A Smart Wearable Navigation System for Visually Impaired

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Abstract. Smart devices are becoming more common in our daily lives; they are being incorporated in buildings, houses, cars, and public places. Moreover, this technological revolution, known as the Internet of Things (IoT), brings us new opportunities. A variety of navigation systems has been developed to assist blind people. Yet, none of these systems are connected to the IoT. The objective of this paper is to implement a low cost and low power IoT navigation system for blind people. The system consists of an array of ultrasonic sensors that are mounted on a waist belt to survey the scene, iBeacons to identify the location, and a Raspberry Pi to do the data processing. The Raspberry Pi uses the ultrasonic sensors to detect the obstacles, and provide audio cues via a Bluetooth headset to the user. iBeacons will be deployed at different locations with each having a unique ID. In the cloud, there is a database for all the iBeacons attached with the corresponding information e.g. address and information about the place. The Raspberry Pi detects the iBeacon's ID and sends it to the cloud, accordingly the cloud sends back the information attached to this ID to the Raspberry Pi that converts the text to audio and plays it via a Bluetooth headset to the user. Tests demonstrate that the system is accurate within the threshold radius and functions as a navigational assistant.

Keywords: Ultrasonic sensor · Audio feedback · Visual impairment · Navigation assistance

1 Introduction

A variety of portable/wearable navigation systems has been developed to assist blind people during navigation indoor/outdoor environments. These systems can be categorized into three main types: Electronic Travel Aid (ETA), Electronic Orientation Aid (EOA), and Position Locator Device (PLD) [1]. There are many systems that deal with the autonomous navigation for blind people. These systems are using GPS [2], RFID [3], Ultrasonic sensor [4], camera [5], and Kinect sensor [6]. However, some of these systems present some drawbacks e.g., accuracy of GPS is not reliable for indoor use, the camera needs a high bandwidth, Kinect is not working for outdoor use. In addition to the system drawbacks, blind and visually impaired people are handicapped in achieving the desired level of mobility and context-awareness, especially in unknown environments. They rely on their previous knowledge of an environment to navigate and usually get help from guide dogs or white canes [7].

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In the future, everything is expected to be integrated into the IoT, where sensor node dynamically joins the Internet and uses it to collaborate and accomplish its task. The IoT is an expansion of the Internet and incorporates with network connections to allow data transmission between objects and the Internet. The IoT enables researchers to efficiently process and store data to ensure accurate situation analysis. These results can lead to recognizing extremes, anomalies, and trends over periods of time. Overall, the IoT stimulates an increased level of awareness about the surrounding environment and serves as a mean to monitor and respond to the changing environmental phenomenon [8]. Accordingly, the IoT is estimated to become the largest device market in the world in the next few years.

Applications that support navigation in unfamiliar places are very helpful for the blind and visually impaired. Therefore, the development of the IoT navigation system for the visually impaired can not only enrich mobility of them but can also bring an additional sense of security and safety. This paper presents the design and implementation of an IoT-enabled wearable navigation system for the visually impaired to operate in both familiar and unfamiliar environments. This navigation system helps the blind person solve many problems such as, leaving home by themselves in a safe and convenient way and participating in more social and civic activities to improve the quality of life. At the same time, the reliable portable navigation system represents a civilized, harmonious, progressive society, and a service oriented project for the engineers.

2 Proposed System

The proposed system is focused on low-power and low-cost design principles. A reasonable expectation is that the power would last throughout the day and could be recharged at night. The system cannot rely on a large battery because it must remain portable enough for the user to carry comfortably and without significant burden. There is also a high incentive to use low-cost components in the design of the device. As the price of the device falls, it becomes more accessible to people of low economic standing.

The architecture of the proposed system consists of five modules as shown in Fig. 1. The first module is a Bluetooth Low Energy (BLE) iBeacon transmitter [9]. As the user might navigate both indoors and outdoors, the environment is tagged with these iBeacons, and each is loaded with location information. While operating in the BLE mode, each iBeacon can function on a single coin cell battery for extended periods of time without any problems. When a user comes in proximity to any of these iBeacons, the navigation system reads the ID of each iBeacon and sends this information to the cloud server. This information is processed in the cloud to identify the location and responds to the navigation system with the location information.

