Navigation System for Visually Impaired People Based on RGB-D Camera and Ultrasonic Sensor

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ABSTRACT

This paper presents a smart guiding system and wearable device to assist the visually impaired people in avoiding obstacles and navigate safely through indoor environments. The proposed navigation system includes a pair of glasses with a RGB-D camera and an ultrasonic sensor in the front, Raspberry pi 3 B+ board, and earphone. An obstacle avoiding algorithm based on integration of a computer vision and ETA techniques is adopted to provide an accurate and low cost solution. The measuring distance approach depends on an ultrasonic sensor and the raw depth map that is acquired from depth sensor to output several suitable moving directions. The integration of different data input helps to detect the small and transparent obstacles and increases the accuracy of the navigation system output. This work has been tested and evaluated in different real-time scenarios. The experimental results indicate accurate guiding instructions and effective performance of obstacle detected and avoiding algorithm. The guiding instruction has been sent to the user as audio message through earphone.

CCS CONCEPTS

•Social and professional topics → People with disabilities • Hardware → sensor technologies

KEYWORDS

Object detection and avoidance, Computer vision, Depth sensor, Ultrasonic sensor, Visual impaired

1 Introduction

According to the last report published by World Health Organization (WHO), there are about(approximately) 258 million visually impaired people (VI), whereas 39 million people are completely blind. 82% of visually impaired people are with ages 50 years and older. By the year 2020, this number will be increased to double. The visually impaired people have many difficulties and challenges in perceiving and navigating in their surroundings. Recently, there are varieties of assistive navigation technologies were developed and are available for visually impaired people with different degree of effectiveness. The examples of assistive technologies that are newly developed are Microsoft glasses for the blind and Horus wearable technology. Since ninety percent of visually impaired people with low-income setting and from the developing countries, the assistive devices for people suffering of visual disabilities should be low cost and affordable. Traditionally, most visually impaired people used a white cane and trained dog to help them detect and avoid obstacle. The white cane allows the blind to avoid the close obstacles while trained dog is good for navigation service but it is expensive. Comparably, more information about surrounding can be provided by multiple electronic sensors in ETA category (Electronic Travel Aid) to improve the VI's quality of life. This technique will be presented in our work.

Since any technology has a drawback or a limitation, it cannot be a better solution is to use it alone. Therefore, both ultrasonic sensor and RGB-D camera were integrated to give a complete design of indoor assistive navigation system in this paper. The RGB-D sensor based ETA can provide both RGB images and depth data in real-time that are processed by obstacle detection algorithm on the Raspberry pi 3 B+ with the ultrasonic sensor to accurately detect obstacles. The audio warning message is sent to the user to alert him/her attention to avoid an obstacle.

The rest of the paper is organized as follows: Section 2 provides the necessary background of navigation systems with different techniques and different contributions. The proposed system is described in section 3 and section 4. The experiments and results in real time for different scenarios are presented in section 5. Finally, Section 6 concludes this work.

2 Related Work

Many navigation systems with different techniques and different contributions aimed at visually impaired people have been proposed in the last decade.

In some research, Electronic Travel Aids (ETA) technology such as ultrasonic, infrared, sonar, laser, etc. helps the visually impaired person to avoid obstacles. These systems depend on the acquired data from their surrounding environment to detect and avoid an obstacle by measure the distance from the blind to the object. Among these sensors, the ultrasonic sensors are the most

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popular in research and accepted by the visually impaired people due to its accuracy, low cost, low power consumption and ease of use. Ultrasonic sensors don't have many disadvantages but are limited in their capabilities which provide detection range from 2cm to 400cm around a 15 degree beam width (detect an object within a 30 degree). The navigation system that based on the ultrasonic technology is developed in [1]. In addition, [2] proposed an obstacle detection and avoidance system with multi-sensors system that installed on the stick. The ultrasonic sensor array is utilized to detect and avoid obstacles from nine different angles in [3]. The authors of [4] designed indoor navigation system consists of a pair of glasses with RGB camera and 2 ultrasonic sensors to detect and identify the visual markers in the prepared environment. The smart object detection wearable system and the smartphone are implemented in [5] including an ultrasonic sensor, GPS, Google Maps and Bluetooth to provide the visually impaired with information to navigate surroundings.

