DEVELOPMENT OF A WEARABLE ASSISTIVE DEVICE FOR NAVIGATION FOR THE VISUALLY IMPAIRED WITH COMMAND AND REQUEST SUPPORT

コマンドとリクエストのサポートを備えた視覚障害者向けナビゲーション用のウェアラブル支援デバイスの開発

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SYNOPSIS

In this research work, we designed, formulated algorithms, and implemented a wearable assistive navigation device, WAND, to aid visually impaired individuals in safely navigating both indoor and outdoor environments. The proposed approach utilizes stereo data to detect obstacles in proximity and in the user's path, providing safe guidance to their intended destination. The developed modules were integrated into a comprehensive framework deployed on a Jetson Nano, responsible for processing scenes captured by a stereo camera, Zed2. The device offers audio feedback instructions to guide visually impaired users to their desired location. Field test experiments yielded promising results, demonstrating the device's ability to inform Visually Impaired Persons (VIPs) of potential obstacles with an accuracy of 95%. Furthermore, the system operates in real-time, providing alerts within a mere 5 seconds. This wearable assistive device not only guides users effectively in real-time but also prevents collisions with obstacles along their path. Our field tests affirm that this system significantly enhances user safety by enabling them to avoid obstacles and navigate securely to their desired destinations.

Keywords: wearable assistive device, object detection, stereo vision, depth estimation, pathfinding, speech communication

1. Introduction

People with severe visual impairment face numerous challenges [1]. These challenges encompass difficulties in mobility, understanding and navigating their surroundings, and independently performing daily activities. These hurdles arise because many activities and actions are contingent on visual perception and understanding of the environment. Navigational difficulties confine visually impaired individuals (VIPs) to familiar areas with fewer obstacles, adversely impacting their economic and social lives.

To address these challenges, various research endeavors have developed assistive devices for VIPs, aiding in navigation, reading, and comprehending their immediate environment [2]. These devices often incorporate diverse sensors to detect obstacles, paths, and signs, providing VIPs with audio cues or tactile feedback. Some devices incorporate additional sensors alongside traditional white canes [3]. Others utilize cameras [4], including advanced options like stereo cameras and Red Green Blue and depth (RGBD) cameras [5], for capturing and processing environmental scenes. Ultrasound and infra-red based devices leverage distance measurements for obstacle detection.

In this study, we introduce an innovative wearable assistive navigation device, WAND using deep learning techniques approach for obstacle detection and maps for pathfinding to facilitate user guidance to their destinations. We describe the design and implementation of the WAND device, designed for indoor and outdoor use by VIPs. The device relies on a combination of location sensing and GPS with 3D data to ensure secure navigation from one point to another.

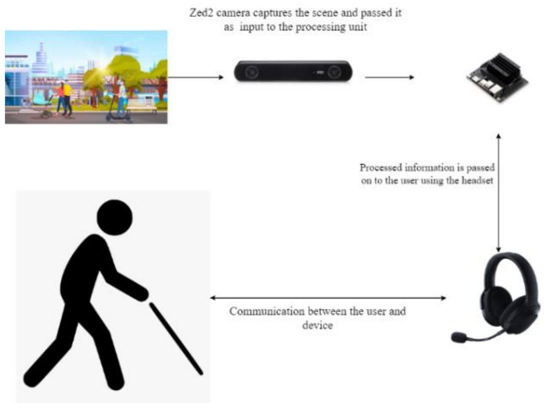

Figure 1 An Illustration of the operational mechanism of the wearable assistive device, where the camera captures the scene, and subsequent data processing comprehends the scenario. If hazards are detected, users are promptly informed.

To enhance obstacle avoidance along the route, we propose a strategy based on the premise that objects in proximity and directly in the user's path are potential obstacles. The selection of the most hazardous obstacles in the detected objects is one of the novelties in the work. We also employ GPS and stereo data to generate an efficient path for VIPs to reach their desired destinations for both indoor and outdoor environments. Additionally, we present an audio feedback mechanism that processes user speech for command recognition, enabling requests for assistance.