The second module in the system is an array of three HC-SR04 ultrasonic sensors mounted on the waist belt of the user, and can detect obstacles at a range of 20–4000 mm, with an accuracy of 3 mm [10]. As there is a mismatch in operating voltage between these ultrasonic sensors and Raspberry Pi, an interface circuit as presented in Fig. 2 is designed for reliable communication between the ultrasonic sensors and Raspberry Pi.

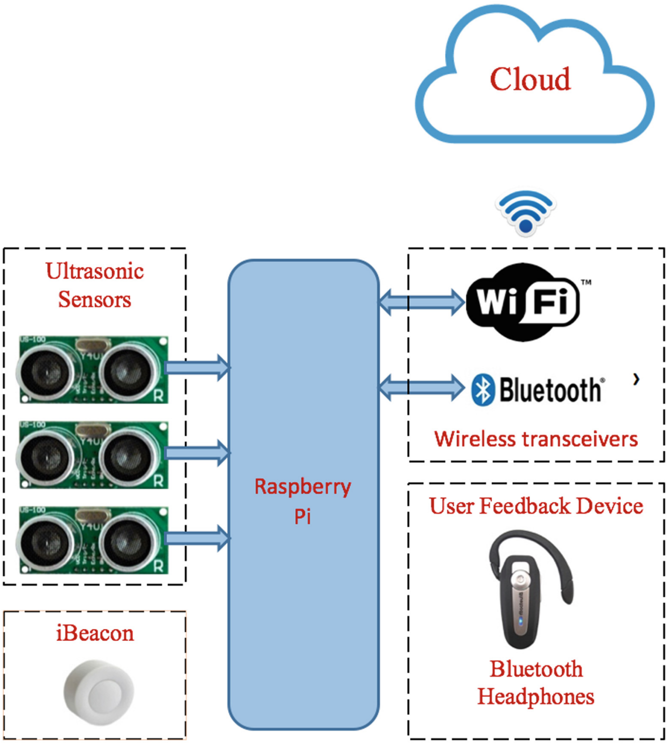

Fig. 1. System architecture of the proposed navigation system

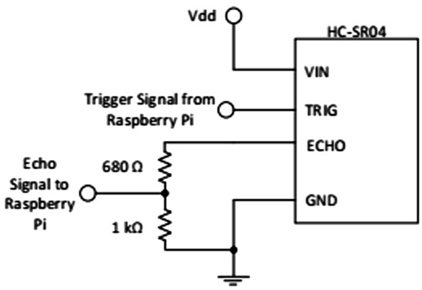

Fig. 2. Interface circuit between ultrasonic sensor and Raspberry Pi

The third module in the system is a set of wireless transceivers, BLE, and Wi-Fi. The BLE transceiver is used to localize the system through iBeacons, and provide feedback to the user through Bluetooth headphones. The Wi-Fi transceiver is used to communicate with the server on localization information, and any other information as requested by the server.

The fourth and core module in the system is a Raspberry Pi 2 single board computer [11]. This module serves as the central command, reads data from the BLE iBeacons, communicates with the cloud server for location information, reads data from the ultrasonic sensors to detect the obstacles, and also responds to the user through audio feedback. During localization, this module receives information from BLE iBeacons in the vicinity and relays this information to the server through a Wi-Fi transceiver. The server sends back the user's location through comparison of information with a built-in database. Further, this localization information is sent back to the Raspberry Pi, and the user is informed through the wireless headphones. While the user is moving, the Raspberry Pi continually reads the obstacle information from each of the three onboard ultrasonic sensors. When an obstacle is detected by a sensor whose distance is less than a threshold value, the Raspberry Pi informs the user on the direction and distance of the obstacle through the wireless headphones and allows the user to navigate safely.

The fifth module in the proposed system is a user feedback device, comprised of wireless headphones to receive audio feedback on location and obstacle profile information.

3 Experimental Evaluation

Using this architecture, a series of tests were conducted. The first tested the accuracy of the HC-SR04 ultrasonic sensor. The following three were field tests to analyze the efficiency of the system when used to navigate around various obstacles.