RGB-D cameras play a major role in navigation systems because they provide the great amount of information with high accuracy comparing with their low cost. The depth data is the great advantage of RGB-D cameras, which is powerful under any indoor lighting condition and can be used to calculate the distance from the user to obstacle to give warning message. However, a disadvantage of these sensors is that they cannot work well with transparent obstacle such as glass, French door, French window, etc. This is the only sensor used in [6,7] to detect object and classify it as either an object or the floor. In [8], the authors built a wearable device with RGB-D camera on glasses and micro-motor on glove for tactile feedback to help the visually impaired to perceive their surroundings. The detected obstacle is categorized with deep learning for scene understanding. Hoang et al. [9] implemented the assistive navigation system for visually impaired people which consists of two component: RGB-D camera and electrode matrix. The indoor assistive navigation system to help blind people was built by researcher in [10] using on-board RGB-D camera based on a time-stamped map Kalman filter algorithm.

The details of the presented systems in this section show that the systems based on a single technique cannot be considered a complete or robust solution to assist VI people in their lives. Bai et al. [11] proposed an indoor navigation system with multi-sensor fusion using both RGB-D sensor and ultrasonic sensor to overcome the limitation of each sensor.

According to our study and literatures review [12,13,14], there is no system can achieve all the requirement of the user to provide safe mobility indoor and outdoor environments due to the limitation of these techniques. The systems that are based on sensors and computer vision will be the best solutions. Due to this observation, a navigation system that integrates both sensor-based techniques and computer vision techniques is proposed in this paper.

3 The Proposed System

The proposed system includes two components: hardware and software component. The hardware component consists of five main components (1) RGB-D camera (2) Ultrasonic sensor (3) Raspberry Pi (4) Power source (5) Earphone as illustrated in Figure (1). The object detection is done by depth camera (Asus Xtion Pro) for getting the depth information of the user's surroundings and an ultrasonic sensor to measure the obstacle distance. Both of depth camera and ultrasonic sensor are interfaced with the Raspberry pi board which is used as a main processing module due to its low power consumption, small size and low cost. Many operations such as depth image processing, data fusion, guiding sound synthesis, etc. are done by Raspberry pi with Python programming language, which is well suitable for this board. The overall result of the detection system is to generate a sound to the VI person to guide him/her during the navigation.

However, the purpose of the software component is employed an efficient data fusion algorithm that based on multi-sensor fusion to improve and provide the accurate system for object detection/avoidance. The block diagram of proposed system is illustrated in Figure 1 and the system initial prototype is shown in Figure 2.

3.1 Depth Information Acquisition

RGB-D camera provides RGB image as well as raw depth map of 640×480 pixels at 30 fps. It has an angular field of view of 58° horizontally and 45° in vertical axis. The accurate working distance range of the depth camera is from 0.8 m to 3.5 m. With this sensor, it is possible to acquire depth information per pixel in visual image which is expressed in millimeters.

