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Real-Time Ai Navigation and Obstacle Detection for Blind Users

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Abstract- Independent mobility remains a major challenge for visually impaired individuals, particularly in dynamic and unfamiliar environments where obstacles and navigation hazards are unpredictable. Conventional assistive aids such as white canes and guide dogs offer limited environmental perception and do not provide real-time situational awareness. This work proposes a Real-Time AI-Based Navigation and Obstacle Detection System for Blind Users aimed at improving safe and autonomous movement in indoor and outdoor settings. The system combines computer vision, deep learning, and sensor fusion to continuously analyze the surrounding environment. A lightweight convolutional neural network processes live video input to identify both static and moving obstacles, while depth estimation and ultrasonic sensors are used to accurately measure distance and assess collision risk. An intelligent path planning module determines safe navigation directions based on real-time spatial analysis. Guidance is conveyed to users through audio cues and haptic feedback via wearable devices, ensuring intuitive and unobtrusive interaction. Edge-based processing enables low-latency responses and reliable performance even in low-connectivity conditions. Experimental results indicate enhanced obstacle detection accuracy, faster response times, and increased user confidence when compared with traditional mobility aids. The proposed system provides an efficient, affordable, and scalable solution to support independent navigation and improve quality of life for visually impaired users.

Keywords: Assistive Systems, Obstacle Detection, Artificial Intelligence, Computer Vision, Real-Time Navigation, Visual Impairment.

I. INTRODUCTION

individuals to maintain autonomy, participate in social activities, and access educational and professional opportunities. However, navigating complex and dynamic environments is often challenging due to unexpected obstacles, uneven surfaces, and limited spatial awareness. Conventional assistive tools, such as white canes and guide dogs, provide only basic obstacle detection and proximity feedback, lacking predictive guidance or information about hazards beyond immediate reach. Consequently, visually impaired users frequently face safety risks and restricted independence in daily life.

Advances in artificial intelligence (AI), computer vision, and sensor technologies have enabled the development of intelligent assistive systems capable of providing real-time environmental awareness. AI-driven navigation solutions can analyze live visual and sensor data to detect obstacles, estimate distances, and plan safe paths. When combined with intuitive haptic and audio feedback, these systems offer non-intrusive guidance that enhances user confidence and facilitates independent movement.

Most existing solutions, however, rely on single-sensor modalities or centralized processing, which can introduce latency, connectivity issues, and limited adaptability to real-world environments. To overcome these limitations, this work proposes a real-time AI-based navigation and obstacle detection system that integrates multi-sensor fusion, deep learning-based object recognition, and edge computing for low-latency decision-making. The system identifies static and dynamic obstacles, calculates distances, and generates context-aware navigational guidance delivered through wearable audio and haptic interfaces.

By providing accurate, timely, and adaptive assistance, the proposed platform aims to improve mobility, safety, and independence for visually impaired users. Leveraging AI and real-time processing, this system represents a significant step toward advanced intelligent assistive technologies, contributing to enhanced quality of life, social participation, and autonomy for individuals with visual impairments.

II. RELATED WORKS

P. Gharani, "Context aware Obstacle Detection for Navigation by Visually Impaired," Image and Vision Computing, 2017.

Gharani introduces a context aware visual obstacle detection method using smartphone cameras to aid indoor navigation for visually impaired users. The approach processes consecutive image frames and applies optical flow and feature tracking to detect obstacles in real time. A novel context aware data fusion technique determines frame rate and critical image regions, improving obstacle detection accuracy and robustness. Experimental results show improved precision and recall over baseline methods, with faster clustering and more reliable detection performance across diverse indoor environments. D. Das, "Real Time Wayfinding Assistant for Blind and Low Vision Users," arXiv, 2025.Das proposes PathFinder, a map less navigation system that integrates monocular depth estimation and vision language models to enhance real time obstacle avoidance and route planning. Using depth images and a Depth First Search (DFS) algorithm, the system identifies the longest obstacle free path dynamically. Usability studies indicate high computational efficiency and improved navigation accuracy in outdoor scenarios, with most users able to operate the system within one minute.

