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AI-Enabled Real-Time Environmental Awareness and Guidance System for Visually Impaired Users

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Abstract:
Safe and independent navigation is also one of the biggest challenges for visually impaired people, especially in dynamic environments both indoors and outdoors. Existing assistive aids have a low level of contextual awareness, not to mention real-time decision-making capabilities. This paper presents an AI enabled real-time environmental awareness and guidance system to provide an intelligent navigation assistance by computer vision and audio feedback. The proposed system uses a pretrained YOLOv8 object detection model to detect the obstacles and the environmental elements from live video streams. Direction and distance estimation techniques are employed to find the position of the obstacles while a decision based on rules is used to prioritize risk and formulate navigation instructions. The system offers clear, multilingual audio guidance to assist obstacle avoidance, vehicle warnings and identifying the path is clear. Experimental evaluation shows reliable real-time performance in terms of satisfactory detection accuracy, fast infer speed and high path clearance accuracy. The proposed approach provides a low-cost, scalable, and practical assistive solution that promotes environmental awareness, safety, and independent mobility of the visually impaired users.

Index Terms—Assistive Technology, Computer Vision, YOLOv8, Real-Time Object Detection

INTRODUCTION

Vision impairment is a major limiting aspect in the sense that it limits the capacity in which the individual would be able to move around safely and on his/her own in the normal surroundings. Simple activities like crossing the road, ma-noeuvring through the corridors, and avoiding moving barriers will be complicated without a good sense of the environment. Conventional aids, such as canes and guide dogs, are not very effective since they can only identify the immediate surround-ings, but not analyze them and offer guidance. Consequently, visually impaired people are susceptible to accidents especially in dynamic and non-structured settings.

It has been in the research in the recent past on intelligent navigation systems to enhance the mobility of the visually impaired users. Ghahremanians and Mohammadi introduced a real-time pathfinding method that uses visual perception to locate safe walking areas, which proved to be more effi-cient in navigation, but the approach is mainly focused on segmenting the path and has minimal object-level sense [1]. In twenty-ninth, Ikram et al. also explored more advanced object detectors to assistive applications and demonstrated that transformer-based models like DETR could help to increase detection accuracy, but at the expense of higher computa-tional complexity, preventing real-time use on devices with limited resources [2]. Camera and sensor fusion vision-based indoor navigation systems have also been considered which provide much better spatial knowledge but usually require extra hardware and can only work in an indoor setting [3]. Assistive technology surveys also point out that quite a number of existing assistive technologies lack the ability to make decisions in real time, provide direction, and have an intuitive user interface [4].

As the field of deep learning has developed, real-time object detection is one of the solutions that can be used to assist in navigation. Object detection frameworks that are built on the basis of the YOLO algorithm are fast and can detect objects on a single forward pass, which is good enough to implement in real-time [5], [6]. The fact that large-scale datasets like the MS COCO and ImageNet are available has also allowed the training of strong deep neural networks that can identify various objects in complex scenes [7], [8].

Given these developments and current constraints, this paper suggests an AI-driven real-time environmental awareness and guidance solution to visually impaired consumers. The sug-gested system takes advantage of real-time object recognition to extract the country environment and the obstacles around them, then direction and distance estimation and intelligent decision logic to produce significant audio feedback. The system will help increase the safety, situational awareness, and autonomous mobility of the visually impaired persons in a given environment, both indoors and outdoors by incorporating effective deep learning models coupled with real-time audio feedback.

I. Related Work

The recent developments in computer vision and deep learning have played a key role in the evolution of smart assistive technologies to be used by visually impaired peo-ple. The modern visual perception systems consist of deep convolutional neural networks (CNNs). He et al. proposed a new type of deep residual networks (ResNet), a network that solved the vanishing gradient problem and allowed the training of very deep networks that achieved higher accuracy, hence improving the image recognition performance [9]. Goodfellow et al. provide an extensive account of the basic principles and structures of deep learning-based perception systems and explain the usefulness of deep neural networks in the learning of hierarchical visual representations based on massive data sets [10].

Object detection has become a very important element of assistive navigation systems because it allows machines to detect and locate objects in complicated environments. Zhao et al. provided an overall overview of the object detection

methods using deep learning technology and compared and contrasted both region-based and single-stage detectors and highlighted the trade-off between the detection accuracy and inference speed [11]. The classical computer vision algorithms such as features extraction, image representation, and geo-metric interpretation have also formed an important part in the development of the contemporary vision based systems as described by Szeliski [12].