Our research contribution from are as follows:

- Development of a wearable assistive device suitable for indoor and outdoor environments for the visually impaired.

- Introduction of a novel obstacle avoidance strategy that prioritizes the nearest obstacle and provides guidance to avoid it.
- Proposal of a pathfinding algorithm for VIPs, ensuring efficient and safe navigation to their intended destinations.
- Presentation of a request command system empowering VIP users to seek assistance.

The remainder of this work is organized as follows. Section 2 discusses related literature in existing research. Section 3 outlines our approach to wearable assistive device development. In Section 4, we detail the design and implementation of our approach. Section 5 presents field test results and corresponding discussions. Lastly, Section 6 concludes the study and suggests avenues for future research.

2. Approach

The proposed approach is discussed in this section, where we present three conceptual ideas that form the foundation of our wearable assistive device design. These concepts are as follows:

2.1 Obstacle Avoidance Strategy

A fundamental feature of the wearable assistive device for VIPs is its ability to avoid obstacles. Without an effective obstacle avoidance strategy, ensuring the user's safety becomes challenging, with a higher likelihood of collisions and hindered mobility. In our strategy, we leverage a stereo camera carried by the VIP to captures scenes in front of the user and a custom lightweight YOLOv5 detect objects in the scene. We prioritize objects that are closest and obstructing the user's path as potential obstacles. Our assumption is that objects near the user and along the user's path are most likely to be obstacles.

To implement this, we establish two sets of conditions for identifying obstacles among detected objects using our object detection models:

- Objects must be within a 2-meter threshold distance to be considered obstacles, with priority given to the closest objects.
- The central area of the captured image scene is designated as the VIP's pathway, and objects within this region are recognized as potential obstacles.

This strategy ensures a comprehensive evaluation of scene objects, both collectively and individually, to select the most immediate obstacle that the VIP should avoid. This is because the approach checks each detected objects in fast and real-time and dynamically assign the status to them before the selection of the closest and most hazardous objects is selected. The implementation of this strategy is presented in a flowchart as shown in Figure 2. We use one of the best object detection methods, YOLOv5, to detect object captured from the stereo camera. We then calculate the distance from the center of the bounding box to the camera and determine if the closer objects are within the pathway of user using Intersection of Union, IoU method which is given by

$IoU = \frac{Area\ of\ Overlap}{Area\ of\ Union}$.

to check if the objects are in our marked region as the pathway of the user.

