Navigation Assistive System for the Blind using a Portable Depth Sensor

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***Abstract* — The lightweight and low-cost 3-dimensional depth sensors have gained much attention in the computer vision and robotics community. While its performance has been proven successful in the robotics community, these sensors have not been utilized successfully for many assistive devices. Leveraging on this gap, this paper presents the design, implementation, and preliminary evaluation of a haptic feedback system for the blind using 3-D depth sensors. The proposed portable system interprets the visual scene using the depth sensor, converts it into distance map, processes, and evaluates this information using a tablet computer. In addition, it provides haptic cues to the user through an array of vibration motors woven into the gloves. Throughout preliminary evaluation, this system has shown to successfully identify, track, and present closest objects, closest humans, multiple humans, and perform real-time distance measurements.**

Keywords – depth sensor; haptic feedback; blind; navigation assistance

I. INTRODUCTION

The World Health Organization estimates that 285 million people are visually impaired worldwide [1], and the US Census Bureau reported that 54 million people with disabilities [2]. While many of these individuals live and interact independently, it was reported that the majority lack the ability to live and function independently. One of the major issues these individuals face is their inability to interpret surroundings and identify obstacles in their path of commute. This challenge led to the introduction of many assistive devices for navigation assistance, with the two most common being white canes and guide dogs [3]. The white cane is only partially effective as it does not detect objects above the knee height, and does not provide cues in sufficient time to avoid a collision in a populated area. As for the guide dog, unfortunately not all visually impaired individuals have access to dogs due to an ongoing shortage of properly trained dogs. Even when trained dogs are available, their assistance is limited in the inclement weather.

Research demonstrated that assistive technologies could be used to help more people with disabilities to become a part of regular learning environments [4]. This when combined with the number of blind individuals' calls for an impending action in the design of assistive devices [5]. This research presents a depth sensor based haptic feedback system as presented in Fig. 1, and belongs to the category of vision substitution. This haptic feedback system helps the blind person to overcome challenges of dependence, and let them participate in more social and civic activities to improve their quality of life.

II. PREVIOUS WORK

Over the past three decades, research has been conducted to design new navigation devices for the blind [7-17]. Benjamin et al. [7] built a laser cane that uses optical triangulation with three laser diodes. The first laser points at the ground detecting a drop in elevation, the second points straight in front of the user parallel to the ground, and the third points straight ahead at an angle of 45° from the ground to protect the user from overhanging obstacles. Bissit and Heyes [8] developed a hand-held sonar device that gives the user auditory feedback with eight discrete levels. Bousbia-Salah [9] proposed a method of detecting obstacles on the ground through an ultrasonic sensor integrated on the white cane and the user's shoulders. Shoval et. al [10] proposed a navigation belt comprising of an array of ultrasonic sensor to detect obstacles, but it is not an ideal method for operation in dense and noisy environment. Na [11] proposed an interactive guide system for indoor positioning, and Farrah [12] proposed the virtual reality technology to capture images of the house using cameras, and uses this information for indoors navigation. Kulyukin [13] proposed a robot-assisted navigation method for indoor environments.

Vision based situational awareness and haptic feedback systems were proposed and implemented by many researchers. Castellas et al., [14] used a vision sensor to detect possible

Fig. 1. Prototype of Haptic Feedback System on a User

obstacles to supplement the feedback provided by a traditional white cane. They used the images to detect sidewalk borders and obstacles in a predefined window, but have poor accuracy in dense environment. Sainarayanan [15] presented a fuzzy clustering based algorithm to identify obstacles in the path and provide feedback to the user through stereo earphones, but their system requires high computational power, and it is difficult for the user to comprehend signals in a noisy environment. Also, many of these existing systems increase the user's navigation-related physical load, as they require the user to wear heavy body gear, contributing to physical fatigue. Based on the principles of universal design, the navigation based assistive devices for the blind should encompass design characteristics such as: equitable use, flexibility, simple and intuitive, perceptible information, portable, and allow for periodic updates.

III. Design and Implementation

Figures 2 and 3 shows the architecture and data flow for the proposed haptic feedback system (HFS). The first module in the architecture is a Asus xtion pro depth sensor [xx] that is used to observe the environment in a similar fashion as the user, but with several added filters to obtain only the depth information to identify presence of obstacles in the path of navigation. This is accomplished through PrimeSense's 3-D sensors which uses light coding to code the scene with the aid of active infrared illumination [18]. The coded light is processed through the built in chip to obtain depth information of the environment right across [5]. With a horizontal field of view of 57° and vertical field of view of 43°, a distance map across the user is generated in an image with a resolution of 640x480 pixels at 60fps.