3.1 Detection Accuracy

As one of the system's main operations is the detection of obstacles, a test was used to verify the accuracy of the ultrasonic sensors used in this application. As stated, the HC-SR04 can detect obstacles between 20 and 4000 mm. Because of this range, an obstacle was chosen to be placed at three different distances (0.5 m, 1 m, and 3.8 m). After setup, 500 readings were recorded at each of these lengths. Following the collection, a distribution graph of the normalized readings was formed and can be seen in Fig. 3. Further, an HC-SR04 ultrasonic sensor was used to measure the distance to four different types of materials at three distances each. Each test was setup by placing the object directly in front of the sensor and capturing 1000 readings. The results in Table 1 show that the HC-SR04 is able to detect objects within 1 m and 2 m with a probability of 1. On the other hand, the probability of detection starts to drop at 3 m, as presented. This outcome was used in the decision making of the safety distance to be used in field tests.

3.2 Navigation and Obstacle Avoidance Field Tests

This was the first of three navigation tests. In this scenario, the threshold value for sensor readings was selected to be 0.8 m and all sensors readings were capped at 3 m.

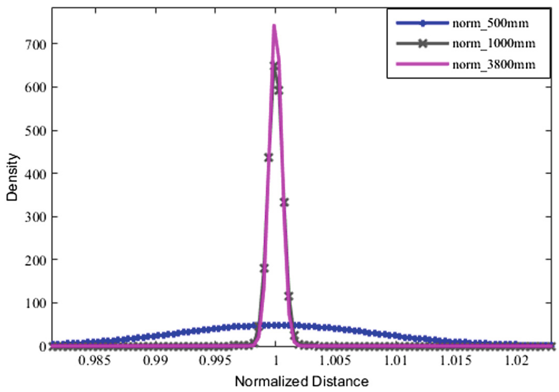

Fig. 3. Data distribution of ultrasonic sensor with obstacles at different

Table 1. Obstacle detection sensor accuracy.

Material	Actual distance (cm)	Measured distance (cm)	Error (%)	Probability of detection
Aluminum	100	99.2	0.79	1.00
	200	198.6	0.70	1.00
	300	294.9	1.70	0.99
Plastic	100	100.3	0.29	1.00
	200	197.1	1.45	1.00
	300	296.5	1.16	1.00
Styrofoam	100	96.9	3.09	1.00
	200	197.6	1.20	1.00
	300	296.3	1.23	0.83
Paper	100	98.1	1.90	1.00
	200	201.3	0.65	1.00
	300	294.9	1.70	0.58

Two users were asked to navigate to a particular location with the system. To give a sense of their initial spacing, they were told which direction the ending location was in. Figure 4 shows the path taken by each user along with an optimal path that would potentially be taken by someone with clear vision.

Figure 5 displays the paths that were taken by each user in the second test and an optimal path was chosen, similar to test 1. The last field test also used the same parameters as test 1 and 2 but had a different route for the users to take. As in the previous tests, the users' paths and an optimal path are pictured in Fig. 6. After the conduction of the third test, the distance for each path in every test was compared to its optimal route to determine how much additional distance was traveled, and results are presented in Table 2.

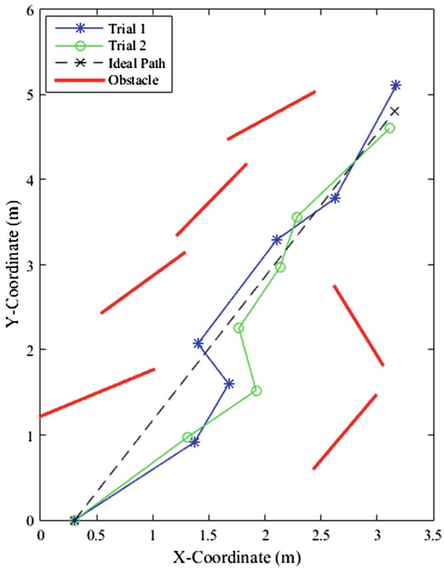

Fig. 4. Navigation Field Test-1 Path

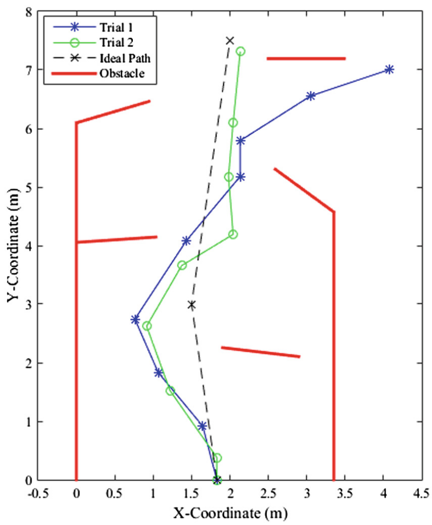

Fig. 5. Navigation Field Test-2 Path

3.3 Localization Using BLE Beacons

One of the primary purposes of the navigation system is to localize the user and inform him/her on the location with respect to a known landmark. Accordingly, the proposed system was programmed to read the ID of BLE beacons in the vicinity, and relay this

