Chapter 8
Intelligent Vision Impaired Indoor Navigation Using Visible Light Communication

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8.1 Introduction

Recent statistics of the World Health Organization (WHO) indicate that over 253 million of the world's population to be visually impaired (World Health Organization, 2017). These vision impaired individuals may come across several challenges in their day-to-day life when self-navigating in unknown environments. For instance, traveling or simply walking down a crowded street could become confounding for those with vision impairment. Furthermore, they may face difficulties in determining the direction of travel without guidance. As a result, vision impaired individuals are often accompanied by a volunteer helper or a caretaker to help them navigate in unknown environments.

The use of technology in facilitating vision impaired navigation has increased over the years with the increasing number of research work. Published literature shows that many researchers have engaged in research work in developing various aids for improving the quality of life for individuals with vision impairment. However, indoor positioning mechanisms require to be sensitive and precise to ensure a high level of positional accuracy.

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The Nottingham Obstacle Detector (NOD) (Sakhardande, Pattanayak, & Bhowmi, 2012) is a hand-held sonar device that provides an auditory feedback that indicating eight discrete levels of distance by eight different musical tones. Borenstein and Ulrich built the “GuideCane” (Borenstein & Ulrich, 1997), a mobile obstacle avoidance device that consists of a long handle and a sensor unit mounted on a steerable two-wheel axle. The sensor unit consists of ultrasonic sensors that detect obstacles and help the user to steer the device around them.

A Finnish company, MIPSoft, developed a mobile application for individuals with visual impairment. This application, ‘BlindSquare’ is the World’s Most Popular accessible GPS-app designed for vision impaired individuals (Blindsquare, n.d.). ‘BlindSquare’ is capable of describing the environment by announcing points of interest and street intersections as the user travels. Vision impaired outdoor navigation could be dealt successfully with the use of GPS. However, GPS receivers cannot be used for indoor navigation as the satellite signals are incapable of penetrating through construction materials (Khudhair, Jabbar, Sulttan, & Wang, 2016).

However, there are several other navigation technologies that could be used to facilitate vision impaired individuals with their indoor navigation. Most popular indoor navigation techniques include RFID, geomagnetism, wireless LAN, IMU (Inertial Measurement Unit), and VLC (Visible Light Communication). The wireless LAN access point method has encountered issues with fluctuating positional accuracy due to reflected signals from the wireless LAN, obstacles, or the surrounding environment (Bai et al., 2014). However, Radio-frequency identification (RFID)-based navigation systems pose no system interference and is resistant to collisions. Moreover, they are capable of identifying the direction accurately and require light maintenance. However, RFID-based navigation systems are susceptible to reader and tag collisions while also consuming much time in deploying the RFID tags (Dharani, Lipson, & Thomas, 2012).

Similarly, inertial navigation is a self-contained navigation technique in which measurements provided by accelerometers and gyroscopes are used to track the position and orientation of an object with a known starting point, orientation, and velocity. However, a paper on “Inertial Sensor Fusion” (Hol, 2011) states that the positioning error of the accelerometer is too high which requires the inclusion of additional positioning sensors for accuracy. Despite its high positioning error, IMU-based navigation systems are comparatively cheaper. As indoor positioning mechanisms require to be sensitive and precise, the authors propose an intelligent indoor navigation system that utilizes Visible Light Communication (VLC), geomagnetism, best path detection algorithms, and obstacle detection to support vision impaired individuals with their indoor navigation.

Visible light communication commonly known as VLC is a communication mechanism that uses LIFI (Light-Fidelity) technology for transferring information between peers (Khan, 2017). VLC enables transmission of data using visible light by encoding data through LED lamps. LEDs are more energy efficient and could be easily illuminated by switching on and off at a higher frequency. Compared to fluorescent light, LED lamps have a long lifespan, low power consumption, and are mechanically robust. Moreover, LEDs are expected to be the next generation of lamps that would be widely installed to replace fluorescent light. Thus, many researchers have studied and published literature on VLC-based indoor navigation systems.

In 2013, a group of Chinese researchers proposed a VLC-based indoor positioning system using dual-tone multi-frequency (DTMF) technique (Luo et al., 2013). This study was based on the different modulation techniques that could be accommodated in visible light communication. The main outcome of this research is that the developed algorithm does not need to synchronize to separate signals from different time slots as it analyses both the frequency domain and the time domain of the received signal to identify the position of the receiver device. This study used image processing to read the data transmitted from the LED lights while the DTMF enabled to distinguish the signals and eliminate inter-LED interference. However, the use of image processing requires a complex algorithm to distinguish the signals while also consuming a high power which is costly.

Similarly, Nakajima and Haruyam (2013) proposed an indoor navigation system that utilized visible light communication technology, which employed LED lights and a geomagnetic correction method, aimed at supporting visually impaired people who travel indoors. Their system composed of LED lights, a smartphone with integrated receiver and headphones. Positional information was obtained and calculated using the route retrieval mechanism together with a positional information base. The LED light sends an ID using visible light communication which is acknowledged by the receiver using Bluetooth technology. The smartphone receives the positional information from the positional information base through Wi-Fi, and the positional information and the guidance content are combined into audio files using a speech synthesizer system and are sent to the user's headphones.

However, the work proposed in this chapter utilizes visible light communication technology, geomagnetism, best path algorithm and database optimization to produce a system that is capable of providing accurate and secure indoor navigation assistance to vision impaired individuals. The integration of several techniques such as geomagnetism, best path algorithm and database optimization differentiate the work carried out by the authors from other researchers.

Benefits of using VLC for the proposed research work include the ability to incorporate communication functionality to the existing lighting equipment, the long operational life and low power consumption of LED lamps, the absence of electromagnetic interference and secure transmission due to limited communication range.

However, knowing the accurate position alone is not sufficient, a navigator should also be aware on the direction of travel. The uniqueness of the magnetic field variations in indoor environments could be used to identify the current position, and possibly the orientation as the three-dimensional magnetic field varies significantly with the position. Through the use of relatively inexpensive three-axis magnetic field sensors, it is possible to estimate the user location in an indoor environment.

Benefits of using geomagnetism for the proposed research work include accurate orientation estimation, direction identification and the use of traveling path correction mechanism to keep the user on the best path and correct direction.

Traditional wireless communication utilizes radio frequencies to transmit and receive data whereas VLC uses the visibility spectrum which offers a great advantage over radio frequency communication due to the free use of visible light. LEDs illuminate by varying its intensity at a faster rate which cannot be identified by the human eye. This is another advantage of LED for visible light communication. Besides, LED bulbs can be controlled by altering the supply voltage at the same power.

In Visible Light Communication, the light source which is used for illumination is also modulated to transmit data to a receiver. This mechanism could be used to provide navigation assistance to users in an indoor environment. In VLC, each LED node is identified by a unique ID number for which navigation is achieved by mapping each ID of the node available in the path to the destination. When transmitting data over a LED light, each LED light should flicker at different rates to provide "1" and "0" (ON and OFF) with respect to the identification number of the LED light. The flickering should happen at a faster rate so that human eye will not be able to detect the change in illumination.

Moreover, there are several modulation techniques available to transmit data using LED nodes. However, VLC cannot accommodate pulse amplitude modulation because of the flicker and dimming of lights (Jha, Kumar, & Mishra, 2017) as data could only be transmitted by changing the intensity of the light wave. Intensity Modulation (IM), Direct Detection Modulation (DD), ON/OFF Keying (OOK), Pulse Width Modulation (PWM), Orthogonal Frequency Division Multiplexing (OFDM), Color Shift Keying (CSK), and Pulse Position Modulation (PPM) are several modulation techniques used in VLC communication.

Since the work proposed in this chapter uses only an ID to transmit data to the receiver, the PWM technique would be the most simple and effective technique to be used. In PWM, the width of the pulses is adjusted according to the encoded ID and the LED light source will be dimmed/flickered based on the ID value which would then carry the modulated data to the receiver.

8.2 System Overview

8.2.1 System Architecture and Framework

Figure 8.1 illustrates the system architecture of the proposed work while Table 8.1 describes the elements of the system architecture.

Figure 8.2 illustrates the framework of the system which consists of four layers namely: the initial layer, interface layer, functional layer, and the backend layer.

