Bionic Kinect Device to Assist Visually Impaired People by Haptic and Voice Feedback

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***Abstract*—This paper presents a wearable bionic Kinect device for blinds that helps visually challenging persons to move freely without any external assistance. This wearable consists of Kinect sensor, NUC (Next Unit of Computing) board and haptic feedback. Kinect sensor is used to get color data by RGB (Red Green Blue) camera and depth data by infrared projector which emits coded pattern received by receiver sensor that captures deformed pattern due to reflection by obstacles; algorithm decodes these variations into depth matrix. Image processing algorithms are applied on depth matrix to remove noise. Two dimensional Image processing algorithms of edge, contour detection and segmentation techniques are applied on multidimensional matrix at each level to extract important information about obstacle, humans and their characteristics. Extracted information of obstacles and humans are converted to haptic sequence and voice commands. Haptic feedback device receives the sequence, decodes sequence by using onboard microcontroller algorithm and creates vibration of different intensity at different regions. Text is recognized by optical character recognition system and faces by machine learning algorithms of device uses Kinect color data. All these tasks are performed by two processing units, a microcontroller and NUC which is excellent combination of wearable ubiquitous computing. Whole system is light weight, battery powered with intelligent power management circulatory to make it portable and easy to use.**

Keywords—Kinect Sensor; Visual Impaired; Haptic Feedback; Depth Data; Color Data; Image Processing; Microcontroller; NUC Board and Ubiquitous Computing

I. INTRODUCTION

About 45 Million people are affected by blindness worldwide and face many difficulties in performing routine task. In Pakistan 8 Million people are visually impaired out of them 2 million are blind and other 6 million people are partially blind [1]. Even mobility from one place to another is troublesome. Mostly visually impaired people frustrated by lack of spontaneous movement. In recent years, several devices are designed for navigation of blind persons [2-7], but these devices were failed due to high cost, inaccuracy and inaccessibility. Due to these problems blind persons still rely on conventional tools like canes or guide dogs. Main purpose of this paper is to provide an alternative that can help the blind people to navigate more freely and easily in surrounding. Hardware and block diagram of bionic Kinect device are shown in figure 1.

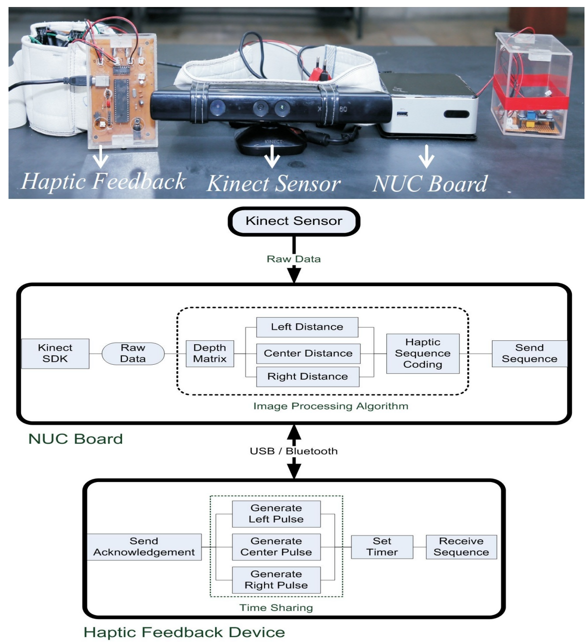

Figure 1: Hardware and block diagram of bionic kinect device.

This paper is divided in five sections. Hardware design and integration with software is discussed in section II and III respectively. Experimental results are tested in section IV and concluded in section V.

II. Hardware Design

A. Haptic Feedback

The sense of touch in human is very responsive and it works in human by connection of nerve ending to skin tis-

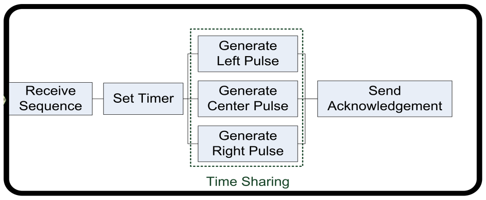

Figure 2: Block diagram of haptic feedback.

sues which provides human information about surrounding environment like hot, cold, pain, pressure on skin and feel of object touching the human body. In recent years different technologies used sense of touch to transfer information to human. Most popular examples are android haptic keyboard and haptic alerts on apple watch. Block diagram of haptic feedback device is shown in figure 2.