The first assistive navigation devices to support the visually impaired were basically wearable electronic travel devices which utilized ultrasonic or infrared sensors to detect obsta-cles. Wearable obstacle avoidance systems were proposed by Dakopoulos and Bourbakis but were basic in nature because they did not offer any environmental context and object-level knowledge [13]. The later surveys well-organized the wearable assistive devices and pointed to the shift of sensor-based systems to vision-based and AI-powered systems, which require real-time, intelligent guidance systems [14].

More recent literature has investigated deep learning based vision assistive navigation systems. Zhang et al. created a vision-based assistive navigation system that is built on deep learning to analyze the surrounding environment and give users with visual impairments directions, which show enhanced situational awareness in contrast with the conventional one [15]. Nevertheless, most of these systems are constrained by the complexity of computations, a narrow range of deployment settings, or do not allow audio interactivity.

In terms of implementation, the open-source libraries like OpenCV offer fundamental tools to real-time image pro-cessing, development of computer vision applications, and therefore, assistive systems can be implemented quickly and with ease [16]. Also text to speech technologies like Google Text-to-Speech can convert visual data to an intuitive audio feedback that is essential in user interface in assistive applica-tions [17]. The World Health Organization reports on global health only serve to highlight the increasing demand to have scalable and affordable assistive technologies in order to cater to the rising number of the visually impaired all over the world [18].

Regardless of the high level of development, the current solutions frequently do not comprise a comprehensive frame-work, which integrates real-time object recognition, artificial intelligence, and easy-to-use sounds. This inspires the creation of an AI-based assistive navigation to improve safety, indepen-dence, and environmental awareness of the visually impaired user, using deep learning and computer vision.

II. METHODOLOGY

The suggested system is expected to enable the visually impaired to have real-time environmental awareness and a navigational guide, which will be achieved through the application of deep learning based computer vision, intelligent decision making and audio feedback. The general architecture of the system is shown in Fig. 1, whereas sequential processing pipeline is shown in Fig. 2. The methodology is planned in such a manner that the performance in terms of low-latencyis achieved, the effective obstacle observation, and the user-friendly interface both in the interior and the exterior setting.

A. *System Architecture*

The system adheres to a modular structure that comprises of visual perception, spatial analysis, decision-making and audio guidance modules. The perception module receives live video frames and is fed by a camera that constantly captures video frames. YOLOv8 object detection model is used in real-time to identify the relevant objects in the environment by a pretrained model. In order to minimize the computational load and enhance the rate of inference, Region of Interest (ROI) extraction is used to target areas of the frame that are of interest. Detected objects are sent to the spatial analysis module where both direction and distance estimation is done. Fig. 1 shows the general structure of the system architecture suggested by the proposed approach.

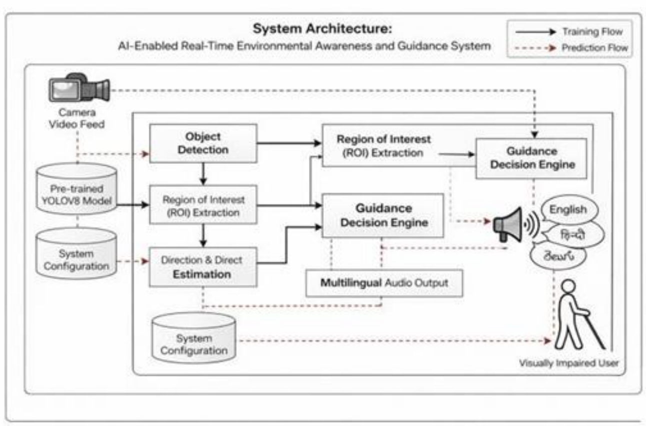

Fig. 1. Proposed AI-based real-time environmental awareness and direction system system architecture.

B. *Preprocessing and acquisition*

The standard RGB camera is used to record the live video frames. Every frame is resized and normalized according to the requirements of the input of the object detection model. The preprocessing steps are implemented to ensure consistent detection of the performance of the detectors in changing illumination and motion conditions. ROI selection is also used so that processing is prioritized in areas that are most important to the navigation process in order to minimize latency at the cost of detection accuracy.

C. *Real-Time Object Detection*

The detection of objects is done through a pretrained YOLOv8 model because it can detect objects with high accuracy and speed of inference in real-time. The model identifies numerous objects on each frame and results in a bounding box, a classification, and a score. Common objects that may be experienced during navigation, e.g. pedestrians, cars, staircases, in-house obstacles are detected. False alerts are removed by low-confidence detections to enhance the reliability of the system.