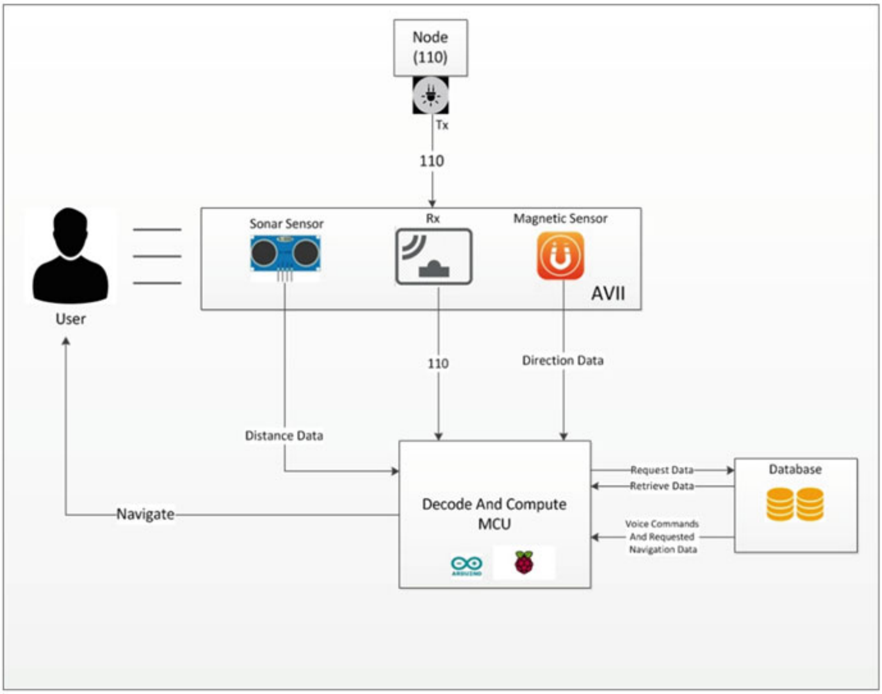

Fig. 8.1 System architecture

Table 8.1 Elements of system architecture

Component	Description
Node (Tx)	The transmitter sends converted digital signals through visible light
Receiver (Rx)	Detects the digital signal and transfer it to the main program which is running in the MCU
MCU	Process the received data and pass it to the backend database
Database	Retrieve only the required data from the DB
Sonar Sensor	Provide obstacle detection
Magnetic Sensor	Provide accurate navigation direction to turn

The initial layer consists of the destination input and the voice output while the interface layer consists of all the sensor functions and user alerting functions. All of the processing takes place in the functional layer while the backend layer consists of the database schema. Figure 8.3 illustrates the workflow of the system.

The proposed navigation system is responsible for guiding the user throughout his/her navigation by determining the optimal route (best path) to reach a specific

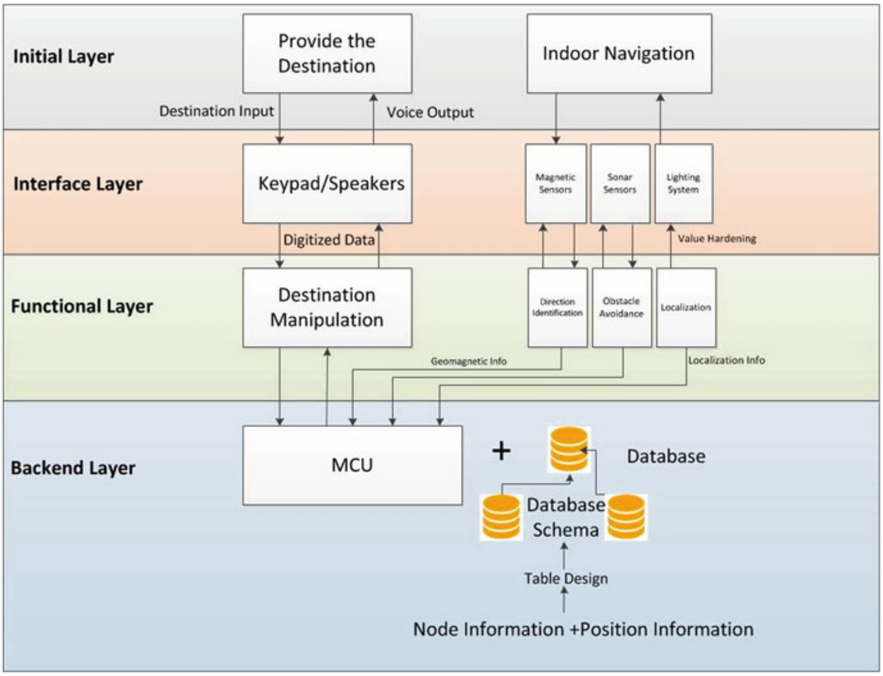

Fig. 8.2 Framework of the system

destination. An algorithm is used to determine the optimal route based on the destination given by the vision impaired individual. VLC is embedded into the indoor lighting system via a Raspberry Pi based embedded device which analyzes the current situation and delivers useful navigation information to the user. The use of a raspberry pi computing module benefits in manipulating the received data as only one serial port can open at a time to receive data from the transmitter which eliminates the receipt of unnecessary data. The system identifies the user's current position by acquiring the node ID (LED ID) transmitted by the LED nodes. The optimal path is then calculated by executing routing algorithms on the data provided by the user and the data stored in the database.

With the best path identified, the system uses voice instructions to guide the user to his/her desired destination. These voice instructions are delivered to the user via an application available in their mobile phones. While in the process of guiding the user, the user's traveling direction is continuously analyzed with the data from the geomagnetic sensor to ensure that the user is travelling in the right direction. If the vision impaired individual is traveling in the wrong direction, the system alerts and guides the user to the correct direction.

A continuous beep sound is generated to inform the user about the distance to the obstacles ahead. A high-frequency beep sound would indicate that an obstacle is very near. As LED lighting is often installed in pathway ceilings, accurate positional

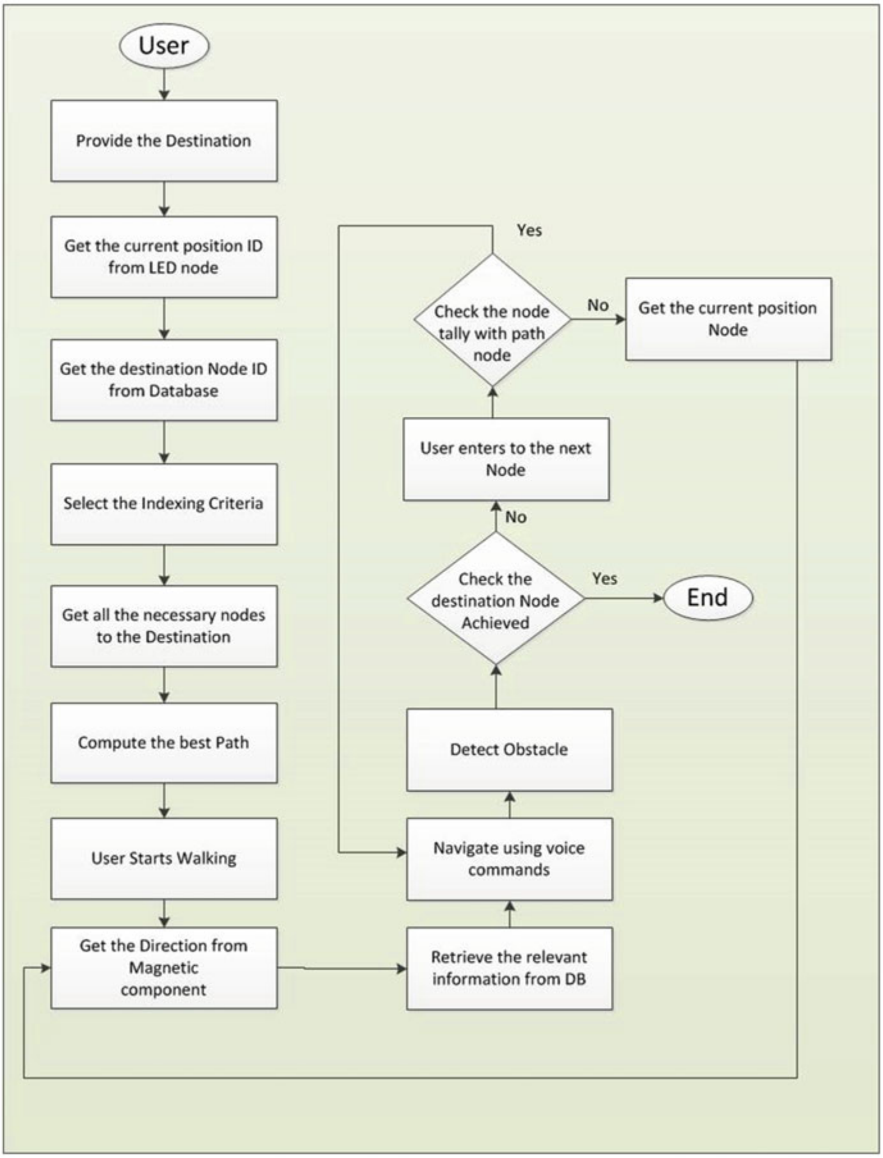

Fig. 8.3 System workflow

information can be obtained naturally above the user's head. The user's direction of travel is obtained by calculating the orientation of the embedded geomagnetic sensor.