Haptic feedback wearable shape is similar to belt has three regions left, center and right. Vibration at each region is created by weighted motors that vibrate with different intensity according to received command. Haptic feedback communicates with NUC board, for this purpose a technique is developed, named as haptic sequence. Information of obstacle position and distance coded on NUC by haptic sequence technique, sent to haptic feedback device and then decoded by haptic feedback device with acknowledge system in place to preserve both bandwidth and message integrity. Haptic feedback device has onboard microcontroller which decodes the received haptic sequence and extract information about vibration location and intensity. PIC microcontroller is used to perform all tasks from receiving coded haptic sequence to send back acknowledgment. Most microcontrollers have one or two PWM (Pulse Width Modulation) modules but needed three or more PWM modules with independent channel. Microcontroller required to not only create PWM but also have to perform other tasks including receive haptic sequence, decode the sequence using encoding technique create PWM strategy for decoded information, start generating PWM, check for new haptic sequence meanwhile maintain previous PWM and send back acknowledgment of currently executing haptic sequence. All these tasks should be concurrent [8]. Most efficient technique for concurrent processes is present in multitasking and multithreading. Thread is a small process that is performed by computer in a given time. While multithreading is way of performing multiple tasks at same time. Multithreading is implemented using different techniques according to computer processor type and number of processor cores. If a processor has multiple cores then each processor core can handle one thread easily if a processor has only one core then all threads have to share the same processor. Different operating system implement algorithm of CPU scheduling like first-come first-served, shortest-job-first, priority, and RR (Round Robin) scheduling. Single core system implements time sharing technique to switch CPU between different processes. There is a problem, all these CPU scheduling systems are present on an operating system but these capabilities are required on a microcontroller which have no operating system, nor any kind of concept similar to this on PIC microcontroller because a microcontroller has limited RAM, flash memory and CPU frequency. If haptic feedback device algorithm implemented using conventional methods microcontroller freezes at first vibration region and will wait until its completion. This approach is useless for haptic feedback device.
To solve this issue combined the different techniques of multithreading and processes scheduling from OS (operating system). RR scheduling algorithm is modified to work with microcontroller. Modified RR scheduling algorithm utilizes hardware interrupts of timer. UART and USB modules are used to create execution strategy that can run multiple threads in parallel to each other. Haptic feedback device supports communication using Bluetooth and USB therefore acknowledgment system should be in place to repeat message if message sent drops. Message acknowledgment system implemented using computer communication network transmission protocols. Two microcontrollers are used, one for Bluetooth and other for USB communication. Designed device supports both microcontrollers. PIC18F4550 is used for USB communication and PIC16F877A is used for Bluetooth communication.

B. Kinect

Basically Microsoft's Kinect Xbox 360 is a motion control sensor used for gaming purpose. Wearable device utilizes Kinect to get depth data. This raw depth data is used in algorithm to detect obstacles. Kinect sensor get depth data by infrared projector which emits coded pattern, reflected pattern is sensed by infrared camera that captures deformed pattern due to reflection by obstacles using triangulation technique [9-10].

C. Intel NUC and Power Management

A small form factor personal computer designed by Intel is selected due to its size and availability in market. Size of it is 4x4 inches which is quite compact for this wearable device. This board runs on conventional AC source after some hardware modification it can run on a DC battery source. Kinect and NUC is powered by a battery pack. This battery pack is made up by connecting three cells in series; each cell is of 3.7 V to 4 V and gets 11.1 V to 12 V. During operation the voltages of a battery fluctuates and may cause damage to attached components, to keep track of voltages and cut-off at critical battery level a power management circuitry is designed that can constantly provide 12 V form battery until battery reaches 10 V. This circuit protects from both over and under voltage. Power management circuitry is so robust that it only cutoff at under voltage and converts over voltages (up to 20 V) to 12 V. Conventional voltage regulator waste energy to step down the voltage this produces too much heat. This causes battery to discharge rapidly and even damage the battery to avoid this, high efficiency voltage regulator is used also called voltage bulk convertor. It utilizes small chunks of power.