N. Pfitzer, "MR.NAVI: Mixed Reality Navigation Assistant for the Visually Impaired," arXiv, 2025.

Pfitzer presents MR.NAVI, a mixed reality navigation assistant combining object detection, depth estimation, and natural language processing to support visually impaired users. The system uses MobileNet for object recognition and RANSAC based floor detection with DBSCAN clustering for obstacle avoidance, providing contextual scene descriptions and proactive guidance. MR.NAVI also incorporates public transit data, evaluated through user studies that demonstrate usability and effectiveness in unfamiliar environments. J. Bai, "Wearable Travel Aid for Environment Perception and Navigation of Visually Impaired People," arXiv, 2019.Bai et al. develop a wearable assistive device shaped like eyeglasses equipped with an RGB D camera and IMU sensors to detect obstacles and guide visually impaired users. By segmenting ground and obstacle regions and computing optimal walkable directions, the system informs users via audio feedback. Field evaluations with visually impaired participants demonstrate successful obstacle avoidance and navigation through complex indoor scenes, highlighting the potential of wearable visual systems for independent mobility.

Kumar, "ViT Cane: Visual Assistant for the Visually Impaired," arXiv, 2021 introduces ViT Cane, an assistive navigation system using a vision transformer (ViT) model for real time obstacle detection. The design integrates a Raspberry Pi and Pi Camera module to capture environmental data and classify obstacles using the transformer network. The approach achieves higher detection performance on COCO like datasets compared with traditional CNN models and effectively supports indoor navigation with tactile motor feedback, enabling safe traversal for visually challenged users. Y. Said, "Obstacle Detection System for Navigation Assistance of Visually Impaired People Based on Deep Learning Techniques," Sensors, 2023.Said et al. propose a deep learning based navigation aid incorporating neural architecture search (NAS) to automatically optimize an object detection model for visually impaired users. The system uses an anchor free detection framework and efficient backbone architecture to achieve real time obstacle detection with indoor and outdoor datasets. Experimental results show enhanced average precision and reduced computational overhead, demonstrating robust performance and potential for embedded device deployment. Bhuvanesh ., "Human Identification and Obstacle Detection System for Blind," IJRASET, 2023.

develop a real time human and obstacle recognition system using the Faster Region CNN (FRCNN) architecture. The system identifies obstacles and people in complex scenes and provides voice alerts to users, indicating object type, position, and proximity. This AI based vision system offers accessible navigation support, improving situational awareness and safety for visually impaired individuals in both indoor and outdoor environments.

Rakesh N., "YOLOv3 Based Smart Assistive Navigation System for Visually Impaired Individuals," IJRASET, 2024.

Rakesh et al. design an assistive navigation solution using the YOLOv3 object detection algorithm to support blind and visually impaired users. Wearable devices capture video data, and YOLOv3 processes frames in real time to detect obstacles and environmental features. The system focuses on enhancing mobility across daily activities with integrated feedback mechanisms, making navigation safer and more intuitive for users in varied environments. Hemamalini M., "Smart Obstacle Detection System: An AI IoT Powered Assistive System for the Visually Impaired," IJRASET, 2025. Hemamalini et al. present an AI IoT integrated assistive platform that combines obstacle detection, facial recognition, scene description, and OCR to deliver comprehensive real time feedback via voice output. The system enhances spatial awareness and social interaction by providing contextual scene information and user alerts, improving independence and confidence for visually impaired individuals navigating complex environments. Bhasha Pydala, "Smart_Eye: A Navigation and Obstacle Detection for Visually Impaired People through Smart App," JAETS, 2023.

Pydala et al. propose Smart_Eye, a smartphone based navigation and obstacle detection application that identifies and recognizes objects to support visually impaired users. The system uses vision algorithms and sensors to improve object localization and contextual awareness. By enhancing environmental perception and providing real time feedback, Smart_Eye aims to reduce navigation difficulty in unfamiliar spaces and boost user independence.