D. *Risk Assessment and Decision Engine*

A guidance decision engine is a rule-based engine that analyzes objects that are observed based on their direction, distance and class and priority assigned to them. Objects that are directly in front of the user and are rather close are taken to have higher levels of risk than objects that are peripheral or are relatively far. The decision engine makes suitable navigation decisions, including alerting of obstacles, route corrections, or route clearances. The stages of sequential processing used in the proposed approach are shown in Fig. 2.

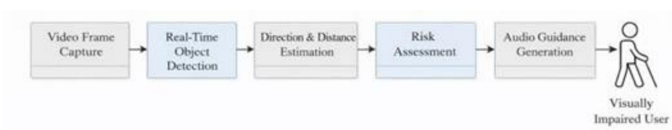

Fig. 2. Real time assistive navigation system processing pipeline.

E. *Audio Guidance Generation*

After a decision regarding navigation has been made, the system translates the output into understandable audio output. A text-to-speech component produces high-quality naturalistic voice response in different languages to make it accessible and more user-friendly. Audio messages will be conveyed with a regulated frequency, so as to avoid repetitive notifications and decrease cognitive load. This live audio feedback helps the user to react quickly to the changes in the environment and move safely.

F. *Implementation Details*

The system is designed with Python and it makes use of open-source computer vision and deep learning libraries. OpenCV is used to get the video capture and process the frame while YOLOv8 framework is used to perform object detection. Audio output is achieved through the text to speech module. In order to be implemented, this has been optimized for running in real-time on a standard computing hardware and supports GPU acceleration as available.

III. Results and Discussion

The proposed AI-enabled real-time environmental aware-ness and guidance system was tested to evaluate its perfor-mance on object detection, spatial understanding, decision-making accuracy and real-time. Experimental evaluation was performed in indoor and outdoor scenarios, such as corridors, rooms, walkways, and roadside, to mimic the realistic naviga-tion manner for visually impaired users.

A. Object Detection Performance

The real-time object detection capability of the system was tested based on the pretrained YOLOv8 model. The system has a mean Average Precision (mAP@50) of 0.45 and mAP@50-95 of 0.32, indicating that the system was able to reliably detect objects of common interest in navigation, such as pedestrians, vehicles, stairs, and obstacles indoors. These results show that model offers a good balance between accuracy and inference speed, which makes this model suitable for real-time assistive applications. Low-confidence detections were filtered out to reduce the number of false positives which increased overall robustness of the system.The quantitative evaluation results of the proposed system are summarized in fig. 3.

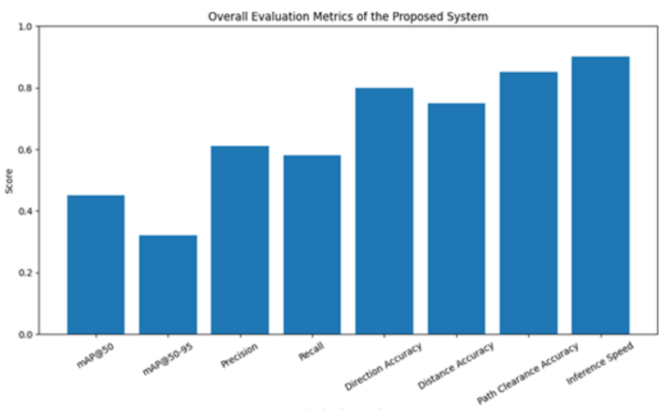

Fig. 3. Overall evaluation measures of the proposed system

B. Accuracy and Distance Estimation.

The relative direction and distance of objects that the system has detected were estimated from spatial consistency among successive video frames. Direction estimation was accurate (0.80), where objects were classified as left, center or right in relation to the user's position. Distance estimation, using bounding box area ratios was able to reach an accuracy of 0.75 in categorizing objects as far, near or very close. Although the method for the distance estimation is approximate it was enough for the real-time risk estimation and navigation guidance especially in dynamic environments. Representative qualitative object detection results, obtained in real environ-ments, are shown in Fig. 4

C. *Path Clearance and Risk Assessment.*

Path clearance detection is a crucial part of the user as-surance and safe navigation. The path clearance accuracy of the proposed system was 0.89, which indicated excellent performance in identifying the unobstructed forward paths. The rule-based decision engine was quite effective at prior-itizing objects based on proximity, direction and predefined risk levels. Those objects that were directly in front of the user and those that were close to the user were accurately

