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Indoor Navigation System for Visually Challenged Using Ultrasonic Sensor Map with Vibrational Feedback

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***Abstract**: Navigation in indoor environments is highly challenging for visually impaired persons. Conventionally, they use white cane or guide dog for traveling to desired destination. Several solutions have been proposed to deal with this challenge. Although, some of them have shown to be useful in real scenarios, they involve an important deployment effort or use artifacts that are not natural for blind users. This paper presents an indoor navigation system that was designed taking into consideration of usability and system cost. In this scenario; which is typically called GPS denied environment, the GPS signal is very poor because of the lack of line of sight between satellites and the receiver. Ultrasonic sensors are very useful for navigation because they have the advantage that the system is simple and are easy to handle. This solution uses prebuilt ultrasonic based map to travel from source to destination. Using this map, the system determines the user's trajectory, locates possible obstacles in that route, and offers haptic navigation information to the user. System is implemented with beagle bone black microcontroller with 3 ultrasonic sensors and three vibrators. This prototype can further be evolved as a device that can be attached to a waist belt.*

***Keywords**: Indoor navigation, Ultrasonic, Visually impaired*

Introduction

World Health Organization (WHO) has released the statistics in 2014 that shows 10% of the world's population have a disability, with 80% of them located in developing countries. This global data on visual impairments shows the people with visual impairment globally is around 285 million which 39 million are fully blind and 246 million are having low vision problem [22]. This total figure does not reflect to the real number of a people with disabilities in this world since the visually impaired people are cannot independently travel by themselves.

Navigation and way finding is crucial for the blind population, as for any other. Visually impaired people in new environments may feel totally disoriented or isolated. These people can easily end up in dangerous and confusing situations as they move in unknown places. Pressing navigation-related problems blind people face includes determining one's position, heading or moving direction, and the detection of close objects. Visually impaired people rely on different tools and skills to navigate. They usually rely on their white canes, seeing-eye-dogs and other skills acquired over time to aid their navigation. Visually impaired people, that are able to perceive sounds, tend to learn how to identify audible landmarks.

Many technologies have been developed to assist blind users with different navigation needs. This includes avoiding obstacles like laser canes and other handheld devices that transmit laser or ultrasound beams to detect objects ahead of the user and give audio or vibration feedback that varies according to how close the objects are. Other technologies developed were to help with localization and tracking the user's current location, like RFID Tags and GIS. These technologies were integrated in some applications or systems to help with routing and giving the necessary instructions to get the user to his/her destination.

The arrangement of this paper is done as follows where Section 1 presents an introduction on problem and challenge that have been faced by visually impaired people. Section 2 expresses previous studies related to the travel aid for visually impaired people. Besides, section 3 deliberates the architecture of the developed navigation system. Section 4 discloses on working of the experimental setup involved in this study while Section 5 elaborates the results that obtained through the developed navigation system and the proposed control approach, and lastly the conclusion and future tasks of this study.

Related Works

The design challenges for the blind navigation device are real-time guidance, portability, power limitations, appropriate interface, and continuous availability, no dependence on infrastructure, low cost solution and minimal training [5]. There are several designs to help visually impaired people to achieve self-independence traveling at indoor environment. Location technology such as infrared data association (IrDA), RFID, Bluetooth or Wi-Fi has been developed to help them travel during indoors with contextual information or sound navigation [21].

The studies focused on indoor environments have proposed several *ad hoc* technologies and strategies to deliver useful information to the user [4]. However, just some of them are suitable to be used by visually impaired people. For example, Sonnenblick [20] implemented a navigation system for indoor environments based on the use of infrared LEDs. Such LEDs must be strategically located in places used by the blind person to perform their activities (e.g., rooms and corridors), thus, acting as guides for them. The signal of these guiding LEDs is captured and interpreted by a special device which transforms it into useful information to support the user's movements. The main limitation of such a solution is the use of an infrared receptor instead of a device with large coverage such as an infrared camera. Because the infrared signal must be captured to identify the user's position, the receptor device must point directly at the light source (e.g., the LEDs), thus losing the possibility of smooth integration between the device and the environment.

