Enhancing Mobility Through Augmented Reality for the Visually Impaired

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ABSTRACT

This project addresses the critical need for enhanced navigation tools for individuals with visual impairments, enabling them to navigate their surroundings safely and independently. By leveraging advanced technologies such as object detection, edge detection, augmented reality (AR), scene understanding, audio interaction, and path planning, The system provides real-time assistance and navigational guidance. It ensures users can traverse complex and dynamic environments with confidence and precision, fostering greater autonomy and mobility in their daily lives. The project focuses on developing an AR-based navigation system designed for visually impaired individuals, combining advanced technologies to deliver real-time assistance. The system employs object detection and edge detection to identify and track obstacles and boundaries such as walls or stairs, preventing collisions. Integrated AR technology, developed using Unity and AR Foundation, overlays virtual information onto real-world environments, enhancing spatial awareness with auditory cues instead of visual markers. Scene understanding dynamically interprets the environment, recognizing changes and adjusting navigation accordingly, while path planning recalculates efficient and safe routes in real time. To ensure accessibility, the system relies on intuitive audio interaction and haptic feedback, providing clear spoken instructions and immersive spatial sound cues tailored to the user's position and surroundings. By processing data from cameras and sensors in real time, the system offers adaptive guidance, seamlessly responding to environmental changes such as shifting obstacles or reconfigured spaces This innovative approach empowers individuals with visual impairments through a robust, user-friendly, and reliable navigation tool, fostering independence and enhancing their mobility across diverse environments.

KEYWORDS: AR-based navigation, visually impaired assistance, Object detection, Edge detection, Scene understanding, Path planning, Audio and haptic feedback.

1. Introduction:

Navigating safely and independently remains a critical challenge for visually impaired individualsas conventional aids like white canes and guide dogs offer restricted support in dynamic and complex environments. These tools are often ineffective in detecting overhead obstacles, moving hazards, or sudden environmental changes, making independent mobility difficult and potentially unsafe. The increasing urbanization and complexity of modern infrastructure further emphasize the need for advanced assistive navigation solutions.

This project introduces an Augmented Reality (AR)-based navigation system that enhances mobility by leveraging real-time object detection, scene understanding, and interactive multimodal feedback. By integrating AI and computer vision, the system actively interprets the surroundings and provides users with step-by-step haptic and audio guidance to navigate safely. Unlike conventional mobility aids, which rely primarily on passive detection, this system proactively analyses the environment, offering real-time updates and contextual awareness to users.

A key feature of the system is its use of deep learning-based object detection, which enables accurate recognition and classification of obstacles such as furniture, vehicles, staircases, and uneven surfaces. This helps users navigate safely even in unfamiliar or crowded environments. Additionally, LiDAR and depth sensing technologies construct a detailed 3D map of the surroundings, allowing for precise spatial awareness and improved navigation accuracy. Unlike traditional GPS-based navigation systems, which struggle with indoor positioning and real-time adaptability, this system dynamically adjusts to changing environments, ensuring continuous, reliable assistance.

Beyond personal navigation, this project envisions seamless integration with smart city infrastructure, enabling visually impaired individuals to interact with IoT-enabled crosswalks, traffic signals, public transit systems, and indoor navigation networks. The system can provide real-time updates on pedestrian signals, guide users to bus stops and train platforms, and ensure safer crossings at intersections by detecting vehicles and other potential hazards.

By combining computer vision, augmented reality, and AI-driven navigation, this project not only enhances the independence of visually impaired individuals but also contributes to a more inclusive and accessible future.

2. Related Work

Zhang [1] highlights the limitations of traditional aids and audio-based navigation, proposing the ANSVIP system, which enhances navigation using ARCore for scene understanding and haptic feedback. Yang [2] develops an AR marker-based navigation system for visually impaired individuals, ensuring high positioning accuracy in GPS-inaccessible areas, though challenges include occlusion errors and marker registration issues. Elgendy [3] explores indoor navigation technologies, finding ArUco markers superior to QR codes, with a prototype system using CV tags for shortest path guidance via voice input. Ouali [4] presents a mobile app for drug identification and navigation using Vuforia, facing challenges like camera positioning and recognition accuracy, with future work aimed at ontology-based improvements.

Tinnirello [5] introduces ARIANNA+, an AR navigation system using CNNs and multimodal feedback, though lighting conditions and high battery consumption pose challenges. Zhang [6] proposes a 6-DOF pose estimation method with Graph SLAM for accurate indoor navigation, reducing pose error but struggling in low inlier data environments. Joseph [7] presents a wearable AR navigation system using RGB-D cameras, visual odometry, and landmark localization, though it faces pose estimation errors and reliance on semantic floor plans. Abidi [8] examines assistive technologies designed for those with visual impairments, classifying them into visual, non-visual, spatial mapping, and auditory-based systems, while highlighting challenges such as high costs and difficulties in low-light conditions. Fathi [9] explores sonar-based systems, SLAM, and CAD models for navigation, proposing Unity-based solutions for auditory scene representation. Xie [10] introduces NAAD, an AR, LIDAR, and deep learning-based system for object identification and navigation, operating offline with a 98% utilization rate. Real [11] reviews the evolution of assistive navigation systems, emphasizing user-centered design, SLAM, and remote processing, with challenges in indoor positioning and spatial cognition.