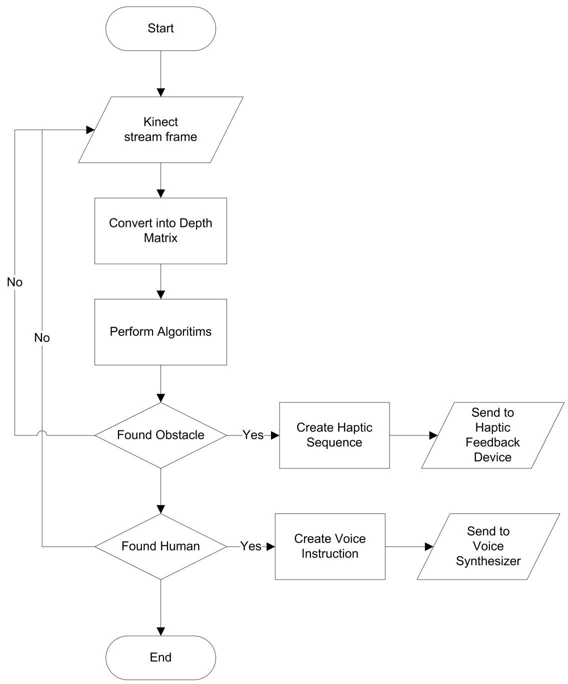

Figure 3: Flow chart.

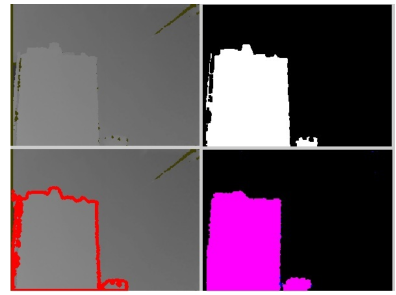

Figure 4: Algorithm results at different stages.

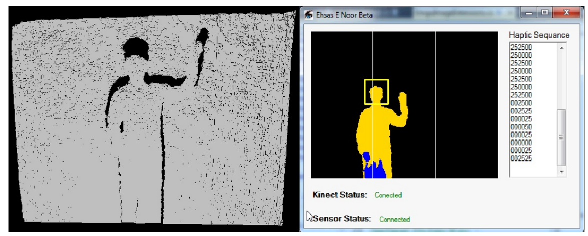

Figure 5: Data before and after processing by algorithm.

III. Integration of Hardware and Software

Software design covers designing of windows based application that gets data from Kinect through Kinect SDK (Standard Development Kit), process data using OpenCV and send data to haptic feedback using Bluetooth or USB protocols as shown in figure 3. Designing of windows based application done by Visual Studio using C# to collect data from Kinect SDK are used, to process data EmguCV wrapper of OpenCV for C# is utilized, to send haptic sequence USB and serial port libraries are utilized. Microcontroller programming is done by MikroC PRO in C. Algorithm runs on NUC to perform following tasks.

In first task, Kinect SDK is utilized to get raw depths data this raw data is retrieved in the forms of depth streams, this stream consists of array for each frame. Every element have 16-bit from which last 13-bits represents distance in millimeters, these 13-bits are acquired by bit mask operator.

In second task, converted distance is transformed into three levels the 400 $mm - 1000$ mm mapped as red, 1000 $mm -$ 1500 mm as green and 1500 $mm - 2000$ mm as blue, these three level are painted into a RGBA(red, green, blue, alpha) color scheme where alpha is brightness which is zero in this case.