The second module in the proposed system is a tablet computer that can decode the proprietary data from the sensor into a meaningful format. This tablet computer obtains the depth images as generated by depth sensor, and decodes the information to form a matrix of 640x480 elements, with each representing distance of the object with respect to the user. Upon generating this matrix, it divides this into eight smaller zones, four on the left (L1, L2, L3, L4) and four on the right (R1, R2, R3, R4), with each corresponding to a respective column in the vibration module. Then, it uses the nearest neighbor algorithm to find the location of the nearest obstacle with respect to the user and generates appropriate signals for the haptic feedback unit. Furthermore, the system can also identify if the obstacles are static or dynamic, and provide real-time information to the user through an audio feedback system.

Once the location and distance information of the nearest obstacle is found, an Arduino micro microcontroller generates signals to actuate the appropriate vibration motors. As the number of vibration motors far exceeds the number of available output ports on the microcontroller, a 16-bit input/output (I/O) expander was used to decode the information from the I^2C bus of the microcontroller. This I/O expander transmits this information to the left-hand and right-hand vibration modules to activate the respective number of actuators.

The left-hand and right-hand vibration modules are an array of shaftless 8mm motors woven into gloves, and serve as our vibrotactile feedback delivery mechanism. Figure 4 shows the architecture of the haptic feedback system with 16 motors woven into the left-hand glove (one column of four motors into each finger sleeve), and Fig. 5 shows the prototype board with all the electronics, and Fig. 6 shows the wiring connections of the motors in the glove. These motors vibrate based on the signal generated from the I/O expander, which inherently is generated based on the presence of the obstacle that is within the depth sensors field of view. For instance, if a static obstacle is found in zones L1 and L2 of the Kinect's field of view, motors in the first two columns of Fig. 4 will vibrate, with the number of vibrating motors proportional to the distance of the obstacle. Also, while operating in densely populated environment, this feedback system could be used to inform the blind user the location of an open space or direction to pursue and avoid collision during a commute.

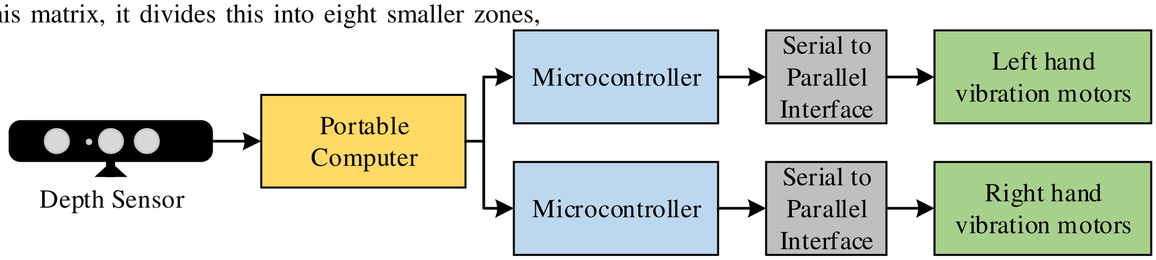

Fig. 2. Architecture of Haptic Feedback System

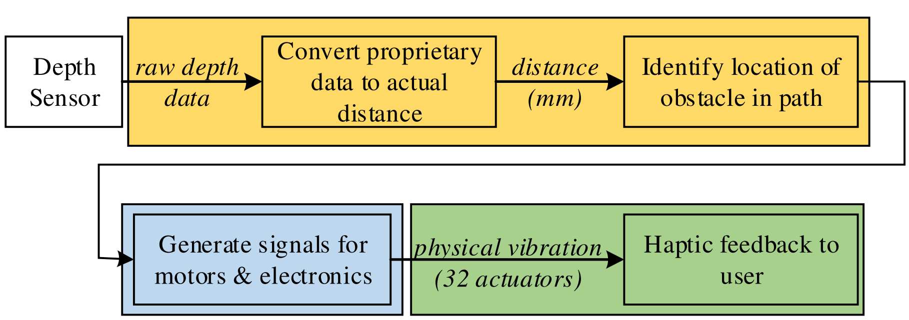

Fig. 3. Data flow and manipulation

IV. Preliminary Testing and Evaluation

The proposed haptic feedback system is a work in progress and preliminary testing has been completed; further evaluation is pending acceptance from the Institutional Review Board at the host institution. To validate the fundamental operation and feasibility of the proposed system, it was subjected to multiple tests as presented below. As it was not feasible to demonstrate the operation of vibration motors in this paper, a simplified test system was assembled with LED's on a breadboard in place of motors for the presented tests.