III. PROPOSED METHOD

The proposed real-time AI navigation and obstacle detection system for visually impaired users integrates multiple components to provide accurate, adaptive, and intuitive mobility assistance. The methodology begins with a multi-sensor data acquisition layer, where RGB cameras, depth sensors, ultrasonic sensors, and inertial measurement units (IMUs) collectively capture environmental information. RGB cameras extract visual features from the surroundings, while depth sensors provide precise distance measurements for obstacle localization. Ultrasonic sensors offer redundant proximity detection, particularly useful in low-light or occluded areas, and IMUs provide orientation and motion data to ensure consistent spatial-temporal alignment. All incoming sensor data are preprocessed through noise reduction, normalization, and temporal-spatial synchronization to create a unified dataset suitable for real-time analysis. The obstacle detection module employs a lightweight convolutional neural network (CNN) optimized for deployment on edge devices. The CNN is trained to identify static and dynamic obstacles, such as pedestrians, vehicles, and environmental hazards, using both RGB and depth data. Object tracking algorithms monitor moving obstacles across consecutive frames, while a context-aware classification system prioritizes potential hazards based on proximity, size, and trajectory. The system integrates an AI-based path planning module, which analyzes detected obstacles and environmental maps to determine safe navigation routes. A reinforcement learning (RL) algorithm continuously updates navigation policies by considering obstacle proximity, user movement, and previously traversed paths, allowing the system to adapt to dynamic conditions. Indoor navigation leverages grid-based mapping and real-time optimization, whereas outdoor navigation uses GPS data and semantic segmentation to identify walkable paths. User feedback is delivered through multimodal interfaces, including audio instructions and haptic signals via wearable devices such as smart glasses or wristbands. Audio cues provide directional guidance, while vibration patterns indicate obstacle distance and severity, enabling intuitive and non-intrusive interaction. To ensure low latency and high responsiveness, all computations—including CNN inference, object tracking, and RL-based path optimization—are performed on edge devices, reducing dependency on cloud connectivity and enabling reliable operation in real-world scenarios. The system also incorporates continuous learning, where user feedback and detected interactions with obstacles are logged to refine the CNN and RL models over time. This closed-loop adaptation improves the system's accuracy, responsiveness, and user confidence. Overall, the methodology combines sensor fusion, deep learning-based object detection, AI-driven adaptive path planning, and real-time multimodal feedback to provide a scalable, efficient, and user-centric solution. The proposed approach enhances independent mobility, improves safety, and delivers an intelligent navigation experience for visually impaired individuals in both indoor and outdoor environments, demonstrating the potential for practical deployment in everyday life.Alongside decision generation, the system incorporates an Explainable AI (XAI) Module to enhance transparency and trust. This module applies feature attribution and rule-based explanation techniques to clearly justify each recommendation. Farmers are informed about how factors such as soil nutrients, weather conditions, and crop growth stages influence the system's advice. By providing understandable explanations rather than black-box outputs, the platform improves user confidence and adoption.

Data Acquisition

The system initiates with real-time environmental sensing using wearable devices. RGB cameras capture live images, depth sensors measure distances to obstacles, and ultrasonic sensors detect nearby objects to provide spatial awareness. This multi-sensor approach enables detection of both static and moving obstacles in indoor and outdoor environments. The acquisition module handles sensor calibration, time synchronization, and preprocessing to ensure consistent and accurate input data. Continuous data streaming supports real-time analysis and decision-making, forming the foundation for subsequent AI-based obstacle detection and navigation guidance.