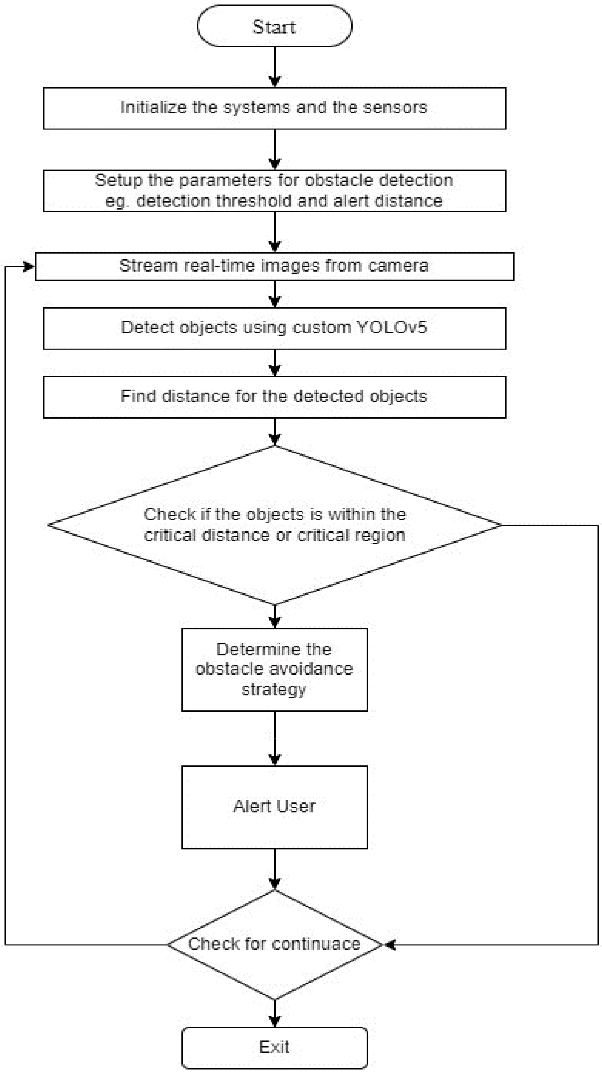

Figure 2 A flowchart show the steps involve in alerting VIP about an obstacle in their path.

2.2 Pathfinding Strategy

Efficient pathfinding is essential for mobility, independence, and safety in assistive devices for the visually impaired. Different strategies are required for indoor and outdoor environments, considering varying mobility restrictions, mapping availability, and environmental factors. We employed the 3D and SLAM approach for indoor environments while the GPS data is used for outdoor environments.

2.3 Audio Communications

In developing an effective audio feedback system for users, the incorporation of dorsal and ventral perception approaches, as proposed in [5], holds promise. These pathways, originating from the brain's distinct sensory processing systems, contribute significantly to our understanding of the environment. While initially tied to visual processing, these principles can be extended to other senses.

The dorsal pathway, often termed the "where" or "action" pathway, focuses on processing spatial location, motion, and object orientation. It guides motor actions and directs attention to pertinent stimuli. By integrating this concept, a navigation guide system can provide real-time user position updates, direction indicators, and alerts about upcoming obstacles, enhancing users' accuracy in reaching

their destination.
Conversely, the ventral pathway, responsible for object and shape recognition, aids users in identifying landmarks and significant waypoints during navigation. Incorporating this idea, the system can present recognizable structures, assisting users in situating themselves and confirming their route alignment.
A successful navigation experience hinges on merging both dorsal and ventral processing. An effective system offers a comprehensive encounter by fusing spatial data (dorsal) with visual recognition cues (ventral). For instance, the system can not only verbally instruct users to take a left turn in a designated distance (dorsal) but also visually display a unique blue building on the left as the turning point (ventral).
Moreover, this integration facilitates dynamic route adjustments. By amalgamating real-time environmental data (ventral) with user movement patterns (dorsal), the system can propose alternative routes when encountering obstacles or traffic congestion, thereby optimizing travel efficiency.

3. System Architecture

In this section we describe the architecture of our wearable assistive device, designed to facilitate safe navigations for the visually impaired in both indoor and outdoor settings.
The architecture comprises three main components: camera system, processing unit, and communication unit (audio and microphone).
The camera system consists of a stereo camera, Zed2, manufactured by Stereolabs. This camera is equipped with depth-sensing, motion tracking, and spatial understanding capabilities. With two cameras, it mimics the binocular vision found in most mammals. The Zed2 is responsible for capturing the scene and depth information, which serves as input for the processing unit. The processing unit is centered around Jetson Nano, one of NVDIA's embedded system designed for microcontroller tasks demanding substantial process power. We will elaborate on the hardware and software components, detailing their functionalities and explaining how they were integrated to create the complete system.

3.1 Hardware Components

We describe the integration of the hardware components for efficient operations and convenience for the user. The Zed2 camera is strapped around the chest as shown in Figure 3 to provide a good viewpoint for objects in front of the user and floor plane that the user will be taking. The strapping of the camera to the front of the users ensures that sensors such as IMU and accelerometers are held in stable positions to prevent the sensors from moving to read wrong values. The camera is connected to the processing which is encased in a box that user can carry around. A headset that comprises of a headphone and microphone is worn by the user for communication. The headset is connected to the processing unit.

3.2 Software system and Modules

In this assistive device, several modules for different functionalities have been integrated to achieve the objectives of obstacle avoidance and pathfinding for the visually impaired. These modules work in tandem to alert the user of potential hazards and provide guidance on necessary turns. The key modules include:

- Obstacle Avoidance Module: This module utilizes the lightweight YOLOv5 model and an algorithm to identify obstacles among detected objects.
- Floor Plane Tracker Module: This module is responsible for monitoring the user's current floor plane and assisting in navigation.