In the proposed system design, the LED driver, Controller unit, and LED light will be used as a transmitter. The controller unit will provide a mechanism to

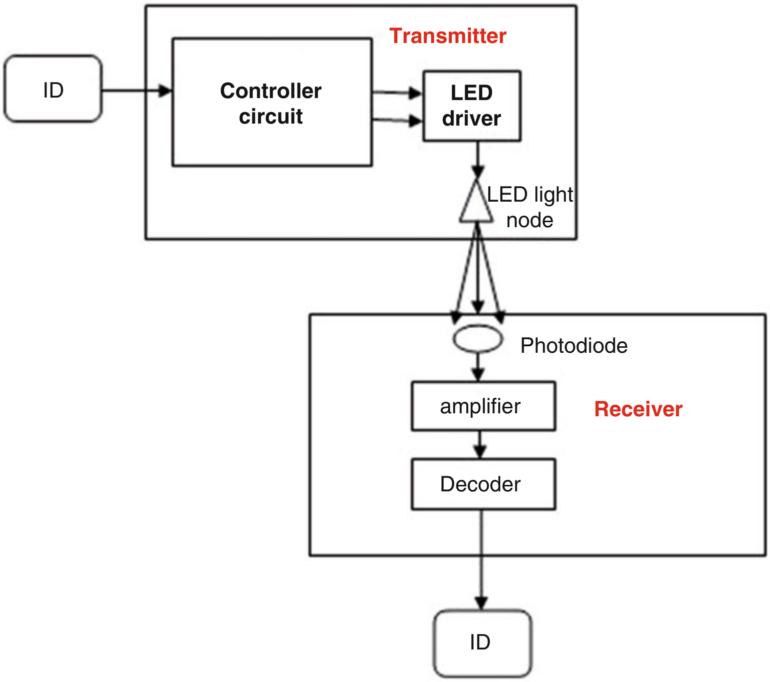

Fig. 8.4 ID transmission process

modulate data using PWM with logical binary “1” and “0” while the LED driver will control the LED with high switching frequency and the LED node will constantly transmit the ID by flickering with high frequency so that the human eye will not be able to identify the changes. However, the sensors at the receiver will be able to recognize the pattern. At the receiver, photodiodes will be used to identify the light signals. The received signal will be amplified and errors will be removed through the use of an error correction algorithm. Thereafter, output values will be decoded and the ID will be fed to the system for navigation. Figure 8.4 illustrates the ID transmission process.

The system hardware consists of a microcontroller (MSP430G25530) with a 16 MHz clock, 16 kB flash memory, 512 B RAM and 20 pins in addition to two 16 bit timers, one I2C, two Serial Peripheral Interfaces, one Universal Asynchronous Receiver/Transmitter (UART), MSP430 Launchpad, CSD18503KCS MOSFET (Metal-oxide-semiconductor field-effect transistor), LD33CV Dropdown 3.33 V regulator, 1 W high power 4 × 5 LED Panel, 20 W LED driver circuit and a 12 V constant current voltage dropdown circuit. The microcontroller is used to transmit the ID to the LED panel one bit at a time. C language is used to program the MCU (Microcontroller Unit) and code is fed to the microcontroller using the Launchpad. This transmission is done using the UART module in the MCU. Serial communication occurs between transmitter (Tx) and receiver (Rx). Both Tx and Rx are configured to use 1 MGHz clock rate and 38,400 baud rate (signal rate).

Baud rate is the factor that decides the amount of information per signal which is the signal rate (Frenzel, 2012). Baud rate factor should match in both Tx and Rx for the communication to occur. If not, the receiving device cannot read the data it receives and the Rx buffer would be filled with garbage values. The UART module can be configured to transmit data using Tx buffer (e.g. TXBUFF = “A”—to transmit node ID ‘A’) by adding the necessary values to the UART registers in the MCU. This value is converted to an 8-bit frame and each bit is transmitted using the Tx pin of the transmitter. Tx pin of the MCU is connected to MOSFET circuit for the switching function of the LED panel.

In order to receive the data transmitted over LED panel, LiFi receiver is used with a raspberry pi computing module. The LiFi receiver sends the data received to the serial module of the raspberry pi. The Raspberry pi is also configured with the same baud rate to read the received data. This received ID is fed to the navigation function of the system. The indoor navigation system proposed in this chapter uses node IDs with ASCII alphabet values. (A–Z). Hence, the Rx should be calibrated to receive only these values.

The LiFi receiver has an angle of arrival of 90° which helps the Rx to receive data from many angles. The distance between Rx and Tx is 5 cm for three LEDs. By making a 20 LED array with 1 W high power LEDs, the distance increases up to 1.5 m. Since it is the average height of an indoor building, it can receive data without any distortion. This distance could be further increased by using parallel LED panels without increasing the voltage or power. Receiving garbage values are totally eliminated by adjusting the code inside the raspberry pi computing module. Line by line reading provides better accuracy and performance.

8.2.2 Database Optimization

Database management systems should be capable of retrieving the right data to display the desired output. However, this is difficult to achieve when databases deal with high volumes of data. Thus, employing data optimization can reduce the complexity of the data retrieval process by reducing the resources required for the processing to occur. In some database applications, the database management system itself is loaded with features to make querying easy while some database applications have its own flexible language for mediating between peer schemas extending from known integration formalisms to more complex architecture.

Data optimization can be achieved by data mapping, which is an essential aspect of data integration. This process of data optimization includes data transformation or data mediation between a data source and its destination, and in this case, the data sources could refer to the logical schema and the destination the data view schema. Data mapping as a means of data optimization could translate data between various

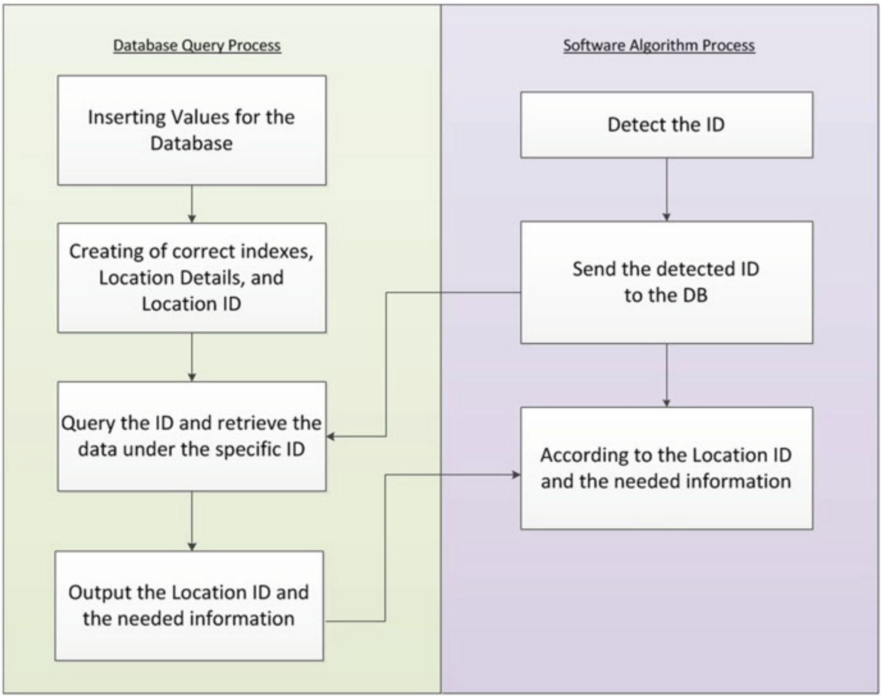

Fig. 8.5 Database function overview

kinds of data types and presentation formats into a unified format used in different reporting tools.

According to the proposed indoor navigation system, there are many nodes in a certain environment. These nodes consist of different ID from one to one, which depends according to the ID given by the controller circuit. Each of these nodes ID should be stored in a database with proper indexing to retrieve the data efficiently. Figure 8.5 illustrates the database function overview.

First the user presses the desired location from the Braille Keypad. Based on the details entered, the program will search the Node details from the table in the Database and retrieve it to the program which runs the shortest path algorithm. Then the shortest path algorithm will output the required nodes. Afterwards the database will retrieve all the information of the nodes given out by the shortest path algorithm required by the user to continue the navigation process. Thus, node by node the algorithm will retrieve data accordingly.

