Indoor Navigation Control System for Visually Impaired People

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Abstract — **Blindness affects the perception of the surrounding environmental conditions. The primary requirement of any visual aid for mobility is obstacle detection. This work proposes an indoor navigation system for the visually impaired people. The system presented in this study is a robust, independent and portable aid to assist the user to navigate with auditory guidance. Computer-based algorithms developed in C sharp for the Microsoft Xbox Kinect 360 sensor allows to build a device for the navigational purpose. Kinect sensor streams both colour and depth data from the surrounding environment in real-time, which is then processed to provide the user with directional feedback using the wireless earphones. The effectiveness of the system was tested in experiments conducted with six blindfolded volunteers who successfully navigated across various indoor locations. Moreover, the user could also follow a specific individual through the output generated from the processed images.**

Keywords - Indoor Navigation; Vision Assistance; Kinect Camera; Collision Avoidance.

I. INTRODUCTION

Visually impaired people often suffer from missing the perception of the environment, which affects them physiologically and psychologically. In the last few decades, many solutions have been proposed and were made available to the blind users through various means, such as white canes, laser canes, binaural sensing aids, Braille, and guide dogs.

The primary requirement is to detect the obstacles and help avoid a collision while navigating to a goal. To help the blind people navigate, the need is to find obstacles and hazards which the regular aids cannot notice. Navigation systems for blind people have been proposed to increase their mobility. However, they were only concerned with guiding the user along a predefined route as in the paper presented by Loomis et al. [1]. In their study, they evaluated the guidance performance in the virtual display mode that allows providing enhanced guidance.

Electronic Travel Aids (ETA) have been considered in the past, such as by Ram et al. [2] as an assistive device which transforms the environment surroundings sensing into signals for the blind. These aids brought a high level of confidence to help visually impaired people navigate. These devices helped to detect obstacles in the pathway of the user. The sensors, software interface, and a feedback mechanism are the three building blocks for any ETA. The sensors communicate the data to the system, where it is further processed using a specialised software and transmit to the user the required information as real-time feedback so that there are no hindrances in the user's way.

Borenstein et al. [3] and Dodds et al. [4] used ultrasonic sensors to augment the performance of the guidance cane. These sensors helped the user to detect barriers and steer accordingly, which proved to be better compared to traditional cane, given that the guide cane provided the path efficiently. Benjamin et al. [5] and Yuan et al. [6] used laser and vision sensors that enhanced user's confidence while navigating as a reasonable way for providing the information in real time using a laser triangulation system. S. T. Brassai et al. [7] provided an overview of the literature on assistive technologies for indoor and outdoor navigation in a dynamic environment. They also provided the list of solutions available for helping visually impaired people, such as navigation system, obstacle avoidance, and obstacle localisation.

The indoor auditory navigation system [8] presented by A. Zeb et al. assists visually impaired people in the surrounding environment using a computer vision technology which detects the markers. The user navigates using a webcam attached to the system which further provides the user with valuable audio assistance whenever it detects any markers in the environment that enables them to navigate independently in the environment.

C. K. Lakde et al. [9] reviewed and further improved a system [10] that guides blind people. This study presents an idea to make a person aware of the available pathway and the obstacles. The system proposed by the researchers here consists of sensors (depth and Red, Green and Blue (RGB) sensors) embedded in shoes, a control board and a communication system (vibration and voice assistance).

Another system, presented by T. Schwarze et al. [11], consists of a wearable assistance system for helping visually impaired people using a stereo camera and acoustic feedbacks. They used basic scene understanding, and head tracking, to make the user aware of the surroundings and allowing the user to walk in an unfamiliar environment and to avoid obstacles safely by sonic signals. There have been numerous solutions, but most of them are limited to specific situations and only for specific areas.

II. METHODOLOGY

A. System Design and Kinect Technology

In this study, a navigation system is proposed based on computer vision technology. The system is much more than a sensor itself; it includes three main components each having a specific functionality. First and the foremost is Microsoft Xbox 360 Kinect sensor, which is used for accumulating the environmental information from the data streams (both depth images and RGB images). The second is the image processing algorithm programmed using C sharp language, performed on a laptop, and the third component is a feedback system for guiding the user using the auditory information.