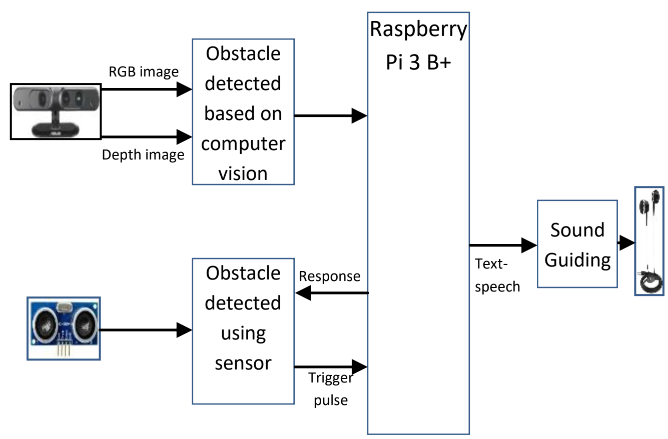

Figure 1: Block diagram of the proposed system

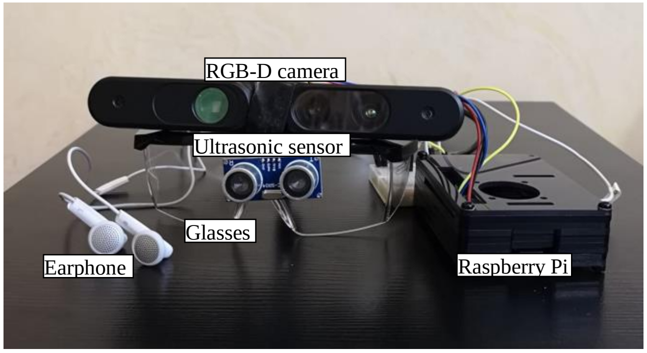

Figure 2: Initial prototype of the proposed system

The zero depth indicates that there is no depth information at that particular pixel. The depth information is computed by an IR laser source to emit IR light and an IR depth sensor that reads the reflected light. The RGB-D sensor deployed in our system works mostly indoor environment, as sunlight produces high intensity IR interference that leads to saturation in the depth acquisition. The Asus Xtion Pro camera is supplied a power from Raspberry pi board. It transmits color image and depth information for each pixel to the system in the Raspberry pi. The color image and its depth information will be processed by object detection algorithm to select the best direction for visually impaired person to avoid the obstacle. In the first step, the frame of color image is divided into three regions to indicate the moving directions: left area, middle area, right area. Since the closest object to user is always in the lower part of the frame, the scanning for an obstacle should be done on this region of the image. The RGB-image is divided into 5 × 3 blocks. The algorithm searches for an obstacle in the three lower blocks as demonstrated in Figure 3.

The image segmentation based on Otsu's thresholding method [15] is used to extract object in these lower blocks after removal noise using Gaussian filter. Otsu's thresholding method required very little time. It is an efficient and important method in computer vision that is commonly used to extract objects from their background image. It assumes that each pixel in image is categorized into two classes either as an object or as a background. The basic idea of it is to use the image histogram for selecting the optimal threshold value between the two peaks (foreground and background pixel values) that minimizes the weighted within-class variance (the variance between the 2 classes), expressed as [15]:

$$\sigma_w^2(t) = w_0(t)\sigma_0^2(t) + w_1(t)\sigma_1^2(t) \quad (1)$$

w_0 and w_1 are weights that represented the two classes probabilities separated by a threshold t, and σ_0^2 and σ_1^2 are the two classes variances.

Finally, the depth values corresponding to each pixel of the detected object is examined to know the distance of an obstacle.

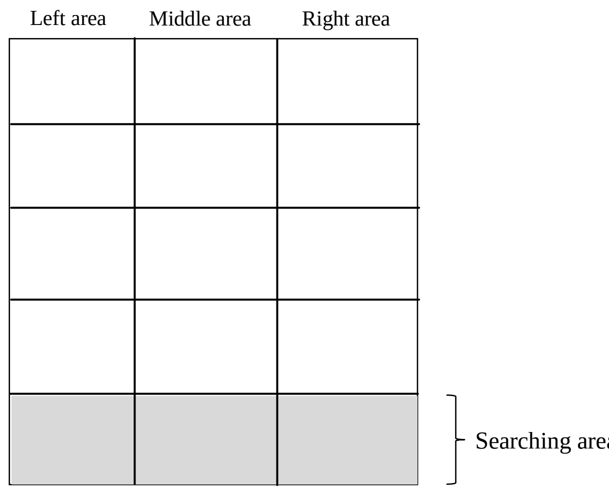

Figure 3: Spliting the visual image into 5x3 blocks

3.2 Ultrasonic Sensor

An ultrasonic sensor is an electronic device that is commonly used for measuring the distance and/or detecting object. The sensor is based on a simple principle, sound echo phenomenon. The transmitter of the sensor sent a signal of 40 KHz samples. When the signal hits an object, it is reflected back and the receiver of the sensor receives it. The time between the sending and receiving signal is used to determine the distance to the object by this formula.

$$\text{Distance} = \frac{\text{time}}{2} * \text{speed of sound} \quad (2)$$

Where the sound's speed in the air is usually 340m/s and the measured time is divided by 2 to get only the straightforward trip time.