The work proposed in this chapter uses SQLite as its database software. SQLite is an in-process library that implements a self-contained, server less, zero-configuration, transactional SQL database engine whose code is freely available for any commercial or private purpose (SQLite, n.d.). Figure 8.6 illustrates the steps followed in optimizing the SQLite database.

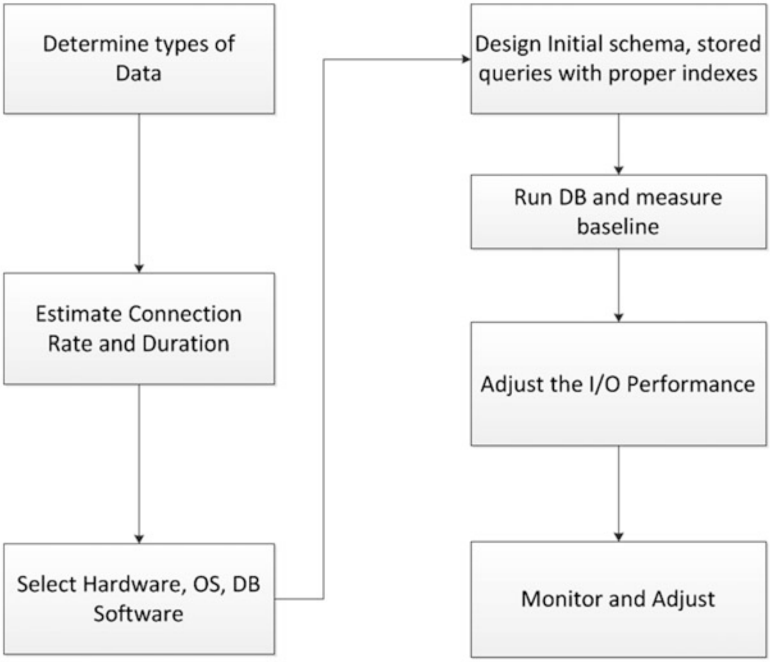

Fig. 8.6 Steps followed in database optimization

- *Determining the Data type* plays a major role in the data retrieval time. In this system, the controller circuit uses binary patterns to process different IDs for the nodes. Using only binary will make the retrieval process much faster than using other data types.
- *Estimating the Connection Rate and Duration* depends on the main system that will be used. It may be an MCU or a mobile phone the connection rate will be varied according to the physical memory of the system that will be used for the processes to be done. Duration depends on the navigation algorithm and the node path. If the required navigation path is long the duration will be high which will require more processing power to complete.
- *Selecting the appropriate hardware, OS, and DB Software* is another challenge in database optimization. The hardware, OS, and the DB software should be carefully decided to achieve maximum efficiency, speed, and reliability.
- *Design Initial Schema, stored queries with correct indexes* is one of the important factors when tuning a database. Many queries rely on sequential (linear) searching. Using default type setting will lead to poor performance when using a database on a set of predefined data. The poorly tuned system can be much slower than a properly tuned one.
- *Run DB and measure baseline* is definitively figuring out, what is normal and abnormal with the database? Without that information, you would be forced to

rely on broad rules that will lead to difficulties in handling the Data inside the database.

- *In Adjusting the I/O performance* Latency, Input/Output Operations per Second (IOPS) and the Sequential Throughput is measured and adjusted. Latency is simply the time that it takes an I/O to complete. This is often called the response time or service time. The measurement starts when the operating system sends a request to the drive (or the disk controller) and ends when the drive finishes processing the request. Reads are complete when the operating system receives the data, while writes are complete when the drive informs the operating system that it has received the data. The Input/Output Operations per Second (IOPS) is directly related to latency. Latency would increase for the increasing number of Ios. Sequential throughput is the rate of data transfer, typically measured in megabytes per second (MB/s) or gigabytes per second (GB/s).
- *Monitor and Adjusting* are the final processes that make the database process fully reliable and error free. Every transaction must be copied and monitored through a log. Future errors could be overcome through regular monitoring. Monitoring and adjusting could be achieved by using a web server connected to the main processing system. Admin can remotely log to the Web server and look into the data movement and can make changes accordingly.

8.2.3 Use of a Best Path Algorithm

The proposed navigation system is responsible for guiding the user by determining an optimal route to reach the desired destination. Each LED node is given a unique ID. The system starts by giving instructions for the user to add a destination (node ID) using the user-friendly braille keypad. According to the destination given by the user from the keypad, an algorithm is used to identify the optimal route.

The system uses a Raspberry Pi microcontroller to process the data collected from the keypad, receiver, and compass module which would then transmit audio signals to the earphone. The LED nodes will continuously transmit the node IDs and receiver will keep track of the user's current position. The system calculates the best path and will guide the user by giving voice commands. Figure 8.7 illustrates how LED nodes transmit IDs.

In order to accomplish all the above-mentioned requirements, the system needs to analyze its environment. It uses three key pieces of information to analyze the current situation and deliver useful navigation information to the user. This key information is the user's current position in the environment, the direction in which the user is moving and the presence of objects in the surrounding area that may be potential obstacles. The navigation mechanism of the proposed research work is illustrated in Fig. 8.8.

With the current position of the user known, it is important to determine the destination that the user wants to reach. The output of this system is an audio instruction that guides the user to their desired destination. The data on the database

Fig. 8.7 LED node transmits ID

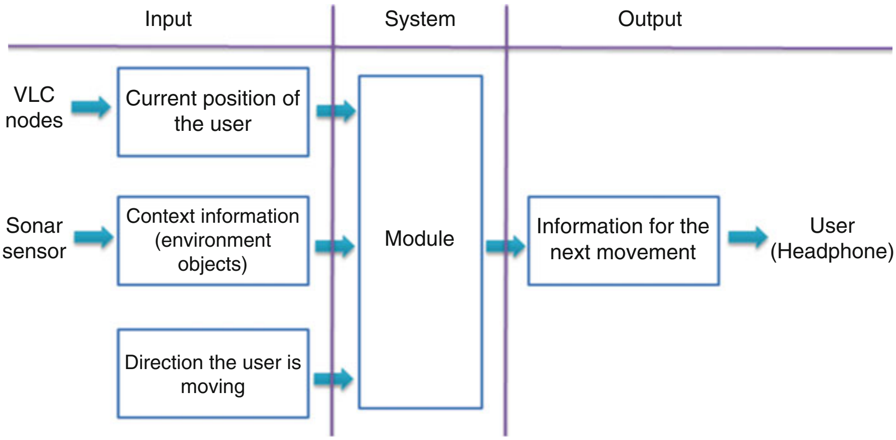

Fig. 8.8 Navigation mechanism

can be a collection of information about nodes that are connected in a tree-like data structure. A node represents a particular position in a building and tells the information about that position. All of these elements will be represented by nodes as shown in the Fig. 8.9 with coordinates and information associated with them. The red color numbers depict the weight (distance) between nodes to explain how the shortest path algorithm works accurately.

The network approach analyzes the indoor environments using topologically based structures that describe the interconnectivity and adjacency between two nodes (Santosa, 2009). The network approach was selected to implement pathfinding for the proposed work due to reasons such as easy implementation and maintenance and low data processing time.

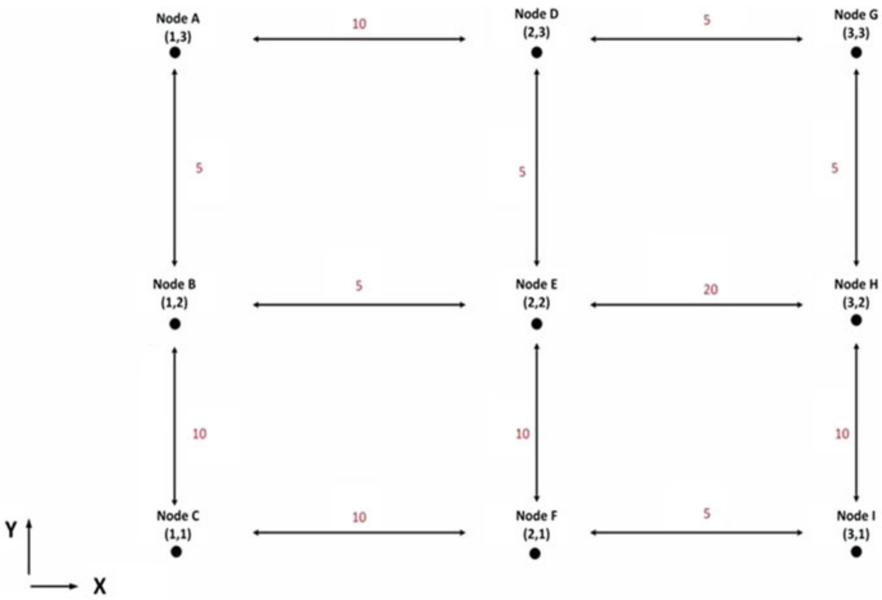

Fig. 8.9 Node map

To select the best path between two nodes, the algorithm must first analyze the assigned cost metrics in each link [path between two nodes] and calculate the cost metrics of all possible paths. From that calculated values, the path with the least value is sorted out as the best path. Figure 8.10 illustrates how each path values are analyzed.