As soon as the system runs the algorithm, the Kinect sensor starts capturing the depth and RGB data from the video streams within the sensor range. The accumulated data is then directed to the processing unit, which, in this case, is a laptop running the Microsoft Visual Studio, which helps with real-time image processing without any noticeable time delay and provides the user with useful directional feedback. To achieve the best out of the Kinect device and to provide better viewing angles, the device is chest mounted using a GoPro chest mount [12]. Mounting the device right from the centre makes it more robust, and stable. The Kinect sensor is powered by a rechargeable 6000 mAh Li-Ion, 12V DC portable battery pack, which makes it portable and can run the system for about 8 to 10 hours.

The primary aim of this study is to provide better vision system as compared to the conventional low-priced sensors as those cannot produce the same quality output as compared to the much more advanced Kinect sensor. The prototype is a robust system comprising of an RGB camera, infrared sensor (IR), and an infrared projector. This device provides the user with an improved understanding of the environment. Moreover, it is a simple, reliable, and low-cost system which helps the user to navigate by providing the right amount of information.

Specific scenarios are tested using the Kinect, to help the user navigate [12].

Three main scenarios tested in this study are:

1. Navigating indoors, such as in classrooms and laboratories, guiding the visually impaired person through obstacles, such as tables, chairs, lab partitions, other individuals, and cabins.

2. Detection of the doors of the classrooms and labs by their names or numbers while in the hallways or corridors and recognition of the stairway going up or down.

3. Following a specific person out of a group of three in the lobby, with audio guidance through Bluetooth headphones.

For the above-mentioned testing scenarios, the system is designed for two different modes of guidance to fulfil the needs of the visually impaired people. First, the Normal Mode of guidance in which the user can roam independently indoors with the help of auditory feedback informing about the obstacles, persons in their way, as well as stairs. Moreover, if in some cases they do not receive precise information, they are backed up with Quick Response Code (QR) placed at various locations in the building. QR codes can be scanned by the Kinect sensor much faster, and these codes can store a substantial amount of data. Moreover, the user can be provided with some additional information such as stairs going down/up and the number of stairs, the location of an elevator, and level information. The other mode of guidance is the Follow Mode guidance in which the visually impaired people can follow a particular person for navigational help without any physical contact, and it would provide assistance which would not be altered even if anyone else is in the range of the sensor.

The depth of the obstacles or objects is measured using the triangulation method. The Prime sense chip sends a signal to the IR projector to start emitting an invisible electromagnetic light onto the object or the scene. It also sends the signal to IR depth sensor to initialise and capture the depth stream and this information is sent back to the chip where the frame by frame depth stream is created for the display.

The IR projector projects the laser pattern which gets reflected by the object in the sensing range and IR camera triangulates it for depth map by recapturing the emitted light, as shown in Figure 1.

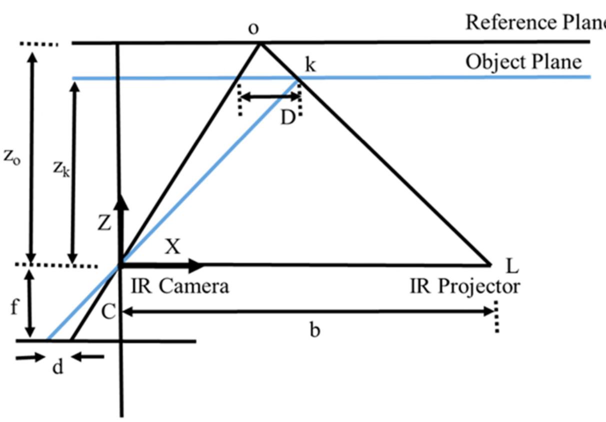

Figure 1. Schematic representation of triangulation method

The distance zk, from the camera to the reference plane is obtained from:

$$z_k = \frac{z_\circ}{1 + \frac{z_\circ}{f \times b} d} \quad (1)$$

where d is the depth distance/observed disparity, z_o is the assumed position of the object on the reference plane, f is the focal length of the Infrared Camera, and b is the baseline between the IR camera and the IR projector. Equation (1) denotes the observed disparity where z_o, f and b can be determined by calibration.

