, distance validation, priority evaluation, and feedback generation was completed in a short time, making the system suitable for practical assistive navigation.

7. Overall Performance

The final prototype successfully demonstrated hybrid obstacle detection, priority-based alert generation, and offline operation. The overall performance of the system confirms its potential as an effective smart mobility aid for visually challenged individuals.

11. ADVANTAGES

The Saarthi system provides several important advantages over traditional mobility aids and basic smart obstacle detection devices. By combining AI-based object detection, ultrasonic sensing, and adaptive feedback, the system offers more meaningful environmental awareness and improves the user's navigation experience.

1. Real-Time Obstacle Detection

The system detects surrounding obstacles in real time, helping the user respond more quickly and safely during movement.

2. Hybrid Detection Approach

By combining computer vision and ultrasonic sensing, the system improves obstacle awareness and reduces the limitations of using only one detection method.

3. Priority-Based Alerting

The system classifies obstacles based on their urgency and provides alerts accordingly, which reduces unnecessary warnings.

4. Audio and Vibration Feedback

The use of both audio and tactile feedback makes the system more practical and user-friendly in different environments.

5. Offline Operation

The system works completely offline, which improves privacy, reliability, and usability in real-world conditions.

6. Improved User Safety

By detecting both static and dynamic obstacles, the system improves environmental awareness and supports safer navigation.

12. LIMITATIONS

Although Saarthi demonstrates effective performance as a smart assistive mobility aid, the current prototype still has certain limitations. These limitations are common in embedded AI-based systems and highlight areas where future improvements can further enhance performance and usability.

1. Lighting Dependency

The object detection performance may be affected in poor lighting or low-visibility conditions.

2. Hardware Constraints

Since the system runs on embedded hardware, performance may depend on available processing power and optimization.

3. Limited Real-World Testing

Although the system was tested practically, larger-scale testing with more users can improve validation.

4. Environmental Complexity

Highly crowded or visually cluttered environments may affect detection consistency.

5. Scope for Miniaturization

Further compact hardware design can improve user comfort and portability.

13. FUTURE SCOPE

The Saarthi system has strong potential for future enhancement and wider real-world application. With further development, the system can become more intelligent, compact, and suitable for advanced assistive mobility support.

1. GPS-Based Navigation

Future versions of the system can include GPS support for route guidance and outdoor navigation assistance.

2. Voice Assistant Integration

Voice command support can improve user interaction and make the system easier to operate.

3. Low-Light Detection Enhancement

Infrared or night-vision support can improve performance in dark or poorly lit environments.

4. Compact PCB-Based Design

A dedicated PCB-based hardware layout can reduce size and improve portability.

5. Better Battery Optimization

Future work can focus on improving battery efficiency and increasing runtime.

6. Advanced Motion Tracking

Motion analysis can be added to improve the detection of moving obstacles and dynamic hazards.

CONCLUSION

The Saarthi project demonstrates how embedded AI and sensor fusion can be effectively used to develop a practical and intelligent mobility aid for visually challenged individuals. The system successfully combines object detection, distance sensing, and priority-based feedback to provide a more meaningful navigation support mechanism.

1. Project Outcome

The Saarthi project successfully demonstrates the design and implementation of an AI-powered smart mobility aid capable of hybrid and priority-based obstacle detection.

2. Technical Contribution

By integrating YOLOv8-based object detection, ultrasonic sensing, and adaptive audio-vibration feedback, the system provides a more intelligent alternative to conventional mobility aids.

3. Practical Significance

The system improves obstacle awareness, reduces false alerts, and supports safer and more independent navigation for visually challenged individuals.

4. Final Remark

Overall, SAARTHI shows strong potential as an affordable, practical, and user-oriented assistive mobility solution for real-world use.

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