8.2.4 Node Identification and Localization with Direction

A variety of data is required to travel indoors, such as the accurate current position, travel direction, distance to the destination, and information about the obstacles in the surroundings. Geomagnetism is used as the method to survey the travel direction. The travel direction is obtained by calculating the orientation of the embedded geomagnetic sensor as shown in Fig. 8.11. Therefore, compass/magnetic sensor is one of the most important parts of the indoor navigation system.

Geomagnetic field variation in support for indoor positioning and navigation has recently attracted considerable interest as it requires no infrastructure needs. Magnetic field variations could be sensed via magnetometers, also known as compass sensors. The best device to sense the magnetic field variation is a three-axis

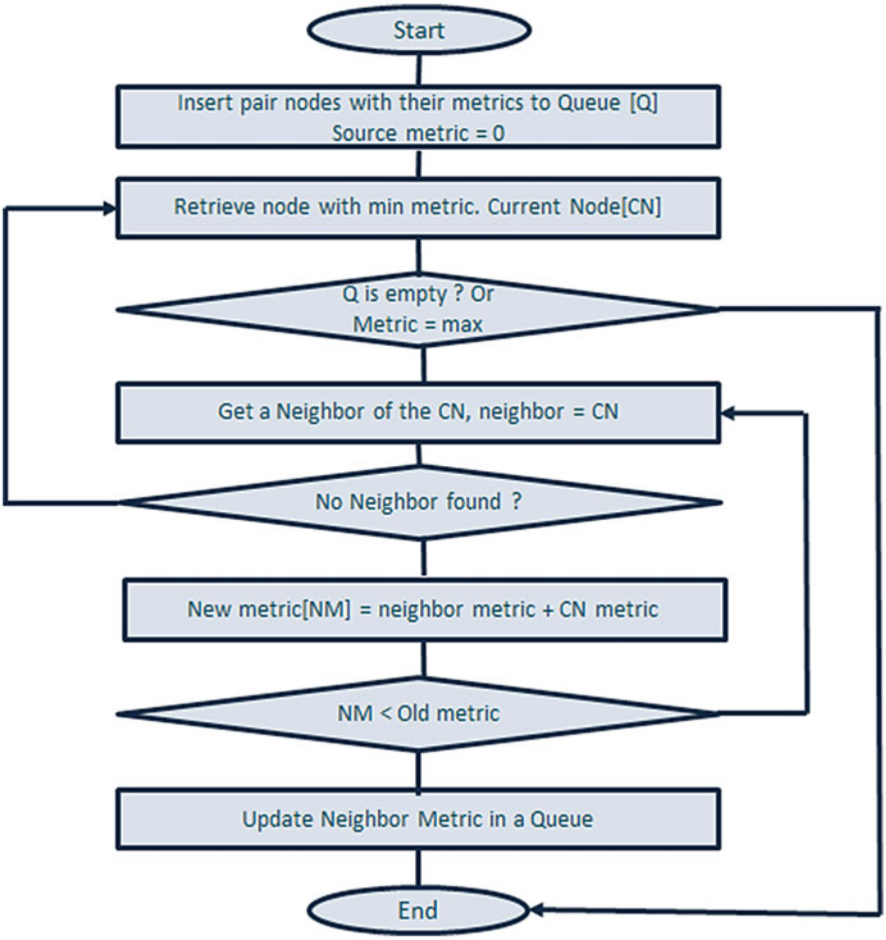

Fig. 8.10 Path value analysis

magnetic field sensor. Even though there are many three-axis magnetic field sensors available in the market, the magnetic sensor for this work should be compatible with Raspberry Pi module and VLC systems. Hence, 3-Axis Digital Compass HMC5883L module is the most appropriate to obtain the geomagnetic field variation in the proposed work.

The system gives voice commands to the user to turn in the correct directions according to the best path. But the system needs to keep track whether the user turns in the right direction. The turning direction is calculated using an algorithm by passing the x and y coordinates of the current and next node according to the best path to the algorithm. Algorithm will return the direction to turn. The value returned from the algorithm is an integer (ID) and direction to turn is predefined for each integer. The voice commands will be given to the user according to the direction (Table 8.2).

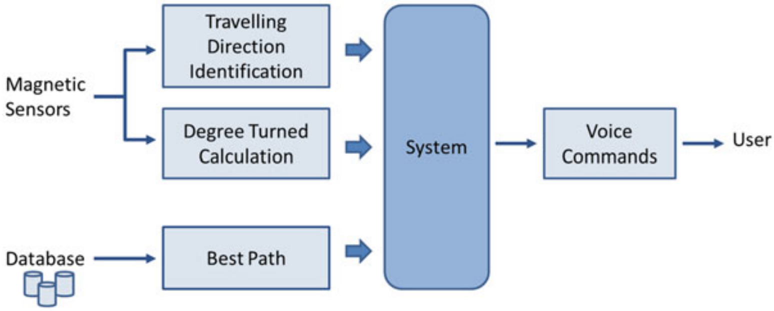

Fig. 8.11 Navigation approach

Table 8.2 Voice commands

Return ID	Direction commands
1	Walk up straight
2	Turn right
3	Turn around
4	Turn left

If the user turned to a wrong direction or path accidently, the system detects the path and alerts the user by giving appropriate warning commands. When there is a bend in the path that the user needs to turn in the correct direction, the system will give voice commands to the user until he/she turns to the right direction by calculating the degree turned. The system will accurately guide the visually impaired individual by correcting the user through voice commands if he/she starts walking in the wrong directions.

The HMC5883L magnetometer plays a major part in guiding the user to the destination. The HMC5883L compass module takes the current position heading/degree and calculates the heading that the user should be after taking the turn. Compass module then continuously checks the heading/degree change, until the user turns to the direction given by the system. When the user reaches the correct position compass module will detect the heading and system will give voice commands to stop turning and to proceed on the path. Heading after tuning is calculated according to the direction that requires to be turned as illustrated in Fig. 8.12.

$$\text{Heading after turning} = \text{Initial Heading} + \text{Degree needed to be turned according to the direction}$$

Vision impaired individuals usually build pictures using his sense of touch and mostly by listening to the sounds that bounce off objects in his/her surroundings. The audio guidance system used in the proposed work will output a voice command with accurate directions to guide the blind individual to the desired destination and warning beep sounds would be emitted to alert the user on obstacles.

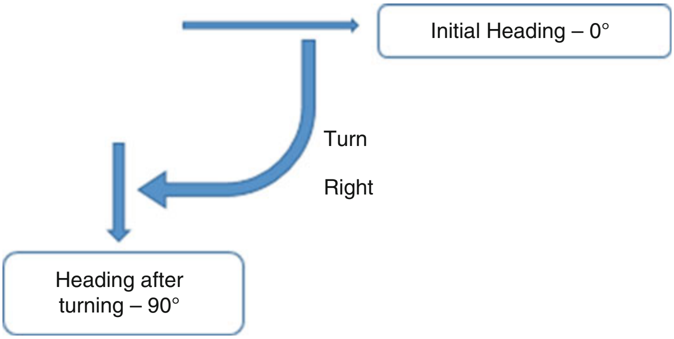

Fig. 8.12 Heading calculation

8.3 Evaluation

8.3.1 Test Case 01: Navigation System Testing

Current position—C

Destination—A

VLC receiver identifies the current LED node and then the system calculates the best path by obtaining the current position and destination given by the user.

Best path—C → B → A

Navigation to the destination starts.

Current node—C

Next node—B

Walk straight to go to the next node according to the best path.

Current heading—88.26′

Heading while walking—88.26′

Current node—B

Next node—A

Turn right to go to the next node according to the best path.

Current heading—96° 48′

Degree needed to be turned—90° to the right

Heading after the right turn—186° 48′

Stop after turning right (after turning 90°) to continue to the destination.