Test-1 (Identify closest object): In this test, the system was programmed to obtain the depth matrix, filter the data to identify the closest object in its field of view, and turn on the appropriate number of LED's with respect to distance of objects from the system. Figure 7 shows the depth image as obtained from the sensor, and the zone partitions (L1, L2, L3, L4, R1, R2, R3, and R4) as presented in section 3. Upon filtering and data processing from this image, the closest object (marked with red dot) was detected in zone-L3. This information was transmitted to the left hand microcontroller, which activated two LED's in zone-L3 through the I/O expander as presented in Fig. 8.

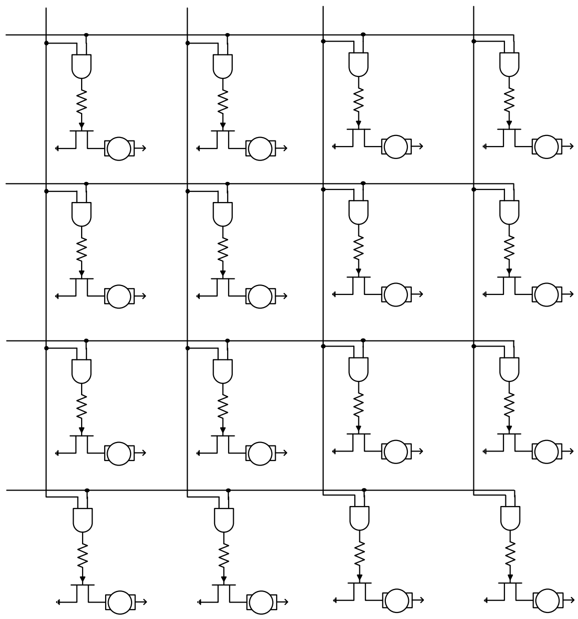

Fig. 4. Architecture of Haptic Feedback Array

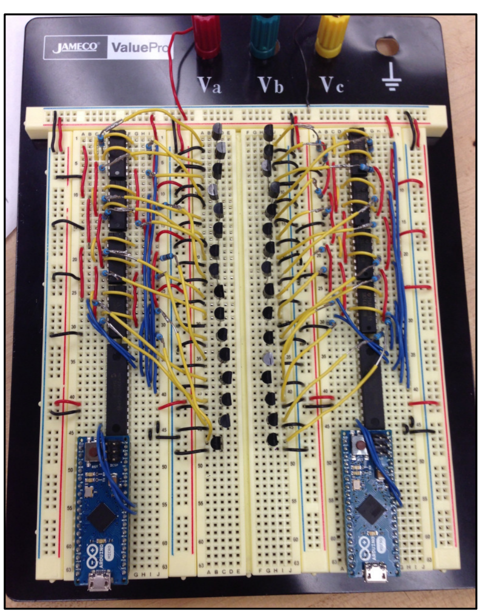

Fig 5. Prototype board with electronics of proposed system

Test-2 (Detect humans): In this test, the system was programmed to filter through the depth image, and detect presence and location of a human, and turn on appropriate number of LED's with respect to distance. Figure 9 shows the depth image as obtained from the sensor, zone partitions, human detected (marked with blue color), and their respective center of mass (marked with red dot) in zone-L3. This information was transmitted to the left hand microcontroller, which activated three LED's in zone-L3 through the I/O expander as presented in Fig. 10.

Test-3 (Measure distance between points): As it is not uncommon for humans to stretch their hands while walking, this test was designed to identify if any humans in the path of navigation have stretched their hands, so as to mark this region as no-pass region. If so, the system identifies location of the human, measures the distance between the two hands, and inform the blind user so that he/she can navigate around by

Fig 6. Vibration motors in the left hand glove

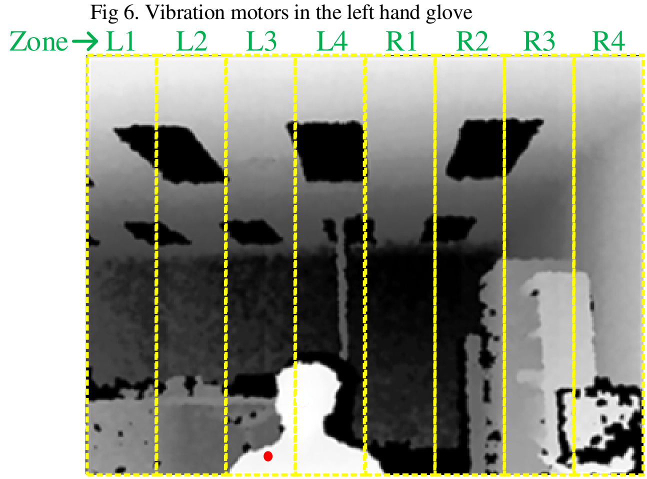

Fig. 7. Depth image for closest object detection test

avoiding the obstacle in his/her path of navigation. The depth image as obtained from this test is shown in Fig.11, where the presence of human is marked by blue area, and the red dots represents the location of head, center of mass, left hand, and right hand, and the distance between the two hands in presented in mm on the left side (mag: 1373.8055), validating that the proposed system can identify movement of the humans in real-time.