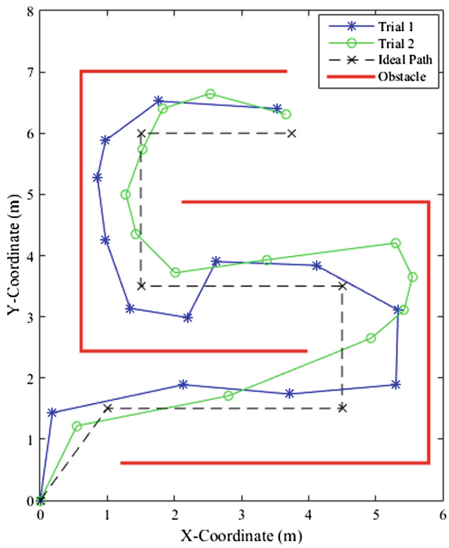

Fig. 6. Navigation Field Test-3 Path

Table 2. Comparison of distance & time traveled.

Test #	Additional distance traveled compared to ideal path (%)		Time to reach destination (minutes)	
	Trial 1	*Trial 2*	*Trial 1*	*Trial 2*
1	12.09	2.33	0.58	0.63
2	15.47	5.18	1:11	1:13
3	21.28	6.85	3:33	2:19

information to the cloud server. The server localizes the user, compares his/her location with landmarks as presented on Google Maps, and sends this information back to the Raspberry Pi device. The Raspberry Pi device relays this information to the user through the BLE headphones and allows him/her to navigate to the next location accordingly. Figure 7 shows a snapshot of the server web page with the location of the user marked by the blue dot and the red circle. This information is stored in the cloud, so any other family member can track the user.

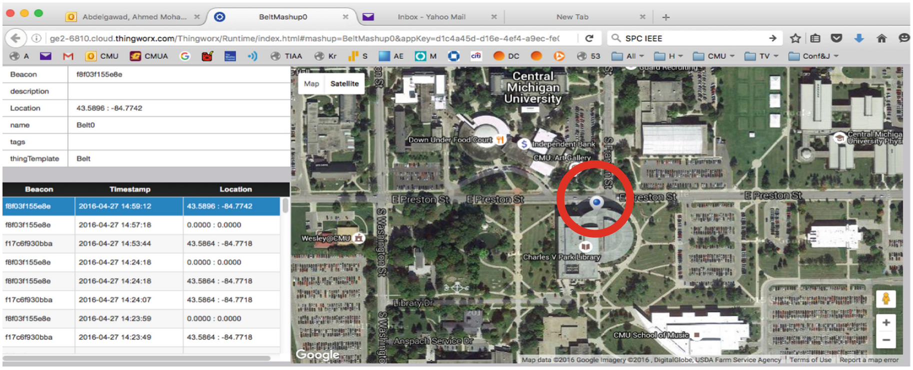

Fig. 7. Location of the user as marked on Google Maps (Color figure online)

4 Conclusion

In this paper, a low-cost and low-power IoT enabled wearable navigation system for blind people was proposed. The system consists of an array of ultrasonic sensors to survey the scene, iBeacon to identify the location, and a Raspberry Pi. The Raspberry Pi uses the ultrasonic sensors to detect the obstacles, and provides audio cues via a Bluetooth headset to the user. Each deployed iBeacon has a unique ID that is related to the location. On the cloud, there is a database for all the iBeacons attached with the corresponding information e.g. address and information about the location. The Raspberry Pi detects the iBeacon ID and sends it to the cloud, accordingly the cloud sends back the information attached to this ID to the Raspberry Pi that converts the text to audio, and plays it via a Bluetooth headset to the user. Experimental tests validate the proposed system and proof that it functions as a navigational assistant for the blind and the visually impaired.

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