These modules operate simultaneously to enhance the device's functionality, ensuring user safety and effective navigation.

Figure 3 shows the setups of the various hardware components integrate into the wearable assistive device.

4. Experiments

In this section, we outline the experimental objectives and setups. The experiment's goal is to assess the device's performance in detecting potential obstacles and selecting the most immediate threats to the user's mobility.

4.1. Experimental objectives

To validate the effectiveness of our assistive device in safely guiding users to their destinations, we have established three experimental objectives aimed at evaluating its performance, accuracy, and efficacy in tasks related to pathfinding and obstacle avoidance:

- Test the effectiveness of obstacle detection in cluttered scenes. This objective involves determining the obstacle detection rate, the accuracy of selecting the most hazardous obstacle requiring immediate action and assessing the response time to inform the VIP user.
- Assess the device's ability to provide accurate navigation assistance to visually impaired users. To ascertain the adaptability of the dynamic environment
- Evaluate the device's adaptability in dynamic environments.

4.2 Experimental Setup

In our experimental setup, we created controlled scenarios with various types of obstacles (e.g., static objects, moving objects) and varying levels of complexity. We measured the device's accuracy in detecting objects, its utilization of the obstacle avoidance strategy to identify potential obstacles and calculated the false positive and false negative rates in these scenarios. To evaluate the device's performance, a blindfolded participant walked through the course while wearing the device, simulating the experience of visually impaired users. We recorded the number of ground truth obstacles in the setup and compared it to the device's predictions to assess the accuracy of its detection capabilities.
In another setup, we aimed to ascertain the device's adaptability to dynamic environments. We check the time taken to alert the VIP and respond to obstacles in their path.

5. Results and Discussions

In this section, we present results from our field test experiments to evaluate the performance and accuracy of the system.

Table 1. A confusion matrix on the recognition of obstacles from the list of objects detected by the custom YOLOv5.

	Objects Detected	**Obstacles Detected**
Actual Objects	95%	5%
Actual Obstacles	4%	96%

Table 1 shows a confusion matrix illustrating the accuracy of the detected obstacles based on the selection strategy we presented. The results demonstrate an impressive accuracy of 95%, with only a few false positives recorded.

Table 2. A confusion matrix on the accuracy of selecting the prioritizing the critical obstacles that were avoided during the field test.

	Critical Obstacle	Obstacle
Critical Obstacle	93%	7%
Obstacle	6%	94%

Table 2 presents another confusion matrix, this time focusing on the accuracy of our algorithm to select the most hazardous among the detected ones. The results indicate that our approach can effectively select the right obstacle and promptly inform the user.

In Figure 4, we provide a screenshot displaying the objects detected with our lightweight custom YOLOv5 model and how our obstacle avoidance system is implemented. On average, it takes approximately 5 seconds to select obstacles from a cluttered scene. Additionally, the average user reaction time to the alert is 15 seconds, which is sufficient for responding to dynamic obstacles.

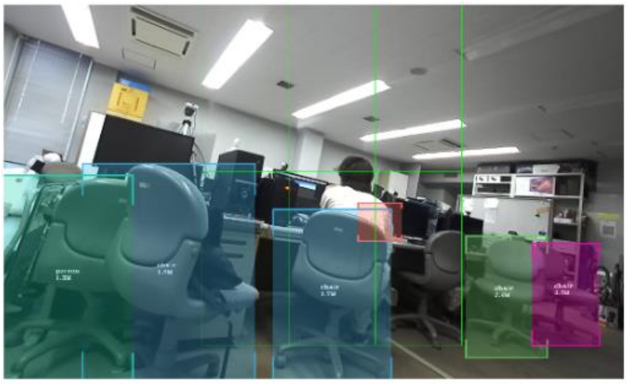

Figure 4 Screenshot of the implemented obstacle avoidance system show the divided screen to show the selection of the prioritized obstacle for the user to avoid colliding into.