B. System Initialization and Implementation

Once the program starts, the very first step is to verify if the Kinect sensor is connected to the computer or laptop. If the system does not find any sensor connected, it will return the program with error and exits. If the Kinect sensor is connected to the system, the program proceeds normally. Once the system is connected and can interact with the Kinect, it will send a signal to both RGB and IR depth sensor to start the streams for colour and depth frames, Figure 2.

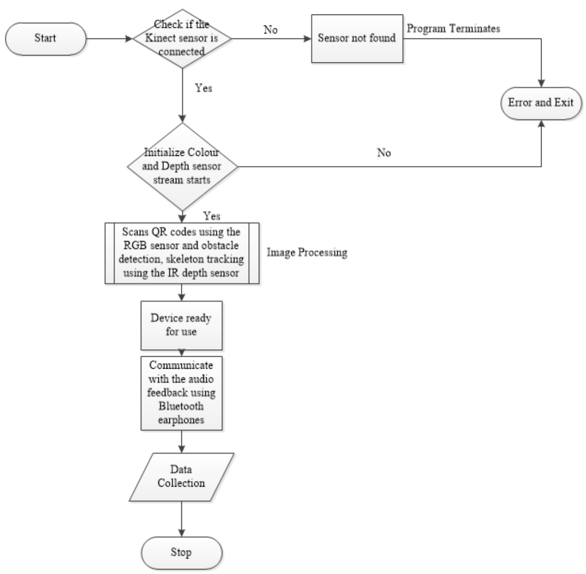

Figure 2. System data flow

If the Kinect sensor is connected to the system, the program proceeds normally. Once the system is connected and can interact with the Kinect, it will send a signal to both RGB and IR depth sensor to start the streams for colour and depth frames, Figure 2.

The RGB camera stream thus provides the QR code scanning for the audio output to the user which is done with the help of ZXing open source library that helps to scan the code and read the information stored. The depth camera stream uses the skeleton tracking and it also helps to provide information about obstacles. The image processing for the depth sensor is done using EmguCV, which is an open source library that helps to find different contours, skipping objects by different width ranges, can count people in the sensor range and take all the necessary decisions which help the user navigate. It also allows the speech synthesis which further provides the user with the necessary audio information. Then, finally, both the streams are displayed on the laptop screen running at 640 × 480 at FPS 30.

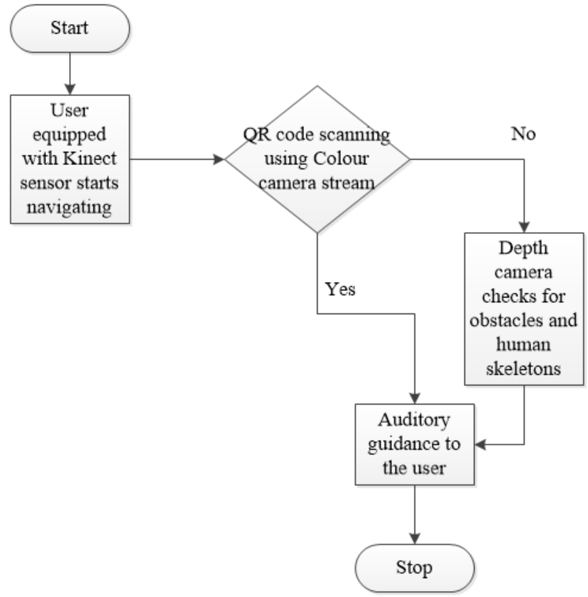

Figure 3. Free Mode of guidance

Figure 3 shows the data flow process for the free mode of guidance. Once the user starts navigating using this mode, the very first thing the program looks is the QR code. In case no QR code is detected by the colour camera, then the depth camera will start to look for the surrounding obstacles and provide the user with audio output necessary for the navigation. In case, the camera detects the QR code, then, it will communicate the information stored using the Bluetooth earphones.