In third task, algorithm converts RGB by thresholding using equation (1) to create compatibility by classifying these levels and create a RGBA image. This image is further converted to bitmap to display in Win-Form GUI. To process this frame by Image processing library, Emgu CV create an Emgu type image and then perform a calculation which decides the region of object. These calculations are performed at each pixel and classify obstacles into left, center and right region. Additionally, classify obstacles and finds nearest distance.

$$g(x,y) = \begin{cases} 1 \; if \; f(x,y) > T \\ 0 \; if \; f(x,y) \leq T \end{cases} \tag{1}$$

Final stage is to combine all information, match with previous information and calculate the difference. When difference is calculated, algorithm decided either any change occurred if true then create a haptic sequence and send to haptic feedback device. Processing at each stages is shown in figure 4, top left data is without processing, top right data after noise removal, bottom left outlining boundary and bottom right another sample coloring of object according to distance.

Information about human is detected by identifying unique skeleton system of human; this skeleton system is identified by Kinect SDK using segmentation for each parts of body and applying some probability analysis and previous trained data. When a human is detected the device tracks movements of human. If human weave his hand, this device create a text instruction and send it to voice synthesizer. The voice synthesizer informs user by voice through headphones. The detection of humans is shown in figure 5. Data before processing is on left, final result of a given data is on right including human and facial recognition. Initially data processed at 30 frames per seconds but due to intensive power consumption reduced refresh rate to 15 frames per second for optimal results and lower power consumption.

IV. EXPERIMENTAL RESULTS

Using bionic Kinect device series of tests conducted. First test is performed by blindfolded person and second test performed on actual blind person in different environment to get more realistic results. Person equipped with device is shown

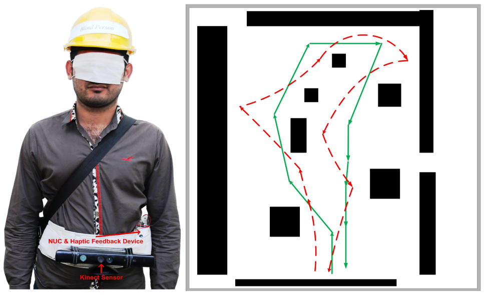

Figure 6: Person equipped with device(left), solid line presents ideal and dotted line presents device path(right).

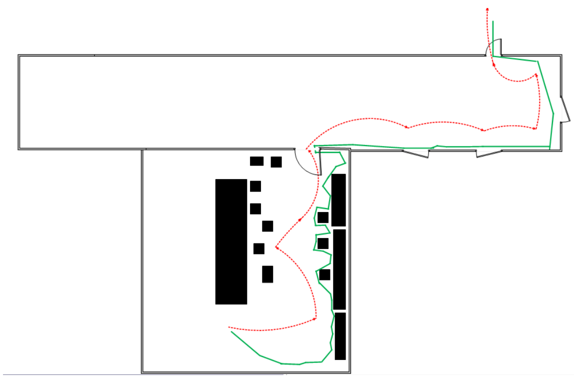

Figure 7: Solid line presents ideal and dotted line present device path.

in figure 6 (left side). All obstacle were placed during experiment and positions of obstacles shuffled throughout experiment to avoid any prediction by test subject.

A. Navigation Tests-1

This test conducted in a lab with different types of obstacles was place in real time after blindfolding. Test result is shown in figure 6 (right side), solid line shows ideal path which reflect how a normal person moved in these obstacles and dotted line shows how a blind (blindfolded) person completed this path by wearing device.

B. Navigation Tests-2

This test conducted on actual blind person. with dynamic obstacles appeared in path unknown to blind person. Test result is shown in figure 7. In this test ideal path represented by solid line reflect how a blind person moved in this environment without any aid and then with the device aid. Dotted line shows how a blind person completed this path by wearing this device.

V. CONCLUSION

Bionic Kinect device is portable and using it a blind person can walk easily with both hands free without any help. Device is inexpensive and training is not required to use this device like other devices do for instance canes and walking dogs. Additionally, device informs user through earphone about gestures of person. People suffering from retinitis pimentos can use this device. Retinitis pimentos is a disease in which person have 20% vision only and unable to observe complete movement of human gestures for example unable to see hand movements while focusing on face as compared to normal person, with help of this device patients can easily interact with society by utilizing gestures which cannot be sensed by having only 20% vision. Device uses Infrared light which make it feasible in low light conditions. This wearable received a very good response from blind community. Future work will be to replace NUC with android, implement OCR (Optical Character Recognition), detect uneven surface and stairs detections.

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