V. Conclusion

In this paper, we presented the design, implementation, and evaluation of a simple, light, and low-cost depth sensor based haptic feedback system. Through the initial prototype, the proposed system has proven to overcome challenges of computational power, comprehension of signals in noisy environment, and heavy body gear as presented in the previous work.Through preliminary testing, it was demonstrated that the proposed system could be used to i) detect presence and location of obstacles in the path of navigation, ii) identify an obstacle-free path in the field of view for the user to follow for safe navigation in a crowded environment; and iii) detect obstacles in the navigation path in real-time. While designed and implemented as a navigation system for the blind, the proposed architecture has a broad

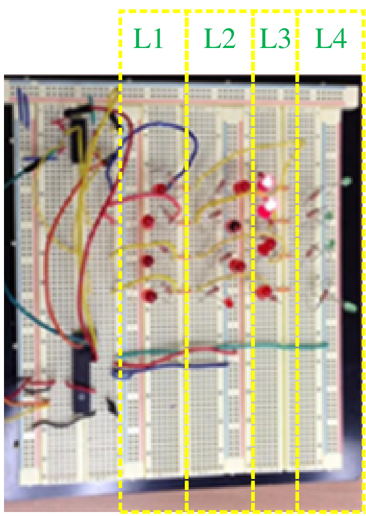

Fig. 8: Verification of closest object detection test

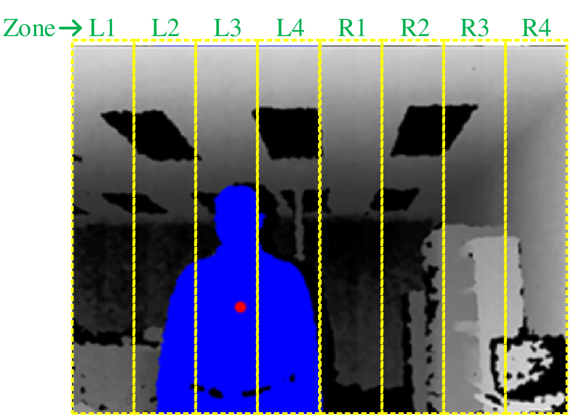

Fig. 9. Depth image for human detection test

range of applications including, but not limited to body tracking for clinical assessment and monitoring, body tracking during rehabilitation, and touchless interaction in image guided interventional medical treatment. The proposed system is a work-in-progress, subjected to multiple tests to validate the feasibility of implementation, and is awaiting IRB approval for real-time testing with the blind individuals.

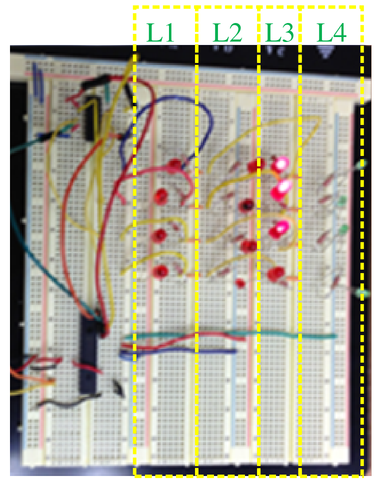

Fig 10. Verification of test for detecting human

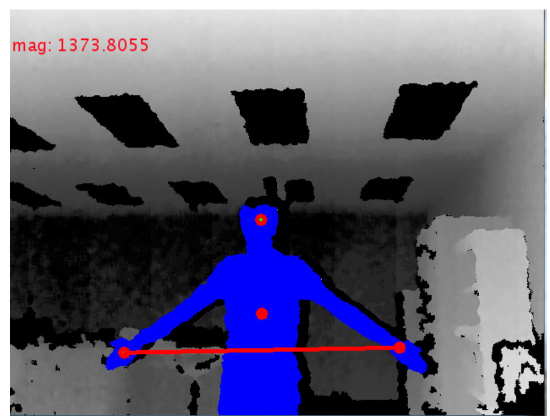

Fig. 11. Depth image for test of distance measurement between two points

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