The screenshot in Figure 5 demonstrates how our approach can map out the optimal route for the user to take by providing clear guidance. The audio feedback mechanism, influenced by the ventral and dorsal perception concept, informs the user about the obstacle’s location and the required actions to take.

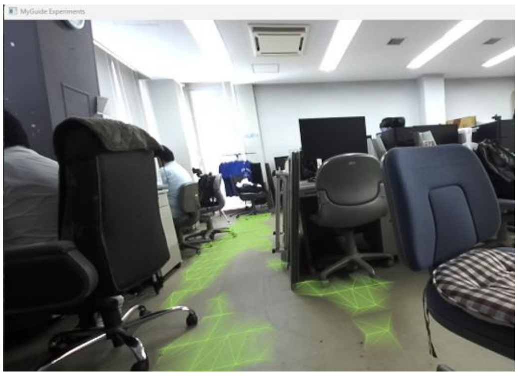

Figure 5 A screenshot of the indoor path selection where the yellow mark safe trails the VIP can walk through.

6. Conclusion

In this study, we introduced our innovative wearable assistive device designed to aid visually impaired individuals in navigating to their desired destinations. This device incorporates a visual system complemented by an audio feedback and request system, enabling visually impaired users to safely maneuver through their surroundings while avoiding obstacles. The system's capabilities include extracting information about potential obstacles, both horizontal and vertical planes, as well as the user's intended destination to plan an optimal path. The results we presented indicate that the system effectively guides users to their destinations while minimizing challenges and circumventing obstacles. In future endeavors, we plan to conduct tests in real-world environments encompassing diverse scenarios to further validate and refine our system.

References

[1] I. Ulrich and J. Borenstein, "The guidecane: Applying mobile robot technologies to assist the visually impaired people," *IEEE Trans. Syst. Man, Cybern. Syst. Humans*, vol. 31, no. 2, pp. 131-136, 2001.

[2] A. Mancini, E. Frontoni and P. Zingaretti, "Mechantronic system to help visually impaired users during walking and running," *IEEE Trans. Intell. Transp. Syst.* , vol. 19, pp. 649-690, 2018.

[3] D. Croce, P. Gallo, D. Garlisi, L. Giarre and I. Tinnirello, "ARIANNA: A smartphone-based navigation system with human in the loop," *In 22nd Mediterranean conference on control and automation,*, pp. 8-13, 2014.

[4] H. Deubel, W. X. Schneider and I. Paprotta, "Selective Dorsal and Ventral Processing: Evidence for a Common Attentional Mechanism in Reaching and Perception," *Visual Cognition,* vol. 5, no. 1-2, pp. 81-107, 1988.

[5] A. Farid and T. Matsumaru, "Path Planning in Outdoor Pedestrian Settings using 2D digital maps," *Journal of Robotics and Mechantronics*, vol. 31, no. 3, pp. 464-473, 2019.

[6] S. Zafar, M. Asif, M. B. Ahmad, T. M. Ghazal, T. Faiz, M. Ahmad and M. A. Khan, "Assistive devices analysis for visually impaired persons: a review on taxonomy.," *IEEE Access,* vol. 10, pp. 13354-13366, 2022.

[7] J. Bai, Z. Liu, Y. Lin, Y. Li, S. Lian and D. Liu, "Wearable Travel Aid for Environment Perception and Navigation of Visually Impaired People," *MDPI Electronics,* vol. 8, pp. 1-27, 2019.

[8] M. R. U. Saputra, Widyawan and P. I. Santosa, "Obstacle Avoidance for Visually Impaired Using Auto-Adaptive Thresholding on Kinect's Depth Image," *2014 IEEE 11th Intl Conf on Ubiquitous Intelligence and Computing and 2014 IEEE 11th Intl Conf on Autonomic and Trusted Computing and 2014 IEEE 14th Intl Conf on Scalable Computing and Communications and Its Associated Workshops,* pp. 337-342, 2014.