Enhanced AI-Based Navigation System for The Visually Impaired

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Abstract— This work introduces an Artificial intelligence (AI) based navigation system using the Raspberry Pi single-board computer. Its primary aim is to assist visually impaired users with precise navigation, achieved through machine learning algorithms for object detection. The development follows an agile methodology, emphasizing flexibility. The work explores integrating essential technologies into a system divided into two major subsystems: hardware and software. The hardware subsystem consists of a Raspberry Pi processor, a camera, an ultrasonic sensor, and a power source, collecting data on road conditions and traffic. The software employs TensorFlow and OpenCV to process data and provide optimized routes. The processed images were classified and identified using the YOLOv3 algorithm. The ultrasonic sensor could measure object distance with about 99.8% accuracy correctly. The test results demonstrate that the AI-based navigation system enhances user experiences and interaction with their environment by simplifying transportation and delivering accurate routes. It effectively analyzes and processes data obtained from the environment, improving accessibility for visually impaired individuals. The work concludes by discussing potential applications and future directions for AI-based navigation systems. It highlights the importance of affordable and accessible technology in improving transportation infrastructure, showcasing the potential for low-cost technology to enhance accessibility and mobility.

Keywords— Visual Impairment; Computer Vision; Raspberry Pi; Tensor Flow; AI-based.

I. Introduction

Approximately 2.2 billion individuals worldwide contend with some form of vision impairment, whether near or far, as reported by the World Health Organization (WHO) [1]. Regrettably, in at least 1 billion of these cases, the vision problems could have been prevented or treated, according to WHO. This stark statistic underscores the urgent need for advanced and cost-effective technological solutions to assist visually impaired individuals in enhancing their environmental awareness. Sight plays a pivotal role in our daily lives, offering a clear perspective of our surroundings and enabling effective environmental interaction. However, navigating their surroundings and identifying objects and potential hazards can be formidable challenges for those with visual impairments. Fortunately, numerous tools and techniques have been developed to facilitate the mobility of visually impaired individuals.

Despite these advancements, individuals who are blind still encounter significant hurdles when moving from one place to another. Infrastructure that does not cater to the needs of the visually impaired, including poorly designed facilities or obstructions in pathways such as benches, large plants, and improperly parked cars, can present considerable difficulties. To navigate safely, individuals with visual impairments often rely on devices or aids to assist in their mobility. The most prevalent aid visually impaired individuals use is the white cane, which assists in detecting obstacles and navigating around them while also serving as a reference point for orientation. Another popular aid is the Seeing Eye dog, which aids in navigating various obstacles. In this case, blind users must rely on the dog's signals rather than acquiring reference points, unlike individuals using a white cane.

Nonetheless, the white cane has limitations, as it can only detect obstacles up to waist level and sometimes creates unspoken barriers between sighted and blind individuals. Some cane users may feel ignored or overwhelmed by individuals assuming they cannot navigate safely.

Furthermore, wear and tear on a white cane can lead to safety concerns, as a broken cane while outdoors could leave the user without a safe means of returning home. Additionally, certain obstacles remain undetectable to the cane due to their shape or location. Similarly, Seeing Eye dogs have drawbacks, including the potential for illness and the associated veterinary expenses, as well as the daily responsibilities of feeding, watering, relieving, playing, and grooming.

Recent advancements in AI and machine learning technologies present an opportunity to create a more effective and innovative solution for visually impaired individuals. An AI-based blind guide system has the potential to identify possible hazards and offer voice instructions and alerts to users, thereby boosting their confidence and independence in navigating their surroundings. This is accomplished through the utilization of computer vision algorithms and real-time environmental analysis [2] [3]

While prior research has explored the application of AI-based systems in assistive technologies, such as object detection and recognition, speech recognition, and facial recognition, limited research has focused specifically on AI-based systems for the mobility and navigation of visually impaired individuals [4].

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This study addresses this research gap by developing an AI-based blind guide system and evaluating its effectiveness and usability in real-world scenarios. This study can significantly enhance their quality of life by furnishing visually impaired individuals with a tool for independent and secure navigation of their surroundings. Moreover, it contributes to advancing innovative and effective solutions to the challenges those with visual impairments face. According to the paper review, the C-5 Laser Cane, developed by Benjamin et al. [5], utilizes optical triangulation to aid visually impaired individuals by detecting obstacles within a 3.5-meter range. The device provides audio feedback on obstacle distance and direction, featuring sensitivity adjustment for customization. Laboratory tests affirmed its effectiveness and user-friendliness, showcasing the potential of optical triangulation and audio feedback for flexibility.