Current node after right turn—B

Destination—A

Walk straight to go to the destination according to the best path.

Heading while walking—185° 33′

User has successfully arrived at the desired destination

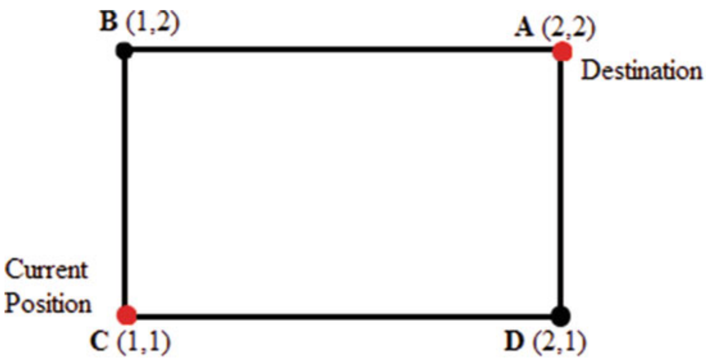

Fig. 8.13 Test map 1

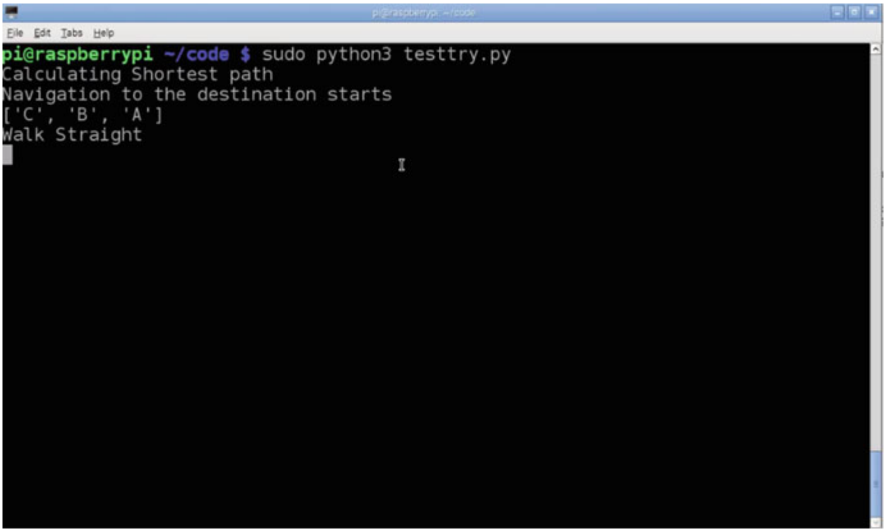

Fig. 8.14 Best path testing

8.3.2 Test Case 02: Navigation System Testing (Test Map 2)

Current position—C

Destination—G

VLC receiver identifies the current LED node and then the system calculates the best path by obtaining the current position and destination given by the user.

Best path—C → B → E → D →G

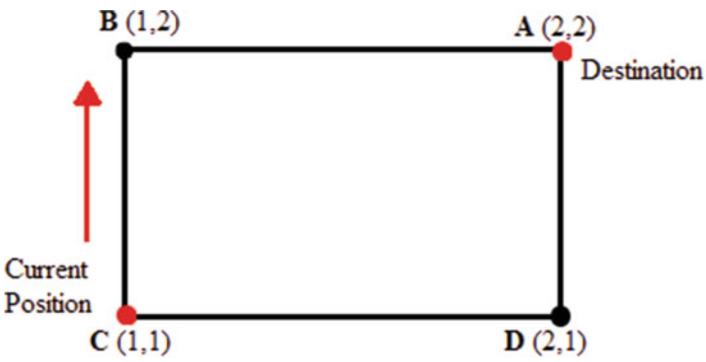

Fig. 8.15 Test map 1 - Walk straight

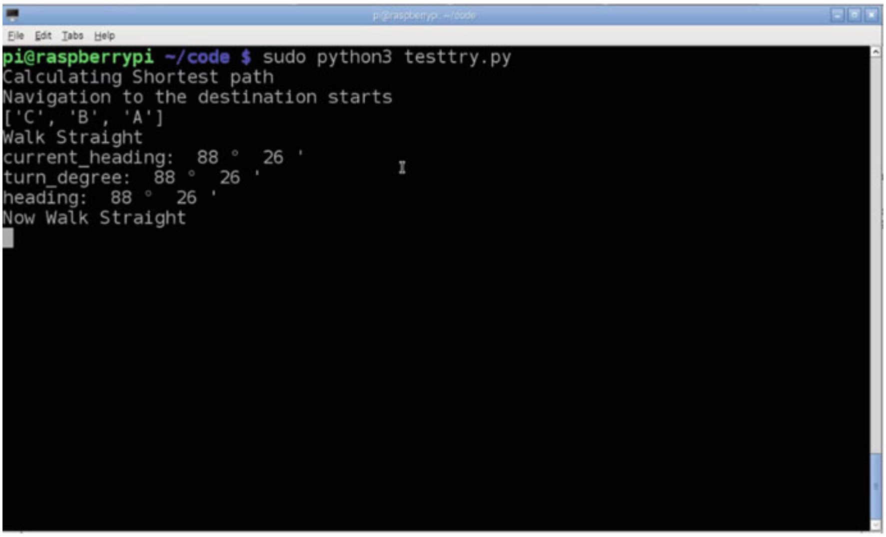

Fig. 8.16 Walk straight testing

8.3.3 Test Case 03: Wrong Direction Navigation Testing (Test Map 2)

Current position—C

Destination—A

VLC receiver identifies the current LED node and then the system calculates the best path by obtaining the current position and destination given by the user.

Best path—C → B → A

Navigation to the destination starts.

Current node—C

Next node—B

Fig. 8.17 Test map 1 - Right turn

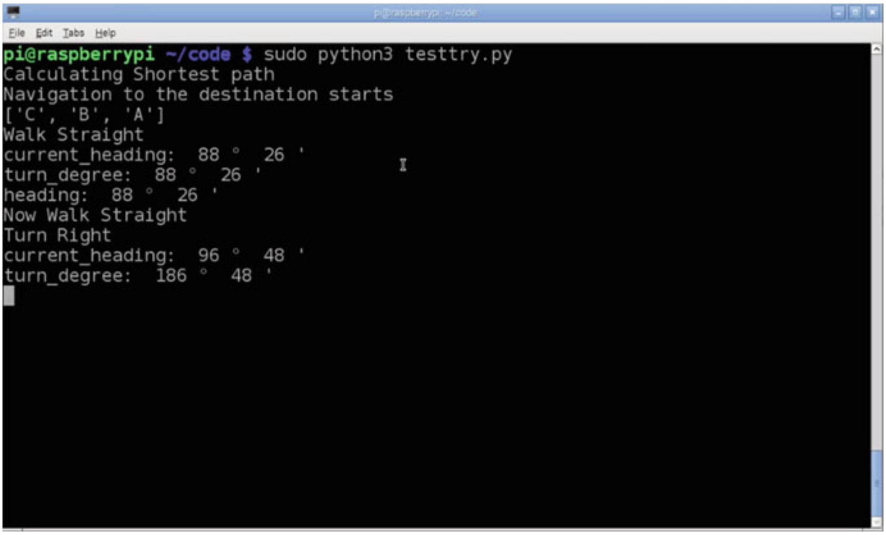

Fig. 8.18 Right turn testing

Walk straight to go to the next node according to the best path.

Current node—B

Next node—A

Walk straight to go to the next node according to the best path.

But the user turns right accidently without following the instructions to the node E.

System inputs the correct destination again to correct the path.