III. Experimental Results

A total of six blindfolded sighted individuals participated in this experimental trials performed for both free mode and Follow Mode guidance. Each performed two trials on the specified path for the system testing and feedback. The blinded person starts from a lab on the level 2 on the free mode as shown in Figure 4 [12]. Then the individual must be able to avoid all the obstacles making their way out of the lab using the exit door. QR codes posted on the door gives the information to the user saying exit. Once the user exit the lab, they can either take the stairway or the elevators to reach down to the level 1. QR codes help assist the user with the number of stairs going up or down. The user then walks through the hallways which have many classrooms doors. QR codes posted will assist the user about their final destination.

In Follow Mode guidance, the user will just keep on following a particular person in the indoor environment. In this mode, a few assumptions are made such as no more than three individuals are walking in the hallway and following the designated guiding person. Directional feedback guiding the individual about every movement of the person being followed helps them to reach their destination. The red box highlights the person being followed, as shown in Figure 5. This lets the system guide the user accordingly and, at the same time, lets the user know about the obstacles.

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For the Follow Mode of guidance, before iterations were done, it is assumed that there is no interference between the user and person being followed. In this case, the depth camera will help to locate the motion of the subject being followed using skeleton tracking and guide the user accordingly ignoring other humans in the surroundings. After the feedback from the blindfolded test subjects, another major iteration was done which improved the system.

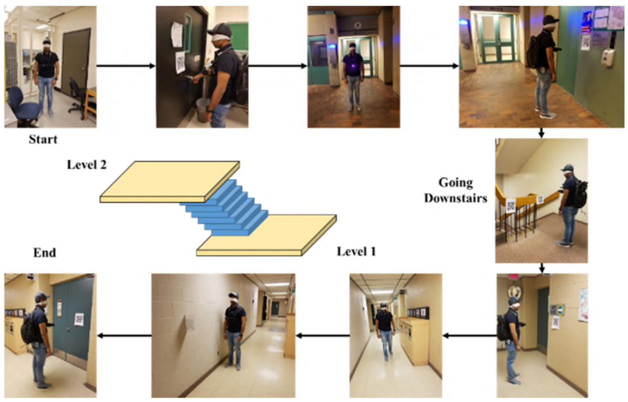

Figure 4. Experimental Environment for guidance

In this Follow Mode testing, instead of using the skeleton tracking, it was decided to follow a person with QR code at the back, and the sensor will keep on following that QR even if there is an interference of another human which would be ignored by the system. This change increased the capabilities of the proposed system; with further algorithm changes, it modified the way Follow Mode works as the part of iteration after the test results. In this iteration, the visually impaired person follows a QR code which was found to be more accurate for the Follow Mode of guidance. Results for this iteration are shown in Figure 5 and Figure 6. Whenever the sensor detects the QR code is saying ‘Follow’, it will keep on following that person even if any other person interferes or passes across.

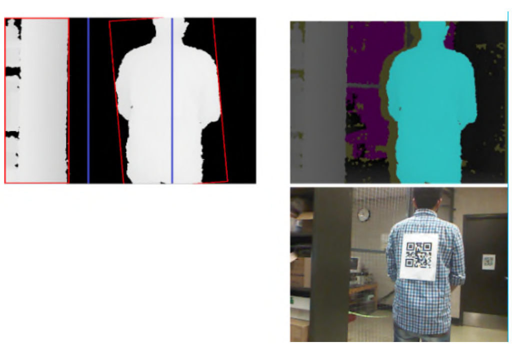

Figure 5. Follow Mode using QR code in a lab

Further experimentation with people interfering during the testing using Follow Mode was found to be better with the use of QR code, as shown in the Figure 7. The results below clearly show that the sensor is only tracking and following the person with the QR code which is highlighted with the red box and is not tracking the other two humans.