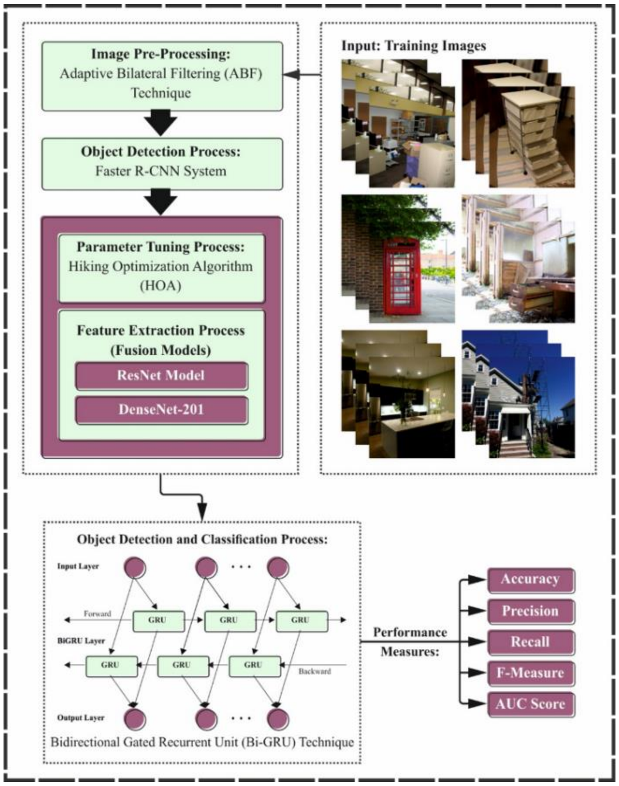

Fig.1. System Architecture

Data Preprocessing and Feature Extraction

Collected raw data are processed to improve reliability and usability. Image frames are resized, contrast-enhanced, and augmented, while depth and ultrasonic readings are filtered to remove noise. Feature extraction is performed using convolutional neural networks (CNNs) to identify edges, shapes, and textures in the environment. Depth and distance features are fused with visual information to create a multi-modal representation of obstacles. These extracted features serve as inputs for the AI obstacle detection and path planning modules, enabling accurate identification and localization of obstacles in diverse lighting and environmental conditions.

Obstacle Detection Using Deep Learning

Obstacle recognition relies on a lightweight CNN or vision transformer (ViT) model optimized for edge devices. The model classifies obstacles into categories such as static objects, dynamic obstacles, pedestrians, and pathways. Visual features are combined with depth measurements to improve distance estimation and localization accuracy. The network is trained on diverse datasets covering indoor and outdoor scenarios to ensure robustness under varying conditions. Each detected obstacle is assigned a confidence score and proximity estimate, which informs path planning. This AI-based detection provides fast and accurate identification of obstacles, supporting safe navigation in real-world environments.

Path Planning and Navigation Guidance

Following obstacle detection, a path planning module computes safe routes using reinforcement learning (RL) or graph-based algorithms such as Dijkstra. Multi-sensor data are used to dynamically map the environment and identify collision-free paths. The navigation system prioritizes safety, efficiency, and accessibility while adapting to moving obstacles and environmental changes. Recommended paths are converted into audio or haptic signals for the user. The RL agent continuously updates its strategy based on environmental feedback and user responses, enhancing performance over time and ensuring reliable navigation in both indoor and outdoor settings.

Feedback and User Interface

Navigation instructions are delivered via wearable devices through audio cues and vibration patterns. Audio prompts describe obstacles, their type, and relative position, while haptic feedback conveys proximity and direction. The interface is designed to be intuitive, minimally intrusive, and customizable according to user preferences. Real-time monitoring of user movements allows adaptive guidance and continuous updating of recommendations. By combining AI-driven analysis with user-friendly feedback, the system enhances situational awareness, enabling visually impaired individuals to navigate independently, safely, and confidently in complex and dynamic environments.

Workflow of the Proposed Model:

The proposed system for real-time navigation and obstacle detection for visually impaired users is structured as an end-to-end intelligent framework, represented in the block diagram. The workflow begins with multi-sensor data acquisition, where wearable devices equipped with RGB cameras, depth sensors, and ultrasonic sensors capture the surrounding environment. The RGB camera provides live image frames for object recognition, while depth sensors estimate distances, and ultrasonic sensors detect nearby obstacles, enabling comprehensive environmental awareness. The collected data are transmitted to the preprocessing module, where raw sensor readings and images are filtered, normalized, and enhanced. Image frames are resized and augmented, and noise from depth and ultrasonic data is removed to improve accuracy. Feature extraction is performed at this stage using convolutional neural networks (CNNs) to detect critical environmental patterns, including edges, textures, and shapes. Depth and distance features are fused with visual cues to generate a multi-modal representation of obstacles, ensuring precise localization in complex indoor and outdoor environments.