Current node after the wrong turn—E

Destination—A

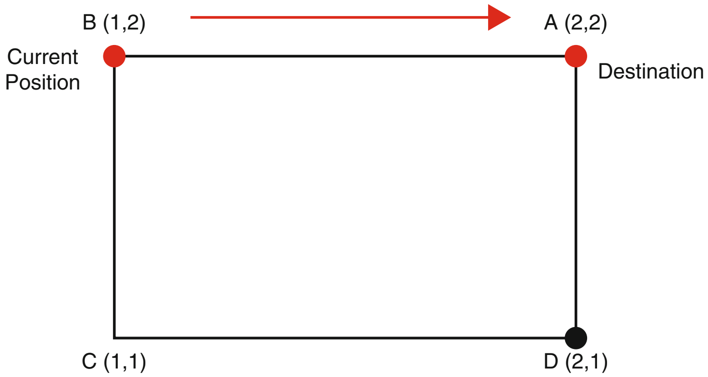

Fig. 8.19 Test map 1 - Walks straight

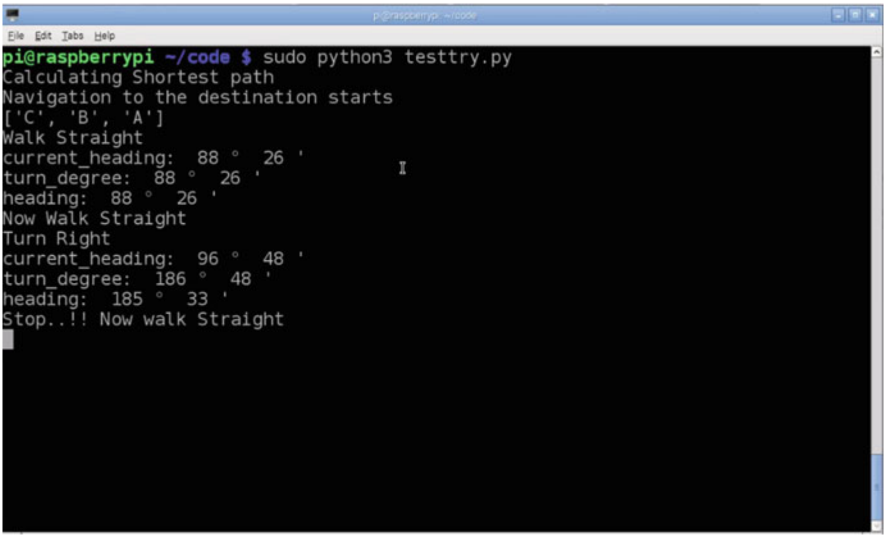

Fig. 8.20 Walk straight testing

The system calculates the best path according to the current position and destination gave by the user.

Best path—E → B → A

Navigation to the destination starts.

Walk straight to the node B go to the destination according to the best path.

Current node—B

Next node—A

Turn right to go to the next node according to the best path.

Since all the three test scenarios have been executed successfully as expected, it can be concluded that the proposed VLC-based indoor navigation system is