Du [12] develops an AR-based annotation tool using YOLOv3 and ARKit, reducing reliance on crowd-sourced navigation data. See [13] discusses the need for improved assistive technology as the visually impaired population grows, proposing depth cameras in smartphones for enhanced navigation. Sokolov [14] examines AR's role in visually impaired navigation, finding ARCore effective for low-speed mobility with a 7.5% error margin. Troncoso Aldas [15] presents AIGuide, an AR-based real-time guidance system addressing the "last meter problem" without requiring external hardware or internet. Future research aims to refine these technologies by improving scene understanding, reducing power consumption, and integrating multimodal feedback more effectively.

Advancements in deep learning and edge computing may further optimize real-time processing, enabling more adaptive and personalized navigation experiences. Collaborative efforts between AI researchers and accessibility experts can enhance user-centered design, ensuring these systems meet diverse mobility needs. The continuous refinement of AR-based navigation systems holds significant potential for improving the freedom and security of people with visual impairments across the globe.

3.Methodology

3.1 System Overview

The designed system incorporates YOLO (You Only Look Once) for instant scene analysis and utilizes Unity for augmented reality (AR) visualization, delivering audio feedback to assist individuals with visual impairments in navigating more effectively.

The system consists components such as :

Object Detection and Scene Understanding: Utilizing YOLO to detect obstacles and key navigation elements.

AR Interface Development: Implemented in Unity to overlay detected objects with spatially mapped data.

Audio-Based Feedback Mechanism: Providing users with real-time spoken alerts for navigation.

The methodology follows a structured approach, beginning with data collection and preprocessing, followed by object detection, AR implementation, feedback integration, and system evaluation.

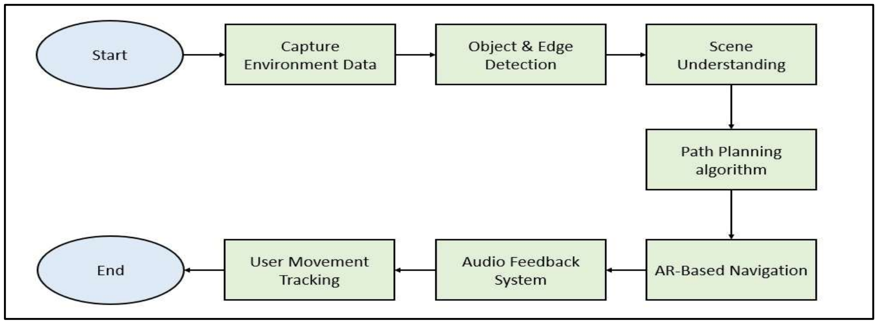

Fig1: Work Flow of Proposed System

3.2 Data Preprocessing

Since this study utilizes a pretrained YOLOv5s model for real-time object detection, no separate dataset was collected. Instead, preprocessing techniques were applied to optimize input data for inference. Images Adjusted in size and standardized to align with the model's requirements while ensuring minimal computational overhead. Additionally, data augmentation techniques such as brightness adjustment and contrast enhancement were used during preprocessing to improve detection performance under varying environmental conditions. These steps ensure that the model effectively detects obstacles and navigation-critical elements in real-world scenarios**.**

3.3 Scene Understanding Using YOLO

3.3.1 Model Selection and Training

The **YOLOv5s** model was chosen for its ideal trade-off between precision and real-time performance, making it well-suited for navigation assistance. The training process involved fine-tuning the model on a custom dataset using transfer learning to enhance detection performance on navigation-critical objects. Hyperparameter optimization was conducted to refine parameters such as learning rate, batch size, and confidence thresholds, ensuring improved model convergence and detection reliability. The model's performance was validated using mean Average Precision (mAP) and confusion matrices, which provided comprehensive insights into detection accuracy across various object categories.

