

Sensor Enabled Proximity Detection with Hybridisation of IoT and Computer Vision Models to Assist the Visually Impaired

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ABSTRACT

Proximity Detection Systems (PDS) are used to detect objects or persons close to Visually Impaired (VI) persons. Sensors are used to identify proximity based on the distance from objects. This study aimed to design a hybrid proximity detection framework for VI people using ultrasonic sensors embedded in a Raspberry Pi board to detect the proximity of a VI user in an office environment. Hybridization was based on the integration of IoT-enabled devices, ultrasonic proximity sensors, and computer vision algorithms to control the detection of objects or people and inform the user with a voice message. The model framework was implemented with 100 samples and tested with 10 analyses in each sample. The results showed significant improvement in detecting the proximity of the objects with an accuracy of 98.7%, outperforming current PDS with good results in precision, range, obstacle recognition, false positives and negatives, response time, usability, durability, reliability, etc.

Keywords-proximity detection systems; hybrid visually impaired proximity detection (HVIPD) algorithm; hybrid proximity detection for visually impaired framework; computer vision; hybrid IoT ultrasonic system

I. INTRODUCTION

Proximity Detection Systems (PDS) and Collision Awareness Systems (CAS) help detect objects and prevent people from being injured from collisions [1]. Such systems let the operator know if people or objects are near them. These systems should be personalized because every need is unique. Customers have many choices to make their system unique to them. Such systems range from very basic systems that use Ultra High Frequencies (UHF) to more advanced systems that have multiple points to detect something [2]. A PDS can use UHF, Radar, and Electromagnetic Field technologies. Ultrasonic transducers and sensors are devices that make or listen to very high-frequency sound waves [3]. Transmitters create electric signals, receivers change the electric signals into sound, and transceivers can both send and receive signals.

Ultrasound devices can be used to obtain the speed and direction of the wind and determine how much fluid is in a container or passage. Sensors help determine how quickly an entity is shifting or in which direction it is moving and determine its speed. Ultrasound is a handy tool that can be used in many ways [4]. In addition, technology can predict how close things are and keep track of where they are at all times [5]. Ultrasonic proximity detection can help people who cannot

see properly in many ways. Ultrasonic detectors can be used for obstacle detection and avoidance [6], navigation assistance to help the user move around places they don't know by looking at what is around them [7], object identification to tell the difference between different objects by how they reflect sound waves [8], and customizable alerts with different vibration patterns, sound cues, or a mix of both, depending on the user's preference [9]. Ultrasounds can be used to measure distances between two points by sending and receiving short bursts of ultrasound signals between devices. This method is called Sono micrometry [10].

This study aims to design a PDS based on a hybrid framework using ultrasonic sensors embedded in a Raspberry Pi to detect the proximity of the user in an office environment to assist visually impaired people. Hybridization was based on the integration of IoT-enabled devices, proximity sensors, and computer vision algorithms to control the detection of objects or people and inform the user with a voice message. The scope of this study was to assist visually impaired people with an inability to detect objects around them. The model was developed and compared with existing models and datasets to determine whether it could significantly improve detection.

II. RELATED WORKS

Ultrasonic sensors are quite unique compared to capacitive and inductive sensors and use high-frequency sound waves that humans cannot hear to detect nearby objects [11]. Medical ultrasound transducers are devices that are used to create images of different aspects of the body [12]. The transducer can be used on the skin, such as in ultrasound imaging, or placed on a body. Ultrasounds have many advantages [13]. In [14], a method was introduced to help robots feel things through touch, designing a special robot finger, called Finger-STS, that can sense things. In [15], a method was proposed to improve how machines see things when objects are hidden, which was tested to see how close things are, achieving 96.76% accuracy at a rate of 25 Hz. In [16], a method was suggested to see things using a special computer program. In [17], pictures and smart computer methods were used to address CoViD-19 proximity issues. In [18], a method was introduced to improve signature verification, achieving an accuracy of 85-95%. In [19], special computer programs were investigated to find important parts of people's bodies when they are close to robots. In [20], a method was proposed to use sensors to gather data in complex learning situations where people work together, called Computer Vision for Position Estimation (CVPE). In [21], a new kind of soft robot sequence, called ProTac, was proposed to sense things in two ways: feeling touch and knowing when something is close.

In [22], a system was proposed with multiple robot arms and special cameras to correctly organize objects based on their size and shape. In [23], a system was introduced that used cameras to detect fires and smoke indoors. Many studies suggested different models for proximity detection in different scenarios. In this framework, proximity detection was used to assist visually impaired people in detecting the presence of obstacles in their position by measuring the distance between them. In [24], advanced computer vision was used to protect against attacks. In [25], a method was proposed to track how close people are to each other by watching videos in public places. In [26], devices were designed that used sensors and pictures to help people who have trouble seeing. In [27], a method was designed to understand how the physical environment of green spaces affects the leisure activities of people. Ultrasonic sensors are best used for non-contact detection of presence, level, position, and distance [28].