In our system, HC-SR04 ultrasonic sensor has been used which requires 5v to work. The Trigger pin of the ultrasonic sensor is activated by giving it a short pulse (10µs) to start a measurement cycle and sends out a short 8 cycles at 40 kHz. Figure 4 shows the operation of ultrasonic sensor when the 8 ultrasonic pulses have been sent from the transmitter of the sensor. The width of the received pulse at the Echo pin is used to determine the distance to the reflected object.

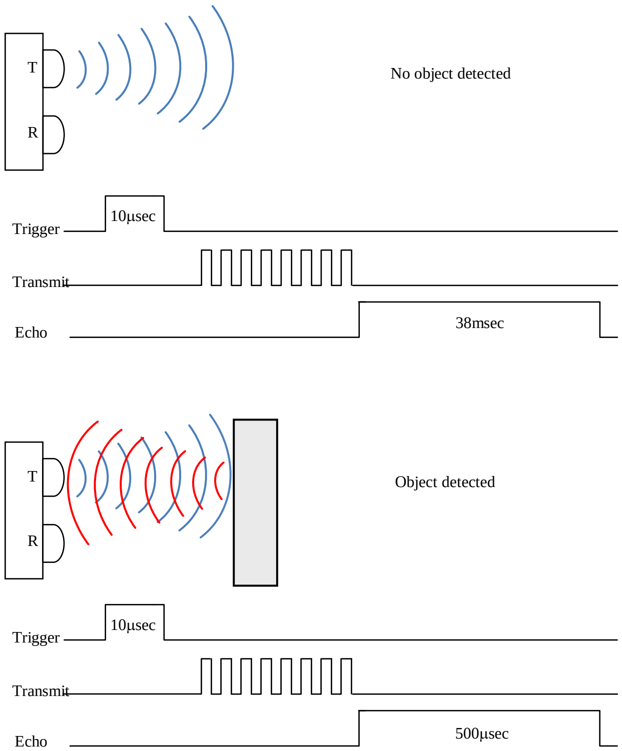

Figure 4: The operation of ultrasonic sensor

The GPIO pins of Raspberry Pi 3 Model B+ are connected to the ultrasonic sensor as shown in Figure 5. Our algorithm based on inputs that receive from the ultrasonic sensor is used to calculate the displacement to an obstacle.

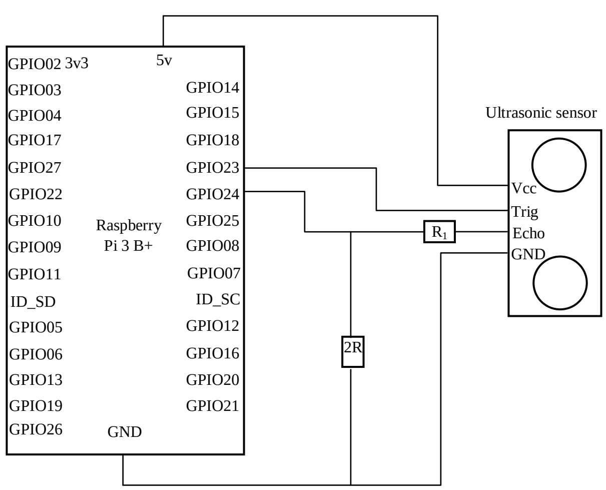

Figure 5:The basic connection of the HC-SR04 module with the Raspberry Pi

4 The algorithm steps

This section illustrated the overall object detection algorithm based on multi-sensor fusion that used both depth sensor and ultrasonic sensor to provide optimal navigational information.

The processing algorithm starts when the Raspberry pi is on. At this time, the depth sensor grabs a visual image and depth image. The steps to detect an object in the lower blocks of 2D image using Otus's method is done to get the depth information of the detected object. When an obstacle is detected in front of the visually impaired person, the middle area will be discarded and a free path is determined by searching for an obstacle on both two areas (right or left area) simultaneously. If there is no detected object on the right region, the system commands a VI person to turn right and go forward. Otherwise, if an obstacle exists on the right region then the system scans the left area. If an object on the left area is not detected, the system issues a command to VI person turn left and goes forward. When the objects are detected on the three areas that mean no free area is detected for movement then the stop and wait command is issued by the system. During this time, the visually impaired person changes his/her direction by turning to right or left by 90 degree to find a free path to pass through it. The searching process of the detected object is applied simultaneously on the three areas.