The research [6] introduced a versatile system for the visually impaired, offering applications such as identifying people, navigating public spaces, and locating landmarks. The portable mobile device allows remote updates, ensuring continual functionality. However, limitations include challenges in crowded or noisy environments and the need for a database of known individuals.

The study researchers [7] presented the "Accessibility Bot," a Face Recognition Application on Facebook Messenger. This system aids users in identifying friends by comparing user-captured photos with tagged Facebook images, providing details like name, age, gender, and emotional attributes. Testing yielded improved friend recognition, but challenges include low accuracy, camera positioning issues, and limited awareness of phone status during usage.

These technologies demonstrate the potential of optical triangulation, AI-based assistive systems, and social media integration to enhance the lives of visually impaired individuals. Challenges such as accuracy and environmental factors are being actively addressed to improve effectiveness.

II. Research Methodology

The methodology employed in this study adheres to a well-organized design process that necessitates a systematic approach, incorporating computer simulations and testing that are guided by intelligent decision-making. Developing an AI-based guide for the visually impaired involved integrating accessible hardware, advanced obstacle-detection software, and essential components for data collection, processing, user notifications, and power supply, empowering visually impaired individuals to navigate safely and independently.

A. System Architecture

The system, depicted in Fig.1, offers comprehensive assistance to visually impaired individuals by integrating multiple components. The process commences with an ultrasonic sensor and a camera, which actively scans the environment for obstacles through sound wave emissions and returns measurements. This data is rapidly processed by the Raspberry Pi 4 Model B, equipped with real-time algorithms, serving as the system's cognitive centre. In conjunction with ultrasonic data, a camera captures real-time visual context, which is also sent to the processor for processing. An audio speaker connected to a Raspberry Pi USB port provides immediate feedback on obstacles. Mobility is ensured through a 5-volt power bank for uninterrupted operation. Additionally, the Raspberry Pi employs the YOLO algorithm for advanced object detection, creating a robust, versatile system that enhances safety and independence for visually impaired individuals.

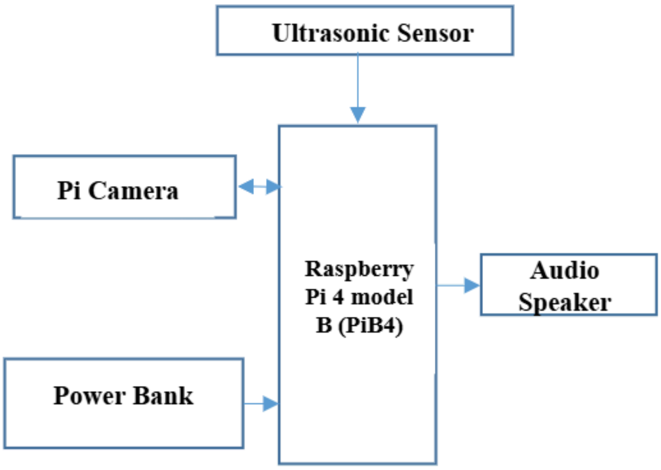

Fig.1. System Architecture of the AI-Powered System For The Visual Impaired Individual.

B. Hardware Design

Raspberry Pi Connection: The Raspberry Pi is the prime choice among available microcontrollers for implementing machine learning algorithms. Its remote access capability simplifies operating system management and supports various programming languages, including Python, Java, and C++. This versatile device combines image recognition and text navigation, operating at a precise 900MHz speed. It employs a camera module to capture and transmit images while an ultrasonic sensor measures distances, storing values in the Raspberry Pi. The system accommodates audio output via a speaker and supports high-bass headphones. The Raspberry Pi 4 was chosen for its enhanced processing power.

Fig.2. Raspberry Pi 4 Model

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C. Object detection using Ultrasonic Sensor

The ultrasonic sensor is positioned at the front of the system and serves as a second means of detecting environmental obstacles. This data provides crucial distance information, helping the system understand the proximity of objects in the user's path. Distance measurement relies on the HC SR04 ultrasonic sensor, equipped with four pins for connection: grounding (pin 6), triggering (pin 16), echoing (pin 18), and VCC power supply (pin 1). The sensor is effective in measuring distances up to 400 cm. It calculates the time interval and then records it within the Raspberry Pi's port. To determine the distance using Equation (1). Time elapsed denotes the duration between stop time and start time, and the constant 34300 represents the speed of sound in centimeters per second.

$$Distance = (Time\ Elapsed * 34300) / 2 \tag{1}$$

D. Image Processing Using YOLO Algorithms

The YOLO (You Only Look Once) algorithm is a real-time object detection system that processes an entire image in a single forward pass through a convolutional neural network (CNN). Its working principles can be summarized as follows: Grid-based Division, bounded box Predictions, Confidence Score, Class Probabilities, on-maximum Suppression (NMS), and Output. Here, the captured image is divided into NxN grid cells of equal shape. The cells are used to localize and predict the class and confidence score of the object it covers. Next, using a single regression module, the YOLO determines the attributes of the bounding boxes (corresponding to rectangles highlighting the target object in the image). This module effectively classifies the objects, predicting their class based on the confidence value. If, like most times, an object in the image has multiple grid box candidates for prediction, the intersection over union (IOU) discards such grid boxes to keep only the relevant ones using the defined threshold. Where multiple boxes have IOU beyond the threshold, the Non-Max Suppression (NMS) keeps only the boxes with the highest probability score. YOLO's key advantage is its speed and efficiency since it processes images in a single pass through the network, allowing real-time object detection.

The YOLO loss function is used during the training of the YOLO model to update its parameters and improve its ability to accurately predict bounding boxes and class probabilities. The goal during training is to minimize this YOLO loss, which means that the predicted bounding boxes should closely match the ground truth boxes, and the predicted class probabilities should be accurate. Loss functions in YOLO include:

1) Localization Loss (L_coord): It measures the error between the predicted bounding box coordinates and the ground truth coordinates using Equation (2). Where the x and y variables are the center coordinates of the true bounding box, the x_{gt} and y_{gt} variables are the predicted center coordinates, the w and h variables are the true width and height of the bounding box, the w_{gt} and h_{gt} variables are the predicted width and height, and the $\sqrt{w}$ and $\sqrt{h}$ variables penalize large errors in large boxes more than small boxes.

$$L\_coord = \lambda\ [(x - x_{gt})^2 + (y - y_{gt})^2 + \sqrt{w} - (\sqrt{w_{gt}})^2 + (\sqrt{h} - (\sqrt{h}\_gt)^2] \tag{2}$$

2) Classification Loss (L_cls): It measures the squared error of class conditional probabilities for each class when an object is detected using Equation (3). Where the λ variable is a weight factor, the c_i variable is the number of classes, and the p_i variable is the predicted probability of the true class for the i-th bounding box.

$$L\_cls = \lambda \times \Sigma[(p\_i - c\_i)^2] \tag{3}$$

3) Confidence Loss (L_conf): Detects the objects present in the box by comparing the predicted confidence scores (conf) with the ground truth objectness indicator (conf_gt). Mathematically, it can be represented as Equation (4), where the λ_conf variable is the weight factor.

$$L\_conf = \lambda\_\text{conf} \times [(\text{conf} - \text{conf\_gt})^2] \tag{4}$$

E. System Integration Testing and Evaluation

The flowchart in Fig.3 outlines the sequence of actions within the software design cycle.

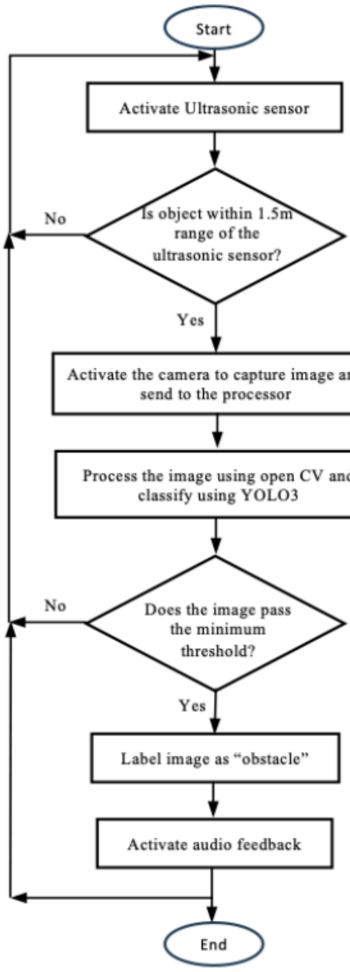

Fig.3. Software Flowchart

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When the system is activated, the ultrasonic sensor immediately emits ultrasonic waves. If an object is detected within the 1.5-meter range set on the sensor, it triggers the Raspberry Pi, instructing the camera to capture an image of the object. This captured image undergoes a series of processing steps, including object filtering and recognition, utilizing software algorithms like OpenCV and YOLOv3. Objects in the image are identified and labelled based on available libraries, and feedback is sent to the user through the audio feedback module.

Suppose the objects within the image meet or exceed a 50% probability (i.e., a probability of > 0.5, as defined by the user in the IOU selection or correctness threshold). In that case, the system provides an audio output with the corresponding label. Otherwise, if the probability threshold is not met, the system alerts the user of the obstacle's presence without providing a description.