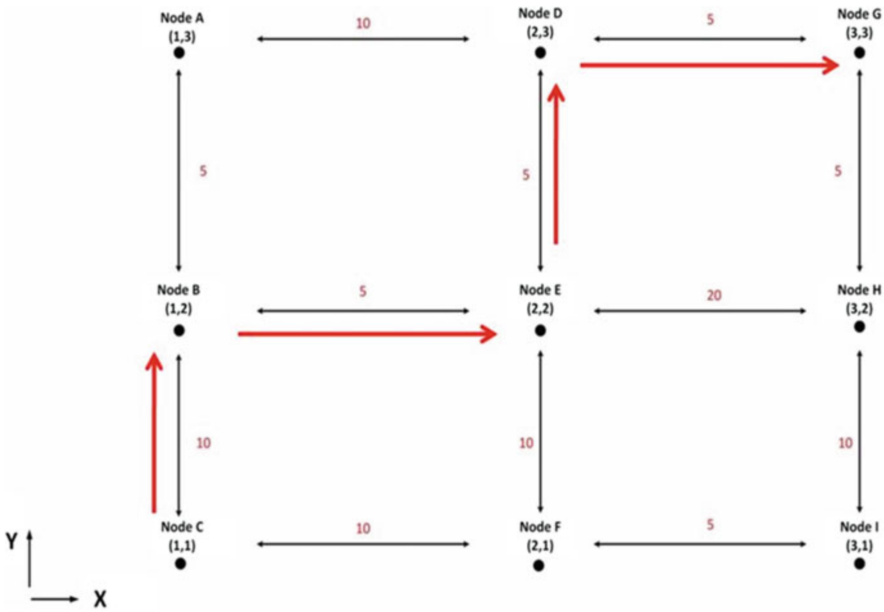

Fig. 8.21 Navigation path - Test map 02

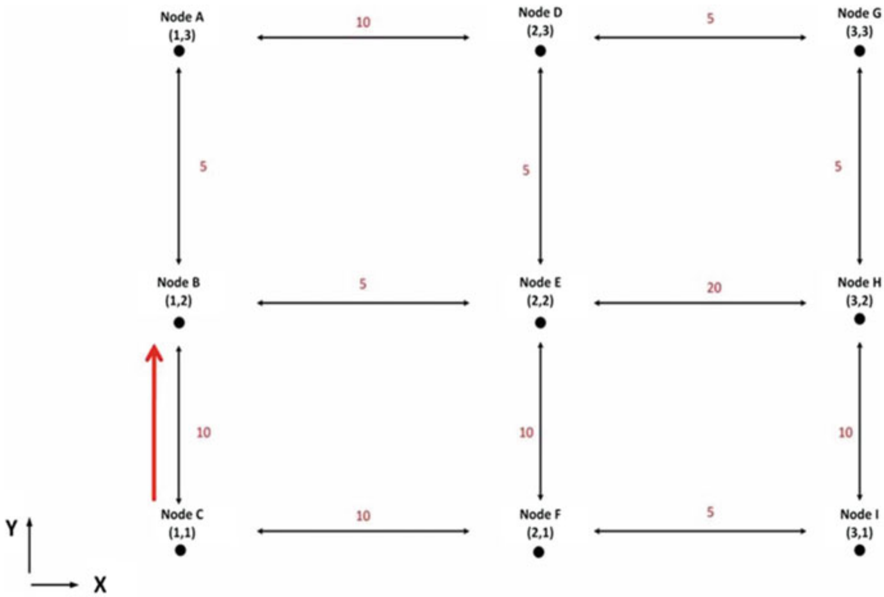

Fig. 8.22 Node map

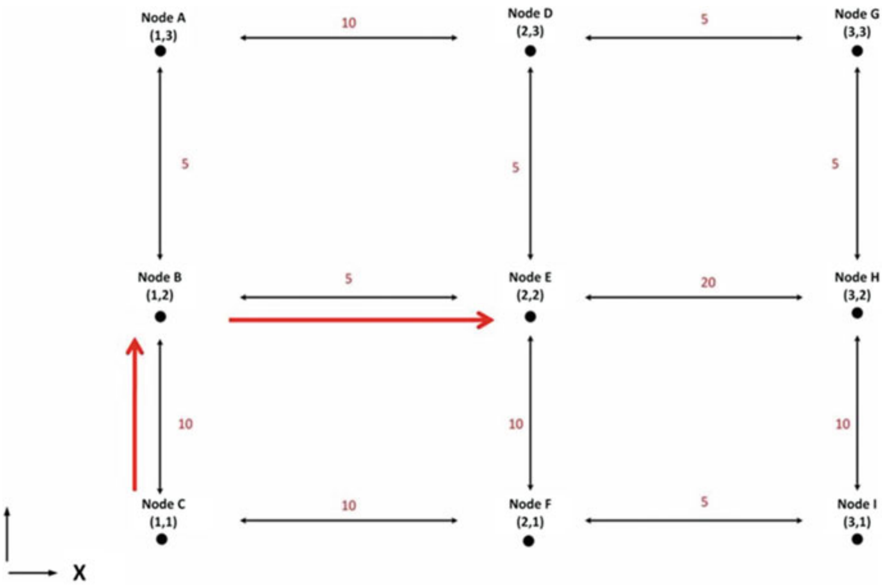

Fig. 8.23 User walks in wrong turn

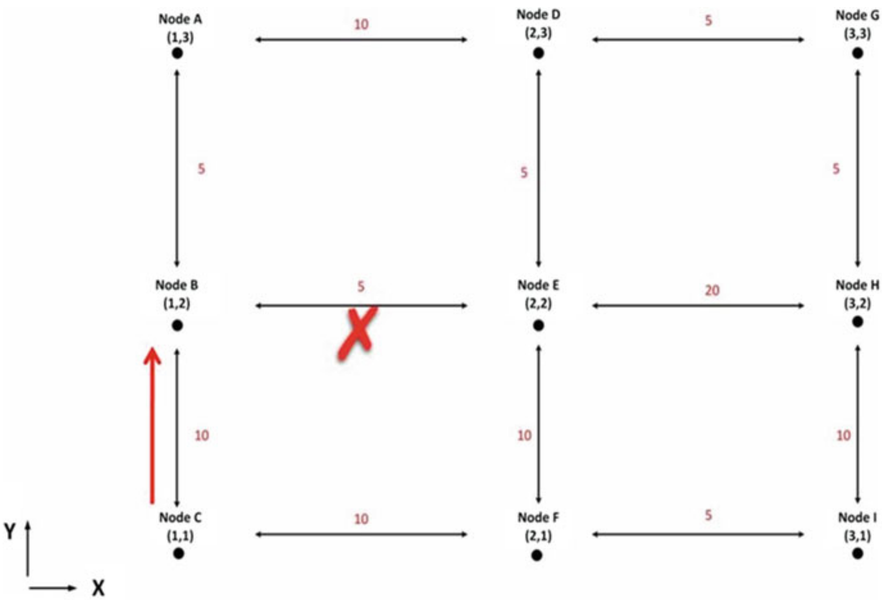

Fig. 8.24 Test map 02 - Wrong path

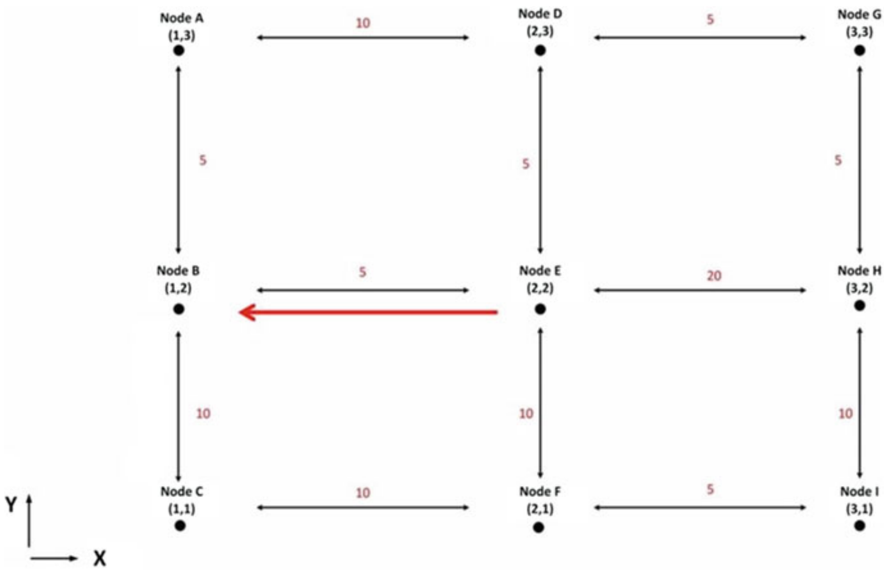

Fig. 8.25 Test map 02 - Correct path

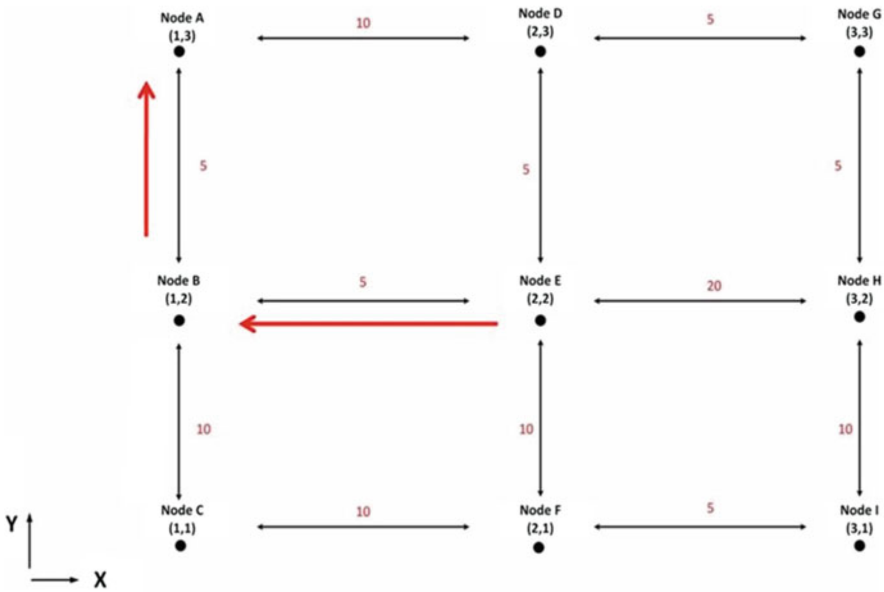

Fig. 8.26 Test map 02 - User walks in wrong turn

reliable to be used by vision impaired individuals in their day-to-day navigation. Furthermore, the system was tested with the aid of eight vision impaired individuals for which they were asked to rate the aspects such as usability, reliability, and satisfaction. The mean scores for usability, reliability, and satisfaction were 72.6%, 78%, and 84% respectively.

8.3.4 Issues in Implementation

The major issues encountered during the actual implementation were the fact that humans do not always walk straight as they tend to hitch while walking which results in the receiver being incapable of retrieving data at times. Additionally, at the receiver, the node ID is received after a difference of 0.5 s.

8.4 Conclusion

The work proposed in this chapter consists of a substitute vision system designed to assist vision impaired individuals using Visible Light Communication and Geomagnetism. It is designed as a product, which provides efficient and accurate guidance for the blind individuals to navigate in an unfamiliar indoor environment without any difficulty. Though many navigation systems to support the visually impaired domain are available, there is no such system that uses both visible light communication and geomagnetism in their work to produce a system that has the capability of providing accurate and secure indoor navigation assistance, which in turn would increase the overall satisfaction of the system users.

The proposed navigation system is responsible for guiding the user throughout map and determining an optimal route to reach the destination. An algorithm is used to determine the optimal route and according to the destination given by the user as a keypad input. The user needs to turn to different directions to reach the desired destination. There will be a large difference in paths if the degree turned is less or more than the desired amount. Therefore, the system checks the angle or the degree turned by the user to give further directions using magnetic sensors. The system guides the user to his/her desired destination through audio instructions via an earphone. A microcontroller is used to process the data collected from the keypad, receiver, and compass module.

Future work could focus on developing and enhancing the system for the use in larger environments. Hence, it could be concluded that the proposed indoor navigation system is capable of eliminating the difficulties prevalent among vision impaired individuals thus providing them with navigation assistance in their day-to-day activities.

References

Bai, Y. B., Wu, S., Retscher, G., Kealy, A., Holden, L., Tomko, M., et al. (2014). A new method for improving Wi-Fi-based indoor positioning accuracy. *Journal of Location Based Services, 8*(3), 135–147.

Blindsquare. (n.d.). *Blindsquare*. (Blindsquare) Retrieved June 21, 2018, from http://www.blindsquare.com/

Borenstein, J., & Ulrich, I. (1997). The GuideCane—A computerized travel aid for the active guidance of blind pedestrians. In *Proceedings of the IEEE International Conference on Robotics and Automation*, Albuquerque.

Dharani, P., Lipson, B., & Thomas, D. (2012). *RFID navigation system for the visually impaired*. Worcester, England: Polytechnic Institute.

Frenzel, L. (2012, April 27). *What's the difference between bit rate and baud rate?* (Electronic Design) Retrieved June 21, 2018, from http://www.electronicdesign.com/communications/what-s-difference-between-bit-rate-and-baud-rate

Hol, J. (2011). *Sensor fusion and calibration of inertial sensors, vision, ultra-wideband and GPS*. Linköping, Sweden: LiU-Tryck.

Jha, P. K., Kumar, D. S., & Mishra, N. (2017). Challenges and potentials for visible light communications: State of the art. In *American Institute of Physics Conference*.

Khan, L. U. (2017). Visible light communication: Applications, architecture, standardization and research challenges. *Digital Communications and Networks, 3*(2), 78–88.

Khudhair, A. A., Jabbar, Q. S., Sulttan, Q. M., & Wang, D. (2016). Wireless indoor localization systems and techniques: Survey & comparative study. *Indonesian Journal of Electrical Engineering and Computer Science, 3*(2), 392–409.

Luo, P., Zhang, M., Zhang, X., Cai, G., Han, D., & Li, Q. (2013). An indoor visible light communication positioning system using dual-tone multi-frequency technique. *2013 2nd International Workshop on Optical Wireless Communications (IWOW)*, Newcastle upon Tyne.

Nakajima, M., & Haruyam, S. (2013). New indoor navigation system for visually impaired people using visible light communication. *EURASIP Journal on Wireless Communications and Networking, 2013*, 37.

Sakhardande, J., Pattanayak, P., & Bhowmi, M. (2012). Smart cane assisted mobility for the visually impaired. *International Journal of Electrical and Computer Engineering, 6*(10), 1262–1265.

Santosa, S. (2009). *Indoor Centrality.* Master thesis, Melbourne.

SQLite. (n.d.). *About SQLite*. (SQLite) Retrieved June 21, 2018, from https://www.sqlite.org/about.html

World Health Organization. (2017, October 11). *Blindness and Visual impairment key facts*. Retrieved June 19, 2018, from http://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment