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A Smart Real-Time Standalone Route Recognition System for Visually Impaired Persons

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ABSTRACT

Visual Impairment is a common disability that results in poor or no eyesight, whose victims suffer inconveniences in performing their daily tasks. Visually impaired persons require some aids to interact with their environment safely. Existing navigation systems like electronic travel aids (ETAs) are mostly cloud-based and rely heavily on the internet and google map. This implies that systems deployment in locations with poor internet facilities and poorly structured environments is not feasible. This paper proposed a smart real-time standalone route recognition system for visually impaired persons. The proposed system makes use of a pedestrian route network, an interconnection of paths and their associated route tables, for providing directions of known locations in real-time for the user. Federal University of Technology (FUT), Minna, Gidan Kwanu campus was used as the case study. The result obtained from testing of the device search strategy on the field showed that the complexity of the algorithm used in searching for paths in the pedestrian network is $O(N^2)$, at worst-case scenario, where N is the number of paths available in the network. The accuracy of path recognition is 100%. This implies that the developed system is reliable and can be used in recognizing and navigating routes by the visual impaired in real-time.

Keywords: Visual Impairment, Route Recognition, Global Positioning System, Text to Speech.

1. INTRODUCTION

Vision is the most significant part of human physiology as 83% of information human being receives from the environment is through the human visual system [1]. World Health Organization (WHO) estimated about 253 million human beings living with imaginative and prescient impairment, at which 36 million of them are blind [2]. Besides that, WHO envisioned that the range of people with vision impairment may grow to triple because of the boom and aging of the population [3]. This could also increase the need for assistive devices for visually impaired. Visual impairment is primarily caused by diseases such as cataracts, retinal diseases, glaucoma, Age-related macular degeneration (AMD), and corneal opacities, and so on [4].

The choice-making of the visually impaired is regularly supported with the aid of the external help provided via white canes, trained guide dogs, human partner, or clever electronic devices [5]. The conventional aids such as white canes and trained dogs have been shown to help daily navigation for many in the vision impaired categories [3]. However, these conventional aids are restricted within the assistance they render, especially in presenting full statistics of the surrounding location to support a secure journey. To address the limitations of conventional aids, electronic assistive technologies (such as electronic travel aids) were developed to further support the daily activities of the vision impaired. Although, the existing navigation structures like ETAs make use of GPS receiver for reporting the present-day region of the user and provide directions to the user. They are primarily cloud-based and depend on Google map for navigation. This implies that systems deployment in areas with poor network facilities is not feasible.

Therefore, this paper proposed a standalone smart route recognition system for visually impaired persons. The navigation unit software makes use of a pedestrian route network, an interconnection of paths and their associated route tables, for providing directions of known locations in real-time for the user. The system was deployed using a Raspberry pi microcontroller and guides its' user through speech. This paper is structured as follows: In Section 1, an introduction to visual impairment and some travel aids were discussed, review of related works was presented in section 2, the materials and methods of the research, including the datasets and systems training are discussed in Section 3. In section 4, the results and deployment of the system are discussed and finally, conclusion and recommendation are presented in Section 5.

2. RELATED WORKS

This section presents an overview of some achievements reported in the literature that informed the decision to embark on this research. Basically, a major demerit with most documented visually impaired devices are (i) Cost: many low-income earners could not afford the devices. (ii) Connectivity: some of the reported visually impaired devices requires internet connection and as such may be constraint to be used only in indoor environment (iii) Portability: some of the devices reported in literatures are not portable which make it difficult for users to carry about. Other drawbacks include accuracy of the device, power consumption and user friendliness etc. Some of the authors who provide solutions for the visually impaired persons includes: An obstacle detection and tracking system presented in [6], the proposed design was made up of two modules: first module consisted of ultrasonic sensor which was used for obstacle detection and a buzzer for alerting the visually impaired while the second module comprised GPS and GSM module. The GPS served as location tracking device and the GSM for messaging the relatives of the visually impaired. However, it's inefficient as it's devoid of obstacle avoidance mechanism. It also required internet connectivity which might not be feasible in outdoor environment.

In [7] an obstacle detection and location finding for the blind was developed. The developed system consisted of sonar sensor for obstacle avoidance, the GPS module for identifying location, the RFID for indoor activities and GSM module for sending messages to the caregiver. All the devices were integrated into a simple walking stick as against the traditional walking long cane that need the help of a sighted person. However, the use of internet connectivity makes the device not feasible for a region with no or poor internet connection. An inexpensive solution for the visually impaired known as Robot-Assisted Way finding (RAW) was presented by [8] using

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the RFID sensors and Robotic guide. It was designed for use in both indoor and outdoor environment to help the visually impaired persons navigating their ways. Another indoor navigation scheme was developed [9], the system used neural network for feature extraction, which was relevant from the depth information provided by the Kinect. Thus, the accuracy was good enough, however, Microsoft Kinect is not a practical solution as it cannot be carried about due to its size and weight. An app Bespecular [10], was also developed to be used in a specular community where the sighted assist the visually impaired by taking a picture of what they need help with a follow up voice message. The sighted reply either through voice or text to the inquiring of the visually impaired, who in turn rates the degree of the helpfulness of the received response from the sighted persons. Further, a novel wearable device to assist the visually impaired person to navigate indoor environment in real time was presented in [11], Google Project Tango, path planner, sensors and human computer interaction subsystems were all incorporated into the wearable device to assist the users in navigation. The system could explore complex indoor environment based on the prior knowledge of the environment extracted from CAD files and spatial information from Google's Area Description files. The system proved efficient and effective but required high cost of maintenance. A smart wheelchair known as Wheelesly [12] was also developed to assist the visually impaired in the navigating effectively and efficiently even in an unconstrained environment with the aid of sensors and on-board computer. The Wheelesly was specially designed to be used in an indoor environment and had the capability to detect both dynamic and static object. Thus, it required an internet connection for some of its functionalities. However, it did not provide user dependency as a user was required to sit on the wheelchair.

Furthermore, Li, *et al.*, [13] proposed an Intelligent Situation Awareness and Navigation AID (ISANA). The system used a scheme known as "Time-Stamped Map and Kalman Filter" for obstacle detection and avoidance. The developed system was incorporated into a cane, which can help the blind, and the visually impaired persons in navigating during indoor activities. However, the system consumed more energy and also required internet connection and as such not suitable in outdoor environment. Also, Nanavati, Tan, & Steinfeld [14] developed an indoor activities device for the visually impaired persons. The device was an autonomous navigating system, which helped the visually impaired in navigation. The model computed the current position using the A* graph search with the aid of the initial robot and human post. A stereo vision-based obstacle detection system to aid the visually impaired in walking was implemented in [15]. It was able to detect an obstacle with 10cm height and 3 to 5 meters distance, but the algorithm was slow.

Finally, in the work of Kayukawa *et al.*, [16], a sonic collision avoidance system known as Bbeep for the visually impaired travellers was proposed. The developed system used a pre-emptive sound alert system to notify both the visually impaired and a close by pedestrians in case of possible collision ahead. Bbeep triggered notifications by tracking pedestrians, predicting their future positions in real time, and provided sound notifications only when it sensed collision ahead. It used YOLOv2 and stereo image sensing for this purpose. Thus, it proved to be efficient and mainly built to be used in an outdoor environment where the chances of collision were high. However, it was cost ineffective and as such, a low-income earner could not afford the proposed system. Therefore, in other to address the challenges stated in the reviewed literature, this research work proposed a smart standalone route recognition system for the visually impaired persons.

3. MATERIALS AND METHODS

The developed system is composed of three different modules, which are route recognition module, control module and feedback module. The Route Recognition Module uses the GPS receiver to collect longitudinal and latitudinal information in real time for navigating the user through his selected route. The control module is the user interface of the system that enable the user select route patterns available in the system for route navigation guide assistance. The feedback module uses speech to inform the user through any audio outlet, of directions the user should follow through the selected route. Raspberry Pi is the Micro Controlling Unit (MCU) used to deploy the system. It possesses the desired processing capacity required for route recognition. It interfaces with GPS receiver, control buttons and earpiece. The route recognition module software makes use of a pedestrian route network, which is an interconnection of paths and their associated route tables. Java programming language was used in developing the software of the system. Figure 1 shows the system architecture of the system.

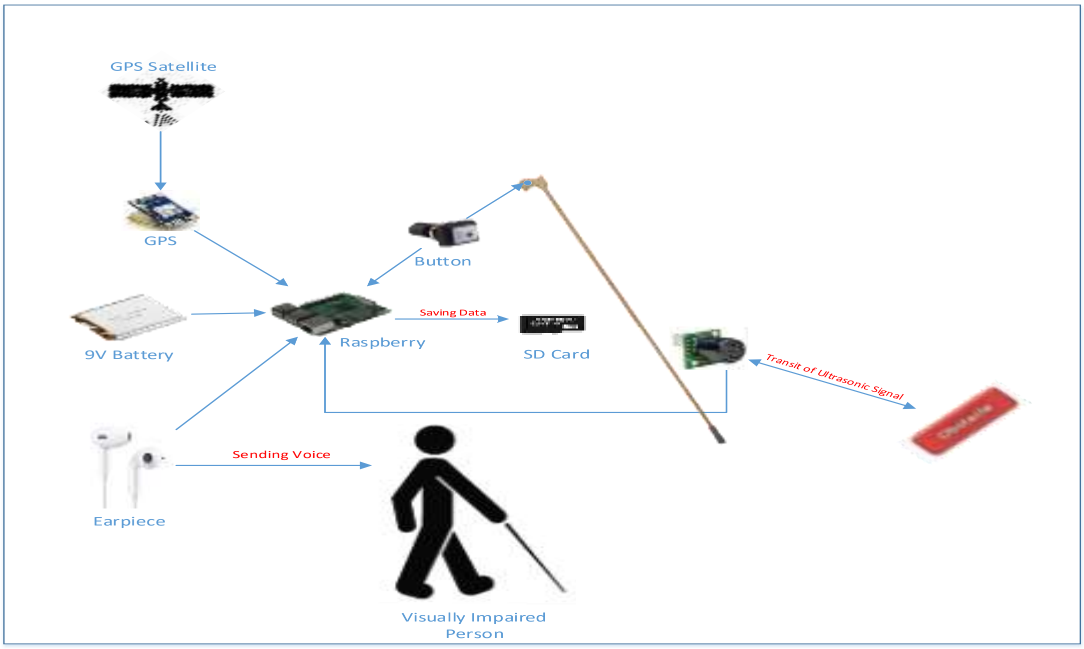

FIGURE 1. Smart System Architecture

3.1 DATA ACQUISITION AND PROCESSING

The GPS data collected were sequence of coordinates acquired from the GPS receiver connected to the system via USB to TTL. These coordinates were taken along the paths of the locations intended for navigation, which could be any number of paths. The GPS navigation software was used to group this coordinate in order of their occurrence and integrate them into the pedestrian route network base. The GPS

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coordinates that were acquired were maintained in their other of occurrence, before integrated into the route network.

3.2 SYSTEM DEVELOPMENT

The grouped GPS coordinates that represents paths to specific locations were interconnected into a route network by creating nodes between path intersection and creating a route table for searching for paths in the network. This approach adopted mimics the way network routers operate on the internet. FUT Minna, Gidan Kwano campus was used as a case study to apply this approach. The resulting Route Network consists of 24 paths, 26 Nodes, 1211 coordinates. Figure 2 shows the logical components of the route network and the relationship that exists between them and the roles it played in the pedestrian route network.

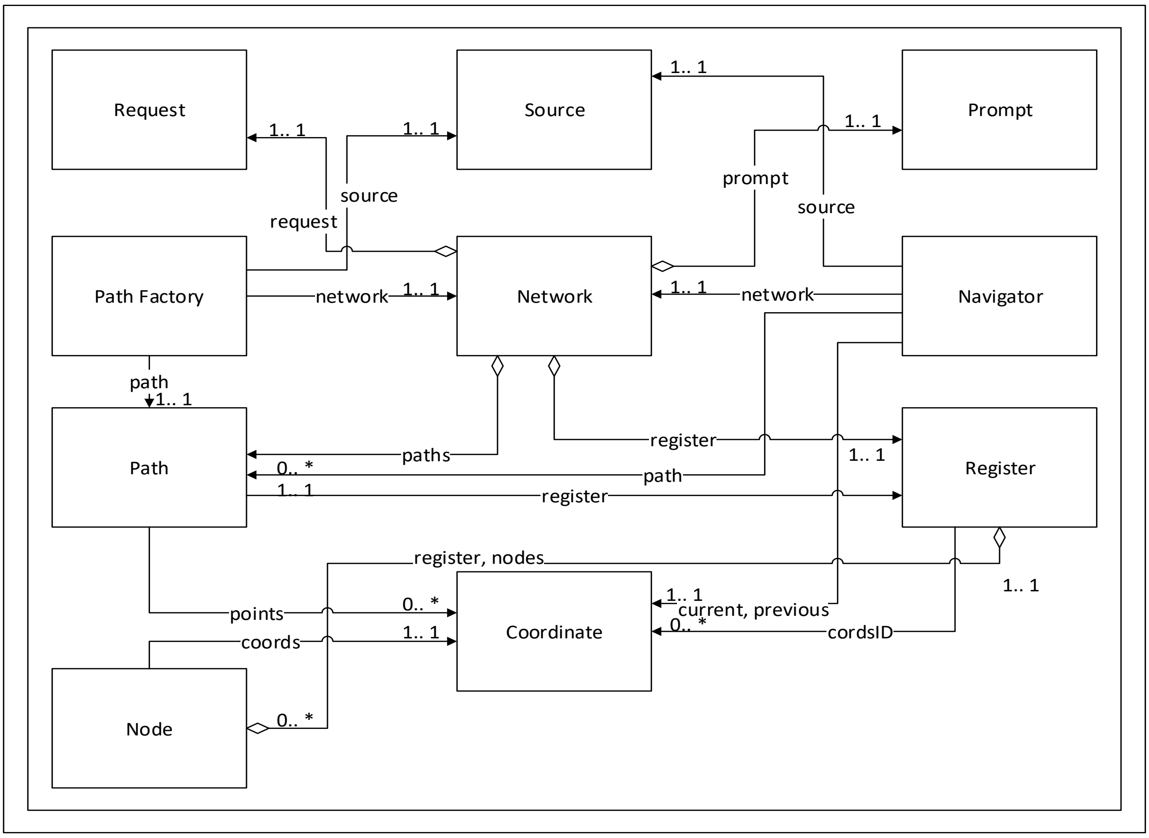

FIGURE 2. GPS Fundamental Module Elided Class Diagram

The pedestrian route network that was developed in the training stage is used to provide directions to the user. The current and the destination coordinate selected by the user is used to query the route network. The route network conducts a recursive search to construct a new route pattern based on the current and the destination coordinate. The constructed route pattern obtained from the network is used to provide navigation assistance to the user. Figure 3 shows the flowchart of the algorithm used to search and construct a route pattern from the route network, also known as path finding.