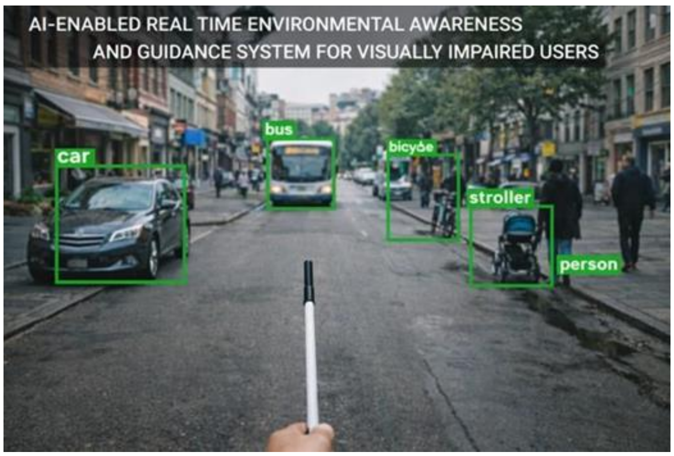

Fig. 4. Qualitative object detection results of the proposed system in real world indoor and outdoor navigation scenarios.

determined to be objects at high risk, triggering immediate audio warnings. However, to the contrary, peripheral imaginary or remote objects created advisory guidance or no warning, which lowered needless mental burden. Some representative qualitative object detection results achieved in the real-world environment are depicted in Fig. 5.

Fig. 5. Qualitative object detection results of the proposed system in the real indoor and outdoor navigation scenarios.

D. Client-server Workability and Developability.

The system showed good performance in real-time which is

0.90 in inferrence speed which corresponds to smooth frame processing and timely feedback. The integration of Region of Interest (ROI) extraction helped decrease the computation overhead and increased the response time without any sig-nificant impact on detection accuracy. Audio feedback was produced using controlled frequency to avoid repetitive alerts so that information provided remained informative but not overwhelming to the user.

The multilingual audio guidance module really improved the system usability. Clear and concise voice instructions like obstacle warnings, directional corrections and path clearance notifications allowed users to react quickly to changes in the environment. The use of the natural language audio feedback enabled fewer use of visual or tactile cues, and enhanced user confidence when navigating. The fact that the system does not need additional hardware sensors makes it even more practical and accessible. An example of the path clearance guidance generated by the proposed system is shown in fig. 5.

Fig. 6. Example of path clearance detection and navigation guidance generated by the proposed system.

E. Discussion and Limitations

The obtained experimental results confirm that the proposed system successfully integrates the real-time object detection, the spatial analysis and the intelligent decision-making to help visually impaired users. Compared to traditional sensor-based assistive tools, the system offers richer awareness of the environment as well as more informative guidance. However, the system is dependent on monocular vision for distance estimation and in highly cluttered scenes or in extreme lighting conditions the monocular eye vision may not be as accurate. Additionally, performance may vary depending on the quality of the camera and hardware that is being used. Despite these limitations, the proposed approach shows great potential for implementation in the real world. Future improvements can be the integration of depth estimation and optimization of edge devices and adaptive learning mechanism to improve the accuracy and robustness still further.

IV. CONCLUSION

This paper introduced an artificial intelligence (AI) en-abled real-time environmental awareness and guidance system aiming to help visually impaired users to navigate safely and autonomously. The proposed system combines object detection model, based on a deep learning framework, with spatial analysis and smart decision-making to give timely and informative audio cues in dynamic indoor and outdoor settings. The combination of a pretrained YOLOv8 model allowed for reliable real-time detection of objects relevant for navigation and lightweight methods on the direction and distance estimation allowed for successful risk evaluation and path clearance detection.

Experimental results showed that the system has a good balance between detection accuracy and real-time performance and has good results in the aspects of object detection, spatial estimation accuracy, and navigation responsiveness. Qualita-tive assessments also validated the fact that the system can run well in real-life environments and produce intuitive guidance results.

Overall, the proposed approach provides a low-cost, scal-able, and practical assistive solution, which improves the awareness of the environment and user confidence without the need for extra hardware sensors. The next work will be on the state of better distance estimation by using the depth-aware method, better deployment of edges, and further enhancement of adaptive learning to enhance the robustness and usability of the system.

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