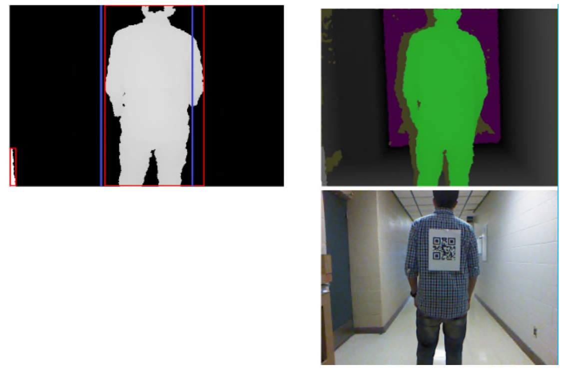

Figure 6. Follow Mode using QR code in hallway

Another scenario is shown in Figure 8, where there is another person in between the visually impaired person and the person being followed. In this case, the sensor highlights both the humans in the range for the normal Follow Mode, but with the iteration which was done with the use of QR for the following mode, now the sensor will guide the user to follow only the person with the QR code at the back. The accuracy of the test object through the test course helps to measure the effectiveness of our device.

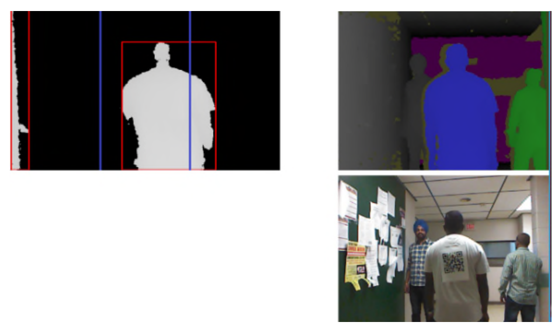

Figure 7. Follow mode with interference

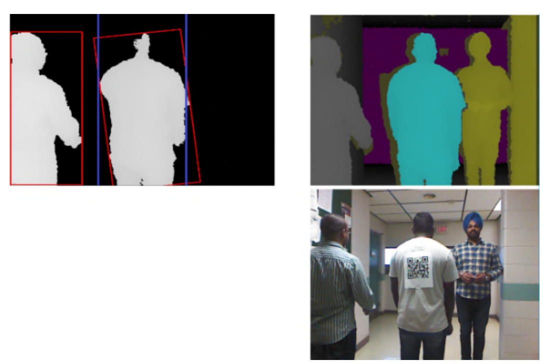

Figure 8. Follow Mode with another person in between user and the person being followed

The ability of the device in tracking all kinds of obstacles and providing auditory outputs was found to be noteworthy as compared to the previous studies discussed in the

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literature review section. The success of the system is in fact how it does the obstacle detection, avoidance, scanning QR codes and tracking humans as well as in providing audio information for the navigation purposes. The Kinect sensor helped to develop a novel approach for navigation as compared to the previously available devices in which there were more components used but for a specific use.

IV. Conclusions and Future Work

This paper presented an indoor navigation system using a Kinect sensor, for the Free Mode and Follow Mode guidance. The prototype is durable, lightweight, and cost-effective, and anyone can use it with ease without any training because of its simple to operate. The real-time image processing, done with the help of computer vision algorithms, helped to detect all kinds of obstacles such as tables, chairs, humans, walls, doors, and stairs. The QR code helped to enhance the accuracy of the system and improved the results. Audio feedback is provided to the user whenever the system scans any obstacle or a QR code, and in case of the Follow Mode guidance, it provides directional information according to the movement of the person being followed. The system was evaluated by the feedback from six blindfolded users for both navigation modes. The results show the effectiveness and efficiency of the system in helping visually impaired users in the indoor environment, based on the navigation success of the users through the test course.

To add to the prototype that can assist the blind or visually impaired, further iterations and improvements can be made in the current system. The further scope of perfection and development can be achieved by designing a more stable mount for the camera, which can provide better viewing angles and even help in calibration. The current Kinect sensor can be replaced by the newer version of Kinect which has all new technology and better sensor quality outputs. These changes would increase the scanning range of the obstacles. There is also a possibility of using multiple Kinect sensors that might help to provide more independence while navigating. Further changes in the algorithm can be made to make it more robust. Radio-frequency identification (RFID) technology can also be incorporated into the current system for better results in outdoor areas which will provide another solution to help to navigate through public places using RFID tag grids, canes or other various devices.

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