III. MATERIALS AND METHODS

Previous studies had two major setbacks: they could not handle sensors and software at the same interface [22] and they could not find proximity based on threshold and distance vector mapping methods [25]. The proposed framework, called Hybrid Proximity Detection for Visually Impaired (HPDVI), was designed to address these gaps and is developed in three different stages as shown in Figure 1. During the first phase, the input is captured from external sources, either from a web camera or a Picamera, as video content. The image frame and the object are detected as inputs that indicate the presence of the object in the environment. In the second phase, the ultrasonic sensor detects an object, records it as an obstacle, and calculates its distance by:

$$dist(Obj) = \frac{Speed(Sound) * Time}{2} \quad (1)$$

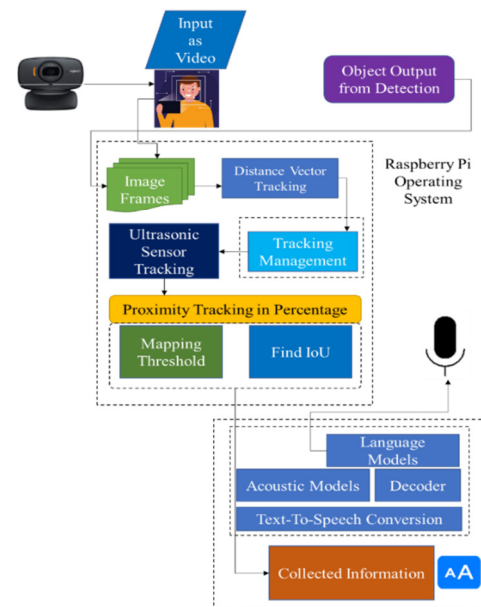


Fig. 1. The proposed HPDVI framework.

The speed of sound was calculated on the density of air at 344 m/s and the time was calculated based on the difference between the time of detection and the time of announcement at regular intervals. This is a general method to detect proximity and update the distance vector tracking between the sensor and the object. The threshold limit was established to identify the object, and the distance vector was regularly mapped based on the Intersection of Union (IoU) [29]:

$$IoU(A) = \frac{Area\ of\ Intersection\ of\ Boxes}{Area\ of\ Union\ of\ Boxes} \quad (2)$$

IoU is used to find the intersected boxes in object detection where two objects merge. The proposed framework could identify individual objects using the direct distance calculation and merged objects with the IoU method. After detecting the proximity and threshold mapping process, the distance was calculated and then sent to the voice-over output. During the third phase, the collected digital information was converted into voice output to be sent to the text-to-speech conversion tools, where the decoder will convert the acoustic models and send a female voice output recorded from online sources to language models, and finally output it through the external output device. Thus, this framework can be characterized as a hybrid framework that integrates Internet of Things (IoT), sensors, and machine learning models. The proposed model was developed and an analysis was carried out with a sample of 100 persons in an office environment with a Raspberry Pi kit. The dataset comprised demographic details and proximity tests with 10 samples, as shown in Table I. Name and place are unpredictable variables, age and gender are categorical variables, and the remaining demographic variables are predictable features. Based on the initial input of demographic variables, tests were performed for the proximity analysis, as shown in Table II.

TABLE I. DEMOGRAPHIC DATA FOR EXPERIMENTAL PROCEDURE

Name	Nominal	Place	Nominal
Age	17-24, 24-30 31-50	Gender	Male, Female
Complexion	Fair, Brown Dark	Race	Black, White Average
PPE – Spex	Yes, No	PPE-Mouth Mask	Yes, No
PPE – Hair Mask	Yes, No	PPE- Ear Mask	Yes, No

TABLE II. PROXIMITY ANALYSIS FOR THE EXPERIMENTS

Threshold Test	0-Exact	1-Proximal	2-Distant
Test #1	0	-	-
Test #2	0	-	-
Test #3	-	1	-
Test #4	-	1	-
Test #5	-	1	-
Test #6	-	1	-
Test #7	0	-	-
Test #8	0	-	-
Test #9	0	-	-
Test #10	-	-	2

Algorithm HPDVI

```

Step 1: Start the Process
Step 2: Import the Basic Packages for Raspberry Pi, Time, and ESpeak for Voice Output
Step 3: Set initial standards for Raspberry Pi Board with TRIG = 16 and ECHO=18
Step 4: Initialise I = 0
Step 5: Set Input ECHO and Output TRIG as False
Step 6: Set the initial time sleep to 2 for placing the object
Step 7: Iterate through the process from Step 8 through Step 9 until True
Step 8: Detect the output of TRIG to be True
Step 9: Set Sleep Time to 0.00001
Step 10: Iterate through the Process of Step 11 until ECHO = 0
Step 11: Set Pulse_start = Current Time of Start
Step 12: Iterate through the Process of Step 13 until ECHO = 1
Step 13: Set Pulse_end = Current Time of End
Step 14: Compute Pulse_duration = Pulse_end - Pulse_start
Step 15: Compute Distance = Pulse_duration * 17150
Step 16: Update Distance = distance + 1.15 (Constant value)
Step 17: Compute Distance_Inches = Distance * 0.393701
Step 18: Test if Distance <=100 and Distance >=5 and perform Step 19 through Step-22
Step 19: Display Distance in cm
Step 20: Display Distance_Inches in inch
Step 21: Initiate ESpeak Module for Voice Output
Step 22: Initialise i = 1
Step 23: Test if Distance > 100 (Maximum Threshold) and i==1 and perform Step 24 Thru Step 25
Step 24: Insist User to place the Object again
Step 25: Initialize i=0
Step 26: Initialize the Sleep time to 2
Step 27: Accept the completion of the process
Step 28: Clean the Process
Step 29: Stop the Process
End Algorithm HPDVI
    
```