After the different system components making up the design had been tested individually, the whole sub-units, i.e., Raspberry Pi unit, Ultrasonic sensor Unit, Camera unit, and Power Source, were integrated, and the final full system testing was carried out. Before hardware implementation and testing, This testing was done through a Raspberry Desktop Simulator. The entire system is tested When all the sub-units have been integrated and tested to ensure they work together and independently. Fig.4 shows a picture of the complete system.

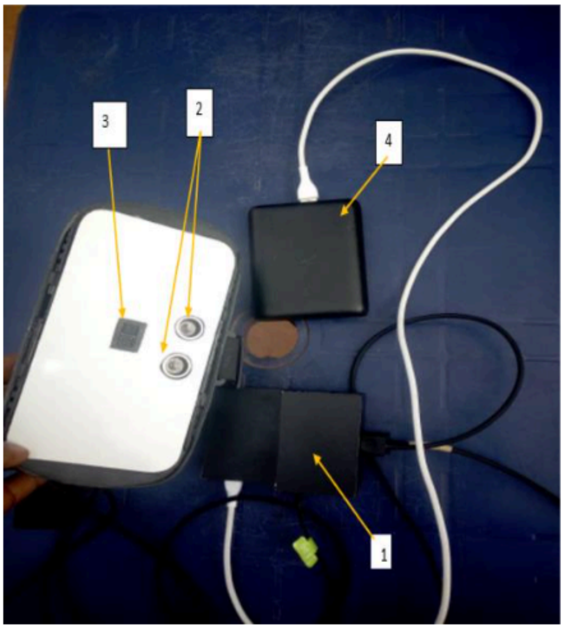

Fig.4. Complete View of the system

III. Result and Discussion

The resulting system was tested, as shown in Table I. Based on the information presented in Table I, it is evident that certain test plans did not yield the precise expected outcomes, showing minor discrepancies. These deviations can be attributed to various factors, including systematic errors, human errors, and experimental inaccuracies.

TABLE I
HARDWARE SYSTEM TESTING AND RESULTS

S/N	Test Plan	Expected Test Result	Actual Test Result
1	Power supply voltage	5Vdc at 1A.	4.95V at 1A.
2	Camera capture	300 x 300 pixel Clear image	300 x 72 pixel Fairly clear images
3	Ultrasonic Sensor	An accurate distance of 150CM	0.1m-0.5m error from the original
4	Feedback speed	Very Fast at 170 secs	Fairly fast at 1sec
5	Controller I/O ports	High= 5V at 20mA	High=4.95V at 20mA
6	Camera Module Test	Vcc =5V, the module should respond to the test program	Vcc=4.9V, the module responded to the test program as expected
7	Speaker Test	The high-quality audio output of 90dB	The audio output of 86dB was achieved
8.	Ultrasonic power Test	Vcc =5V, the module should respond to the test program	Vcc=4.95V, the module responded to the test program

The discrepancy in the expected and actual result, especially with the image quality, could be attributed to the quality of the camera used. A high-resolution camera is often recommended, which increases the accuracy of prediction. Also impacting the pixel quality is the intensity of light in the capture environment.

Table II shows the results of the ultrasonic sensor test. From the result, the optimal distance could be around 40cm with an accuracy of about 99.88% and a percentage error of 1.16. This is controlled; the actual performance could vary depending on other environmental factors.

TABLE II
ULTRASONIC SENSOR TEST AND RESULTS

Actual distance (cm)	Measured distance (cm)			Average	% Accuracy	% Error
	Trial 1	Trial 2	Trial 3			
20	20.5	19	19.5	19.7	98.3	1.7
30	31	30.5	30	30.5	98.4	1.7
40	40	40	40	40	100.0	0.0
50	50	50.5	50.5	50.3	99.3	0.7
60	60.5	61	60.5	60.7	98.9	1.1
70	71	71.5	71	71.2	98.4	1.7
80	80	80.5	81	80.5	99.4	0.6
90	92	91.5	91.5	91.7	98.2	1.9
100	100	102	101	101	99.0	1.0

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IV. Conclusion

The AI-based navigation system represents a significant leap forward in empowering individuals with visual impairments to navigate their surroundings independently and safely. This system offers real-time assistance in identifying and circumventing obstacles by seamlessly integrating image processing, obstacle detection, and audible feedback. The hardware components, including the ultrasonic sensor, camera module, and Raspberry Pi microcomputer, collaborate harmoniously to create a portable and efficient solution for individuals with visual impairments. The agile methodology applied to software and hardware design ensures the system's adaptability and effectiveness.

The system processes sensor data and images to classify objects through machine learning techniques, delivering crucial real-time feedback through the speaker. This technological innovation enhances the confidence and independence of visually impaired individuals as they move about. While the system's portability allows for easy transport in a backpack or waist bag, it's essential to acknowledge the limitations outlined in previous research, particularly in challenging lighting and weather conditions.

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