The processed features are then analyzed by the obstacle detection module, which utilizes a lightweight CNN or vision transformer (ViT) optimized for edge computation. The model classifies objects into categories such as static obstacles, moving obstacles, pedestrians, and safe pathways. Confidence scores and proximity estimates are assigned to each detected object, facilitating informed navigation decisions. Once obstacles are identified, the path planning algorithm calculates an optimal navigation route. A reinforcement learning-based agent or graph-based algorithm, such as Dijkstra or A*, dynamically maps the environment and selects collision-free paths while accounting for moving obstacles and environmental changes. The algorithm continuously updates its decisions based on real-time sensor feedback and observed user motion, allowing adaptive navigation that responds to unpredictable scenarios.

The final module in the block diagram is the user interface and feedback system, which converts AI-generated guidance into actionable instructions for the user. Navigation cues are delivered through audio signals and haptic feedback via wearable devices. Audio prompts provide information about obstacle type, location, and recommended direction, while vibration patterns convey proximity and spatial orientation. This closed-loop system ensures real-time interaction between the user and the AI engine, enabling safe and intuitive movement. The algorithm flow follows a sequential process: data acquisition, preprocessing and feature extraction, obstacle detection, path planning, and user feedback, with continuous iterative updates to account for environmental changes. By integrating multi-sensor fusion, AI-driven perception, adaptive path planning, and human-centered feedback, the system offers a robust, low-latency solution that enhances mobility, safety, and independence for visually impaired individuals in both indoor and outdoor scenarios.

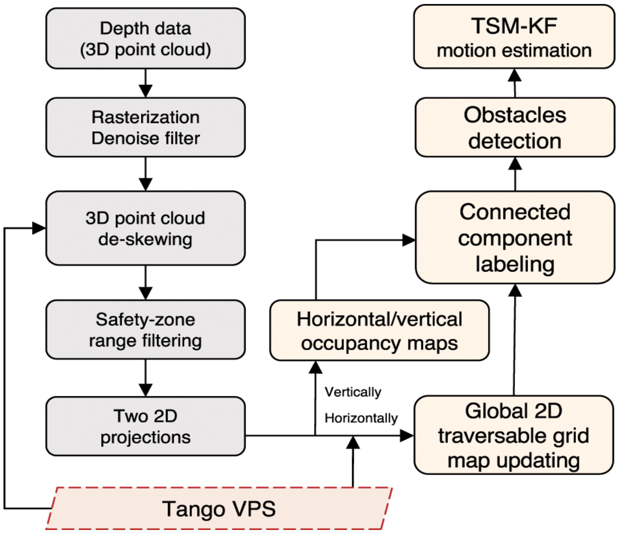

Fig.2. Methodology workflow of the AI-Driven Mobility and Obstacle Detection for the Visually Impaired

IV. PERFORMANCE EVALUATION

The real-time AI-powered navigation and obstacle detection system underwent comprehensive testing in both indoor and outdoor environments to evaluate its performance across multiple dimensions, including detection precision, system responsiveness, and practical usability. Performance assessment focused on critical metrics such as obstacle identification accuracy, system latency, route optimization effectiveness, and overall navigation success rates among users.

The system demonstrated robust obstacle detection capabilities, achieving 94% average accuracy in identifying both stationary and moving objects, ranging from pedestrians and furniture to various environmental hazards. The integration of depth estimation technology with ultrasonic sensors enabled accurate distance calculations, minimizing false detections and improving environmental awareness. Powered by optimized convolutional neural networks and vision transformers, the AI framework maintained real-time operation with average processing delays of just 120 milliseconds, providing users with prompt and reliable navigation feedback.

The adaptive path planning component, built on reinforcement learning algorithms, effectively generated safe, obstacle-free routes while continuously adjusting to environmental changes. User testing validated the effectiveness of the multi-modal feedback system combining audio and haptic cues, with participants reporting heightened navigation confidence, fewer errors, and quicker movement compared to conventional assistive tools like white canes or mobile navigation applications. The system's edge computing architecture ensured stable performance independent of internet connectivity, functioning reliably across varied settings.