To avoid the incorrect reading data that will be produced by the depth camera when the obstacle is a transparent object, the ultrasonic sensor is utilized with depth camera in our system to overcome this limitation.

In parallel to the above process, the ultrasonic sensor is triggered by Raspberry pi to start calculating the distance from the sensor to an obstacle. This measurement is integrated with above computer vision method to provide an accurate decision of the movement direction for visually impaired.

Figure 6 describes the flowchart of the proposed algorithm that was used input data from both sensors and processing it to get accurate navigational information in real time.

The visually impaired person needs to notify about the obstacles that are there. An audio feedback is adopted in this work because it is a better choice for the VI person to easily react to the obstacle as it indicated in many studies. The text-to-speech processing is used to notify the VI person about the best direction as an audio message. The visually impaired hears this audio-message using earphone. Table 1 shows audio feedback of condition that will be provided to the visually impaired. The right area is used as a default path if an obstacle found in front of the user.

Table 1. Audio message that received by visually impaired person

Condition	Audio feedback
Obstacle is detected in front of visually impaired person and both sided are free	"GO RIGHT"
Obstacle is detected in left side and in front of visually impaired person; free path in right side	"GO RIGHT"

Obstacle is detected in right side and in front of visually impaired person; free path in left side	"GO LEFT"
No object is detected in front of visually impaired	"GO FORWARD"
No free path in three areas	"STOP"

5 The experiments and results

Many experiments are implemented in real time for different scenarios to evaluate the performance of our proposed algorithm in indoor environment. As mentioned before, our system is a wearable device that consists of RGB-D sensor (Asus Xtion Pro Live camera) and ultrasonic sensor mounted on glasses with slightly tilted towards the ground. The input data acquired by both sensors are processing simultaneously by our algorithm to get their outputs. It implemented in python programming language using OpenCV2 library and Open Natural Interaction 2 (OpenNI2) library. Each captured image is divided into three areas: left, middle, and right areas according to the standing of the visually impaired person (the position of VI person). Audio messages provide the user with the optimal direction to avoid the obstacle.

The following scenarios were conducted in indoor environments, to evaluate the proposed algorithm in Computer Engineering Department's Lab. at University of Basrah:

Scenario 1: two obstacles found, one on the left side whereas the other in front of the visually impaired person as shown in Figure 7 (a). Audio message (GO RIGHT) is provided to avoid the obstacles.

Scenario 2: an obstacle in front of the visually impaired person and there is free path on both sides as shown in Figure 7 (b). The audio message (GO RIGHT) is given to the user.

Scenario 3: two obstacles are detected on both sides of the visually impaired person as shown in Figure 7 (c). The system provided audio message (GO FORWARD).

Scenario 4: this scene has multiple objects. The navigation instructions are given to avoid obstacles and walk between them. The direction were produced to avoid these obstacle are illustrated as arrows in Figure 7 (d).