Hub, Diepstraten and Ertl [6] developed a system to determine the position of objects and individuals in an indoor environment. That solution involved the use of cameras to detect objects and direction sensors to recognize the direction in which the user is moving. The main limitation of that proposal is the accessibility of the technology used to implement it, since the system requires a specialized device to enable the user to interact with the environment. This system also pre-establishes possible locations for the cameras, which also generates several limitations; for example the detection process requires the person points out his white cane at the eventual obstacles.

Radio Frequency Identification (RFID) is a technology commonly used to guide the visually impaired in indoor environments. For example, in [10, 11] the authors propose a system based on smartphones that allows a blind person to follow a route drawn on the floor. This solution combines a cane with a portable RFID reader attached to it. Using this cane, a user can follow a specific lane, composed by RFID labels, on the floor of a supermarket. Kulyukin *et al.* [8] propose a similar solution, replacing the white cane with a robot that is in charge of guiding the visually impaired person.

Another RFID-based solution that supports the navigation of visually impaired people was proposed by Na [17]. The system, named BIGS (for Blind Interactive Guide System), consists of a PDA, a RFID reader, and several tags deployed in the floor. Using these elements the system can recognize the current location of the PDA's user, calculate the direction of the user, recognize voice commands and deliver voice messages. The main limitations of using RFID-based solutions are two: (1) the reconfiguration of the positioning area (e.g., because it has now a new setting) involves more time and effort than other solutions, like vision-based systems, and (2) the users are typically guided just through predefined paths.

In addition, the usage of Global Positioning System (GPS) device also can help to guide the visually impaired people in an outdoor environment. Since GPS cannot function properly in indoor space, other researchers present the solution by using IrDA technology which works as detector to guide in indoor environment [7]. The Drishti system is the combination of GPS for outdoor navigation and ultrasonic sensor for indoor navigation [9]. One of the problems about GPS is the error with the measurement taken especially inside the tall buildings [15].

Furthermore, BLI-NAV a blind navigation system designed which consists of GPS receiver and path detector. Both devices used to detect user's location and determine the shortest route to destination. Voice command is given throughout the travel. Path algorithm is used to determine the shortest distance from start point to end point together with path detector. Moreover, user is able to avoid obstacles while traveling [18]. This system gave better results in real time performance and improves the efficiency of blind travel at indoor environment.

On the other hand, Pocket-PC based Electronic Travel Aid (ETA) proposed to help visually impaired people to travel at indoor environment. Pocket-PC will alert the user when near the obstacles through warning audio [13]. An ultrasonic navigation device for visually impaired people is designed. The micro-controller built in the device can guide the user in which route should be taken through speech output. Besides, the device helps to reduce navigation difficulties and an obstacles detection using ultrasounds and vibrators. Ultrasonic range sensor is used to detect surrounding obstacles and electronic compass is used for direction navigation purpose. Stereoscopic sonar system is also used to detect nearest obstacles and it feeds back to tell user about the current location [3, 12, 14].

In addition, Blind Assistant Navigation System that can help visually impaired people to navigate independently at indoors. The system provides the localization by using wireless mesh network. The server will do the path planning which then communicates using wireless with the portable mobile unit. The visually impaired people can give commands and receives response from the server via audio signals using a headset with a microphone [19]. The proposed RFID technology in order to design the navigation system by providing information about their surroundings also developed. The system uses the RFID reader that mounted on end of the stick to read the transponder tags that are installed on the tactile paving [1, 2].

In this paper, the development of navigation system is aimed at guiding the visually impaired people to navigate through indoor environment. Minimal interfacing components were used to reduce the system cost. Since the user navigation is based on the prebuilt environment map and haptic feedback, it guarantees efficient navigation, better experience, safer and comfortable travel for the user.