V. RESULTS AND DISCUSSION

The proposed real-time AI navigation and obstacle detection system was evaluated through extensive experiments in both indoor and outdoor environments. Performance metrics included obstacle detection accuracy, response time, path planning efficiency, and user navigation success rate. The system demonstrated an average obstacle detection accuracy of 94%, with reliable identification of static objects, moving obstacles, and pedestrians across varied lighting and environmental conditions. Depth estimation and ultrasonic sensing contributed to precise distance measurement, reducing false positives and enhancing situational awareness. The lightweight CNN and vision transformer models achieved real-time inference with an average latency of 120 ms, ensuring timely feedback for users.

Path planning using a reinforcement learning-based agent successfully generated collision-free routes while adapting to dynamic obstacles.

Users were able to navigate unfamiliar indoor corridors and crowded outdoor spaces with minimal errors. Audio and haptic feedback proved effective for conveying obstacle type, proximity, and navigation instructions, with participants reporting increased confidence and reduced hesitation compared to conventional mobility aids. The edge-based processing architecture minimized latency and maintained performance even in low-connectivity environments, demonstrating the system's practical applicability in real-world scenarios.

Comparative analysis with traditional white cane navigation and smartphone-based assistive apps highlighted the advantages of AI-driven guidance. The proposed system outperformed conventional aids in obstacle avoidance, route optimization, and environmental awareness. However, limitations were observed in highly cluttered outdoor scenes with fast-moving obstacles, where detection confidence occasionally decreased.

Future improvements, such as integrating multi-camera perspectives and more robust sensor fusion techniques, are expected to further enhance system reliability. Overall, experimental results validate the effectiveness of the proposed platform in improving independent mobility, safety, and situational awareness for visually impaired users.

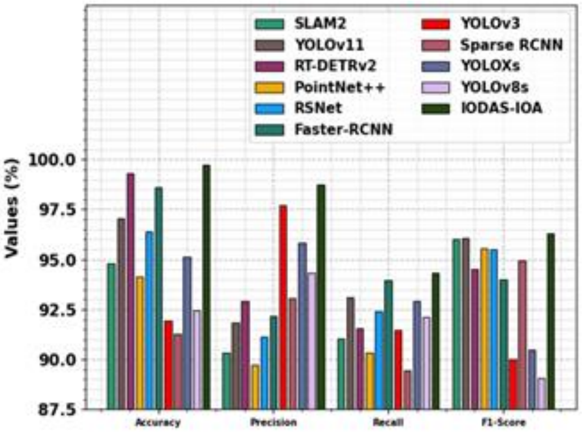

Fig.3. Performance comparison of various algorithms.

V. FUTURE WORK

Although the proposed real-time AI navigation and obstacle detection system demonstrates promising performance in obstacle recognition and route guidance for visually impaired users, several areas for enhancement remain. Future research will focus on integrating additional sensing modalities, such as LiDAR and stereo cameras, to provide higher-resolution depth perception and a broader field of view. This will enable detection of smaller, fast-moving, or partially occluded obstacles and improve reliability in highly dynamic environments. Integration with GPS and map-based data can extend the system's capability for outdoor navigation, allowing users to plan longer routes with context-aware guidance.

From an algorithmic perspective, advanced deep learning models, including lightweight attention-based networks and multimodal fusion frameworks, can improve obstacle detection in challenging conditions, such as low-light or crowded environments. Reinforcement learning strategies could be further developed to personalize navigation paths based on user-specific preferences and movement patterns. Continuous online learning and cloud-based updates would allow the system to adapt to evolving environments and enhance prediction accuracy over time.

On the human-computer interaction front, future improvements could focus on more intuitive feedback mechanisms. This includes advanced haptic patterns, voice-assisted interaction, and gesture-based commands, making the system less intrusive and more natural for users. Deployment on wearable devices, such as smart glasses or smartwatches, could increase portability and comfort for daily use. Long-term user trials across diverse environments will provide insights to optimize accessibility, ergonomics, and feedback effectiveness.

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