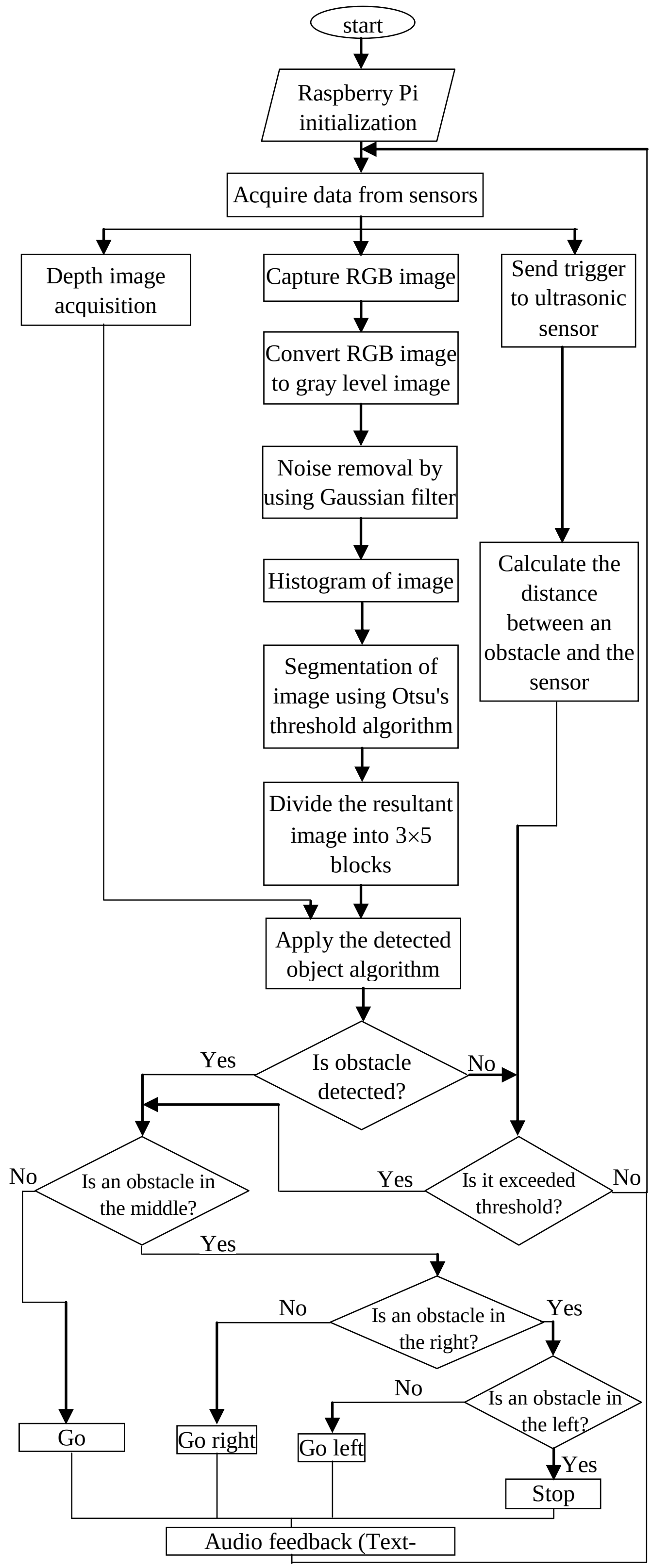

Figure 6: Flowchart of the proposed algorithm

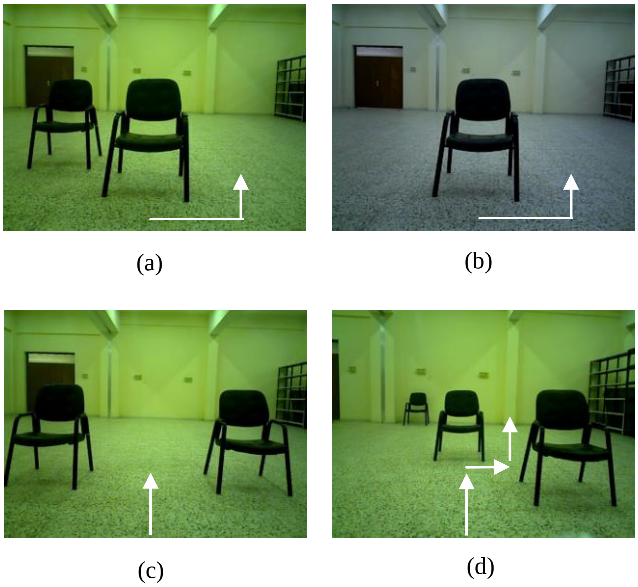

Figure 7: The tested different scenarios

CONCLUSION

This paper presents an accurate indoor navigation system for visually impaired people by using computer vision and sensors methods. The proposed algorithm of object detection solves the small and transparent obstruction avoidance problem in front of visually impaired person. The audio feedback is used to inform the visually impaired user about the presence of obstacles in his/her path through the earphone. Moreover, our proposed system is a portable, low cost, fast enough and operates in real-time condition. This system is tested in real scenarios with any height of the object in many indoor environments. In future work, additional ultrasonic sensors and GPS will be used to support the safe navigation in outdoor environment. Also, the voice of visually impaired person will be used to operate GPS to allow him/her navigates to a specific place. Besides, the object recognition based on deep learning will be adopted in our future work.

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