System Architecture

Our system has two main parts. One is construction of map of user path; this is a one-time process per path. Next is providing direction by comparing the map against received obstacle distance. Last one is provide haptic based direction information to the user. Three components are used in our system. Those are: 1) micro controller 2) ultrasonic sensors 3) vibration motors.

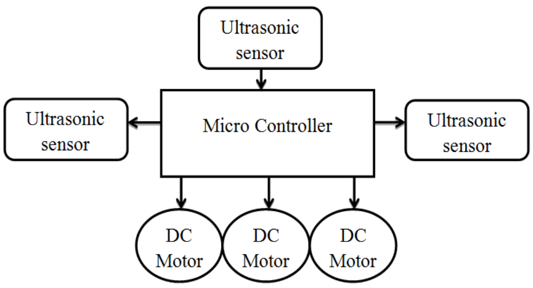

Figure 1. System architecture

The system has two modes of operation, recording and navigation. In recording mode system will record the distance between user and permanent objects that found in the 3 directions: left, right and front. Here system will use ultrasonic sensors to achieve this. To start and stop the recording, user will use a toggle switch. In addition to this it will record the direction information from each waypoint. This is done by selecting the switches provided in the system. Default direction of navigation will be in to the front. According to direction from each waypoint the recording person will select corresponding switch. System will stop the recording once the user is reached the desired destination. At the end of recording, system's flash memory will have the topological information about user route.

In the navigation mode, system will compare the live distance data (received from ultrasonic sensors) against the recorded map and directs the user to reach the destination.

3.1 Map Construction

Same system is used to obtain the map of the user path. Here the system will run through user path and it will record the distance data received from ultrasonic sensors in a file. Using the recorded data, it will generate the map for navigation.

A map consists of set of regions; each region will hold distance to objects for left, right, and front. It will also have a direction value which decides the next turn from the respective region.

Map (A, B) = R0, R1…, Rn.

Where R = (Left, Right, Front, Direction), Direction will be straight (00)/left (01)/right (02).

R0 = (L0, R0, F0, D0),

R1 = (L1, R1, F1, D1) …

Rn = (Ln, Rn, Fn, Dn);

Figure 2 depicts an example map formed based on data collected for path from Bedroom to Dining room.

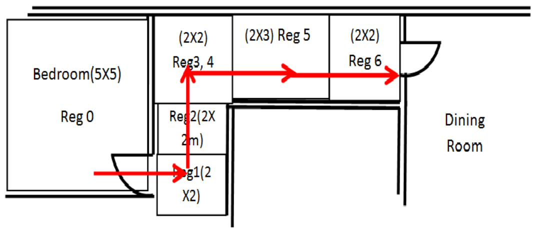

Figure 2. Indoor map

According to the nature of the environment, system will chose a maximum length for object detection; which will be a constant. In this example, maximum detection length chosen is 2m. If the length between the object in any direction is less than this value, it will filled as 1, otherwise its value will be zero. From the above example, the identified regions are given below.

--->Starting location

Region 0 = (L, R, F, D) = (0, 1, 0, Front)

Region 1 = (L, R, F, D) = (0, 0, 1, Left)

Region 2 = (L, R, F, D) = (1, 1, 0, Front)
Region 3 = (L, R, F, D) = (1, 0, 1, Right)
Region 4 = (L, R, F, D) = (1, 0, 0, Front)
Region 5 = (L, R, F, D) = (1, 1, 0, Front)
Region 6 = (L, R, F, D) = (1, 1, 1, Front)
--->Destination

3.2 Navigation Algorithm and Working Principle

In this algorithm, the user path spanned across set of regions. The starting point of the user is always considered as region 0. Target point will be last region. During travel, system will compare the received ultrasonic data against the identified regions in the map. If it matches, it will continue the comparison against the map. If the region is a waypoint, it will instruct the user to take the correct direction as per the map using the vibrational feedback. System will stop the navigation once the user reaches the end point.

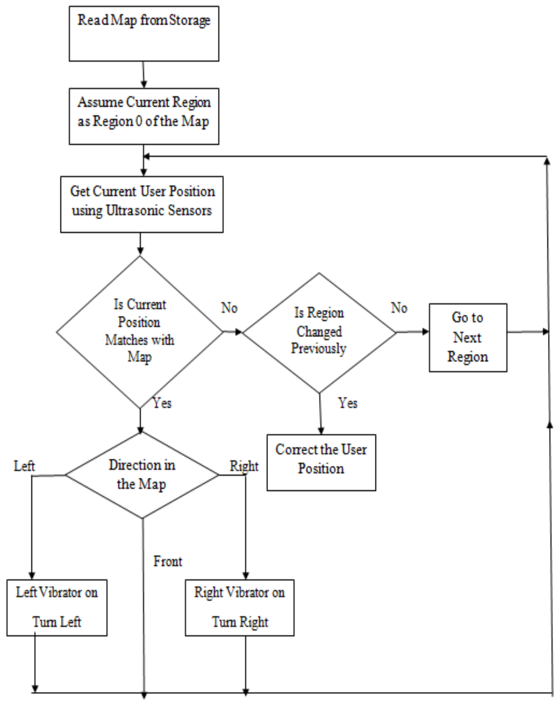

Figure 3. Flow chart

Result and Discussion

In the result, our application will generate vibrator based direction at every turn of the path. It means that at the time of entering in to new region, system will give a vibrational feedback to the user to indicate next direction. If the next direction is left user will get a vibration on his left side, if the next direction is right user will get a vibrational feedback on his right side. This system was experimented in different indoor environments.

Below tables summarizes the result of one of this trial. It is a comparison of the data obtained during recording mode and navigation mode.

Table 1. Recording mode

Sensor raw data	Map
L: 0 R: 107 F: 0 Direction:3 – FRONT	R0(0, 1, 0, FRONT)
L: 0 R: 0 F:67 Direction:2 – LEFT	R1(0, 0, 1, LEFT)
L: 85 R: 117 F: 0 Direction:3 – FRONT	R2(1, 1, 0, FRONT)
L: 95 R: 0 F:67 Direction:1 – RIGHT	R3(1, 0,1, RIGHT)
L: 105 R: 0 F: 0 Direction:3 – FRONT	R4(1, 0, 0, FRONT)
L: 115 R: 85 F: 0 Direction:3 – FRONT	R5(1, 1, 0, FRONT)
L: 108 R: 90 F: 55 Direction:3 - FRONT	R6(1, 1, 1, FRONT)

Table 2. Navigation mode

Sensor raw data	Turn direction
L: 0 R: 121 F: 0 Direction:3 – FRONT	3 - FRONT
L: 0 R: 0 F:77 Direction:2 – LEFT	2 - LEFT
L: 70 R: 128 F: 0 Direction:3 – FRONT	3 - FRONT
L: 105 R: 0 F:88 Direction:1 – RIGHT	1 - RIGHT
L: 118 R: 0 F: 0 Direction:3 – FRONT	3 - FRONT
L: 126 R: 70 F: 0 Direction:3 – FRONT	3 - FRONT
L: 137 R: 68 F: 67 Direction:3 - FRONT	3 - FRONT

Conclusion and Future Work

The main task of this article was design of indoor navigation system for the blind and visually impaired using ultrasonic sensor based map. It is used for both scanning and localization. The article introduces a new algorithm that assists the user to independently reach the desired destination in unfamiliar environments by providing haptic based directions. As a future work, it can be extended to have an algorithm for correcting user positions if he has reached an unknown path, which was not captured in the map. Also develop a mobile based application to select the map for navigation.

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