IV. IMPLEMENTATION AND EVALUATION

Ultrasonic sensors are preferable to infrared sensors because they are not affected by moisture or black materials. In general, using ultrasounds to detect nearby objects can help people with visual impairments feel more confident and safer while moving around. Figure 2 presents the overall implementation and setup of the entire HPDVI model.



Fig.2. Implementation of the HPDVI model with a Picamera for Raspberry Pi kit and ultrasonic sensor on a white walking stick.

V. RESULTS AND DISCUSSION

Considering various aspects is necessary to design efficient and user-friendly systems to aid blind people navigate safely. Here are some important factors to consider when evaluating proximity detection systems:

- Accuracy: 1000 samples were tested and among them, the confusion matrix was identified based on k-means clustering. The overall accuracy of the distance prediction was found to be 98.7%.
- Precision: Based on accuracy, the precision was found to be 98.45%.
- Range: The system could work with a threshold range of 12 m and detect correct outputs in 10 subsequent tests in all environments.
- Obstacle Recognition: The system could detect obstacles and inform the user with a voice-based message, with an accuracy of 98.7%.
- False Positives and Negatives: The test procedure showed very few false positives and negatives, 7 and 6,

respectively, out of 1000 samples, which represent 1.3% overall.

- **Response Time:** The response time was less than or equal to 0.0002 s, which is very low.
- **User Interface and Feedback:** User feedback was collected using an analysis report and was found to be positive with all 100 respondents in proximity detection procedures.
- **Usability:** The experiment was successful with visually impaired people in hospitals and clinical centers with good usability responses.
- **Durability and reliability:** The system was found to be durable and reliable in accidents, temperature, and wetness.
- **Adaptability:** The walking stick could detect all directions and locations without interruptions.
- **Interference and crosstalk:** The device was placed between other ultrasonic sensors, and it was found that no interference or crosstalk was recorded during the experiments.
- **Training and learning curve:** Visually impaired people were found to easily become acquainted with the system without much tutoring or demonstrations.
- **Cost-effectiveness:** The overall kit can be achieved with a maximum of Rs. 30,000, which is quite affordable for the middle class or ordinary people as an important investment to improve their quality of life.
- **User Acceptance:** Many visually impaired people accepted the system as they felt comfortable using it.
- **Collaboration with experts:** The device was tested and monitored by medical experts and was found useful in detection and everyday use.
- **Long-Term Use:** This aspect has to be tested in the future.
- **Ethical considerations:** There were no negative ethics on this system, as it does not collect any information on the privacy of any user at any time.

Table III presents a collective report to determine the evaluation of the results. Figure 3 shows the overall comparison of Accuracy, Precision, and Error rate.



Fig. 3. Performance prediction analysis for the proposed proximity detection framework.

TABLE III. PERFORMANCE METRICS AND RESULTS OBTAINED IN EACH EVALUATION

S.No	Performance Metric	Outcome
1	Accuracy	Positive (98.7%)
2	Precision	Positive (98.45%)
3	Range	Positive
4	Obstacle Recognition	Positive (98.7%)
5	False Positives and Negatives	Positive 1.3%
6	Response Time	Positive (0.0002 sec)
7	User Interface and Feedback	Positive
8	Usability	Positive
9	Battery Life	Positive
10	Durability and reliability	Positive
11	Adaptability	Positive
12	Interference and crosstalk	Positive
13	Training and learning curve	Positive
14	Cost-effectiveness	Positive
15	User Acceptance	Positive
16	Collaboration with Experts	Positive
17	Long-Term Use	Positive
18	Ethical considerations	Positive

As shown in Table III, testing how well proximity detection systems work requires different types of experts in various fields working together. In the above results, all expected outcomes of the experiments were positively evaluated with both qualitative and quantitative factors. These experts need to know about medical, user experience design, accessibility, and user testing to properly evaluate these systems.

VI. CONCLUSION

This study presented a novel hybrid framework for proximity detection for visually impaired people, based on a novel proximity algorithm called Hybrid Proximity Detection for Visually Impaired (HPDVI). The implementation was carried out on a Raspberry Pi kit so that the model could be developed and tested with visually impaired people. A sample of 100 respondents with 10 proximity detection values each was tested and analyzed, using a threshold of 12 meters. The overall framework was highly successful and provided an accuracy level of 98.7%. In future systems, it could be incorporated into an embedded system to perform object, face, and proximity detection at the same time to assist visually impaired people in all aspects of their lives.

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