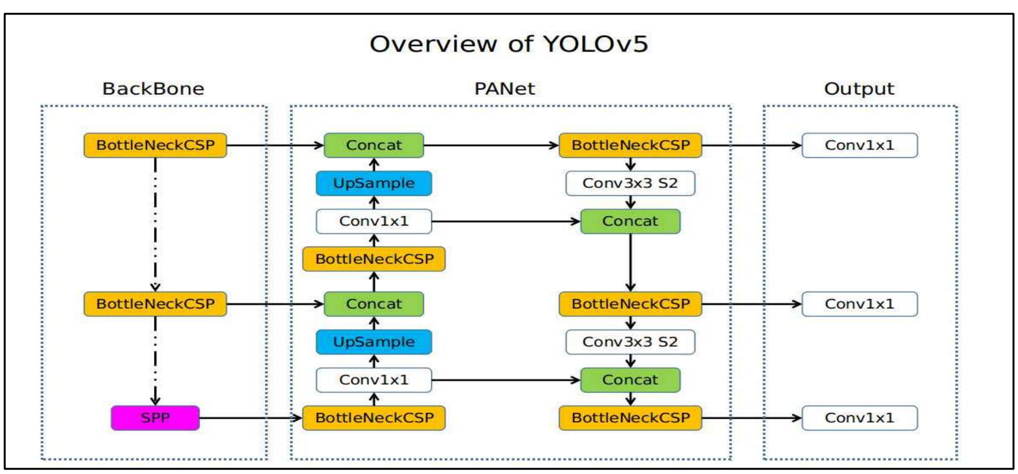

Fig2: Architecture of Yolo v5

3.3.2 Real-Time Object Detection

Once trained, the YOLOv5s model was deployed on mobile devices and AR headsets to facilitate real-time object detection in dynamic environments. Several key parameters were optimized to enhance system responsiveness, including detection speed measured in **frames per second (FPS)**, latency minimization for instantaneous feedback, and depth estimation to assess obstacle proximity. These optimizations ensured seamless detection and timely navigation assistance for users in both indoor and outdoor settings.

3.4 AR Development Using Unity

The AR interface was developed using **Unity's AR Foundation**, a cross-platform framework that enables AR applications across various devices, including mobile and AR headsets. This framework facilitates seamless integration of real-time object detection with augmented reality overlays, ensuring an intuitive and interactive user experience. To enhance situational awareness, spatial mapping techniques were employed to accurately position virtual overlays within the user's real-world environment. By leveraging plane detection and depth estimation, the system ensures that detected objects such as staircases, obstacles, or crosswalks are correctly visualized in relation to the user's physical surroundings. This allows for precise alignment between real and virtual objects, improving navigation assistance.

3.5 Audio-Based Feedback Mechanism

A Text-to-Speech (TTS) system was implemented to deliver real-time spoken alerts for detected objects. The system utilized Google TTS or Microsoft Azure Speech SDK to generate clear and natural-sounding voice guidance. Each detected object was described with key details, including type, distance, and urgency level (e.g., "Obstacle ahead at 2 meters"), ensuring users received precise and actionable information.

4. Results & Discussion

The performance evaluation of YOLOv5s and YOLOv5n for AR-based navigation in assisting visually impaired users was conducted based on three key metrics: mean Average Precision (mAP), inference speed (frames per second, FPS), and latency. The results indicate that YOLOv5s achieved a higher mAP of 75%, demonstrating superior object detection accuracy compared to YOLOv5n, which attained 68%. While YOLOv5n exhibited a slightly higher inference speed of 50 FPS compared to YOLOv5s at 45 FPS, it suffered from increased latency, requiring 40 milliseconds for processing, whereas YOLOv5s achieved a lower latency of 30 milliseconds. These findings highlight that YOLOv5s provides a better balance between accuracy and real-time performance, making it more suitable for AR-based navigation applications where precise and timely object detection is critical. The trade-off observed between speed and accuracy suggests that model selection should prioritize detection reliability, ensuring a safer and more efficient navigation experience For individuals with visual impairments..

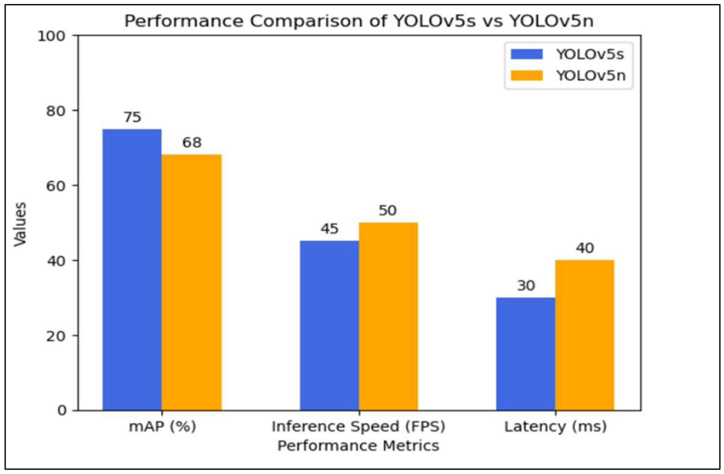

Fig3: Performance comparison of Yolov5s and Yolov5n

CONCLUSION

The AR-based navigation system navigation system for individuals with visual impairments showcases the potential of integrating deep learning-based object detection with augmented reality to enhance spatial awareness and safety. By leveraging YOLO for real-time object detection and Unity's AR Foundation for interactive visualization, the system effectively identifies and overlays critical navigation elements such as obstacles, staircases, and pedestrian crossings within the user's field of view. The inclusion of adaptive audio feedback further improves accessibility by providing intuitive and non-intrusive guidance. Performance evaluation highlights that YOLOv5s strikes an optimal balance between accuracy and real-time efficiency, making it well-suited for AR applications in assistive navigation. The findings indicate that accurate detection with low latency is essential for providing a smooth user experience. Future improvements may focus on enhancing depth estimation, optimizing processing speed, and incorporating user feedback to refine system usability. Overall, the proposed AR-based navigation system represents a significant advancement in enabling visually impaired individuals to navigate their environment with increased independence and confidence.

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