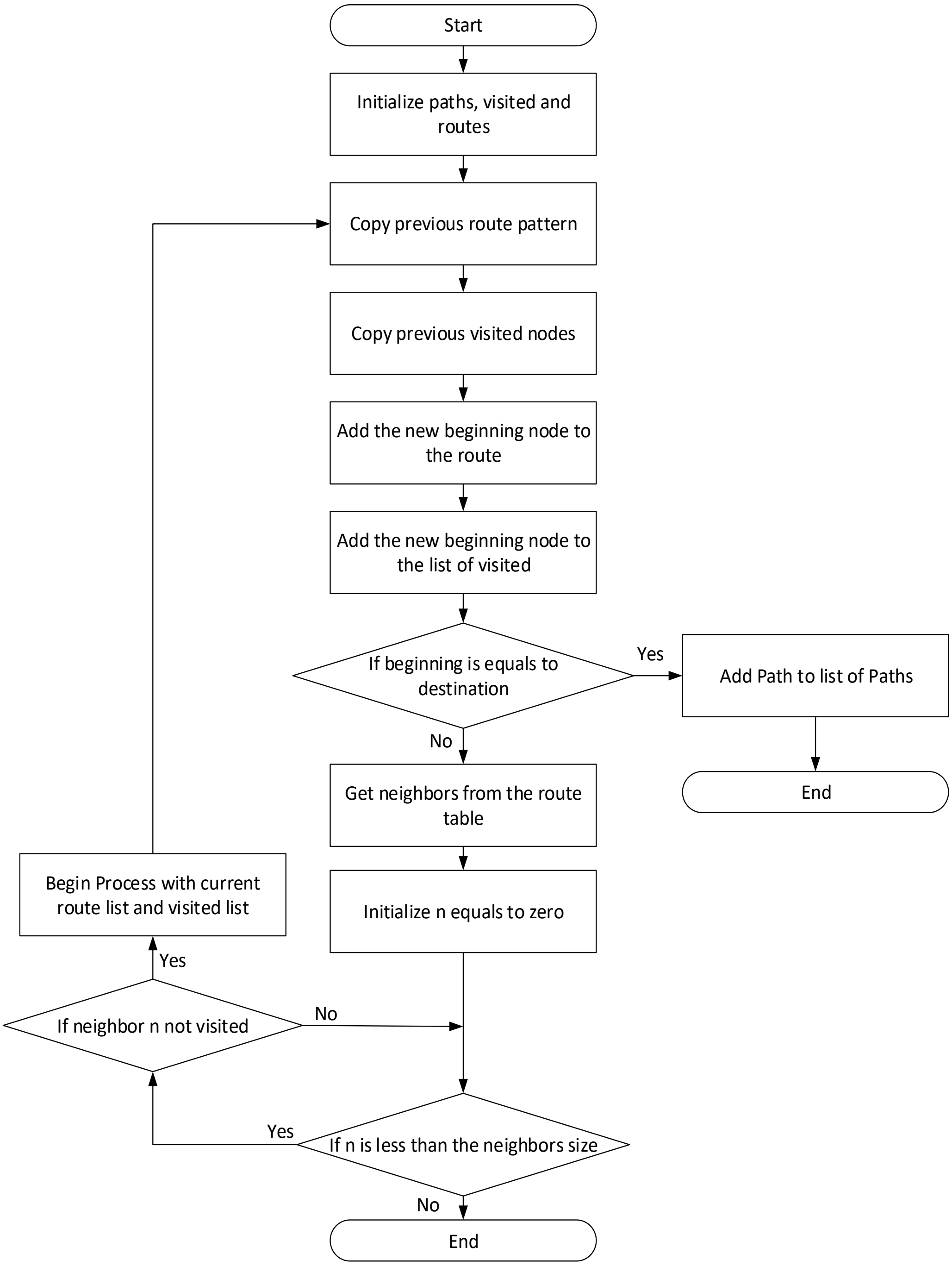

FIGURE 3. Flow Chart for Path Finding

Figure 4 shows the screenshot of the interconnected paths of some routes in Federal University of Technology, Gidan Kwano campus. The nodes represent the different structures and important junctions within the campus which include: School of Agriculture and Agricultural Technology (SAAT), Back of SAAT Junction, Back of SAAT, Caverton Lecture theatre entrance, Central classrooms extension, Central

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classrooms extension junction, School of Information and Communication Technology (ICT) and School of ICT junction, School of ICT entrance are among the 26 nodes and 24 paths.

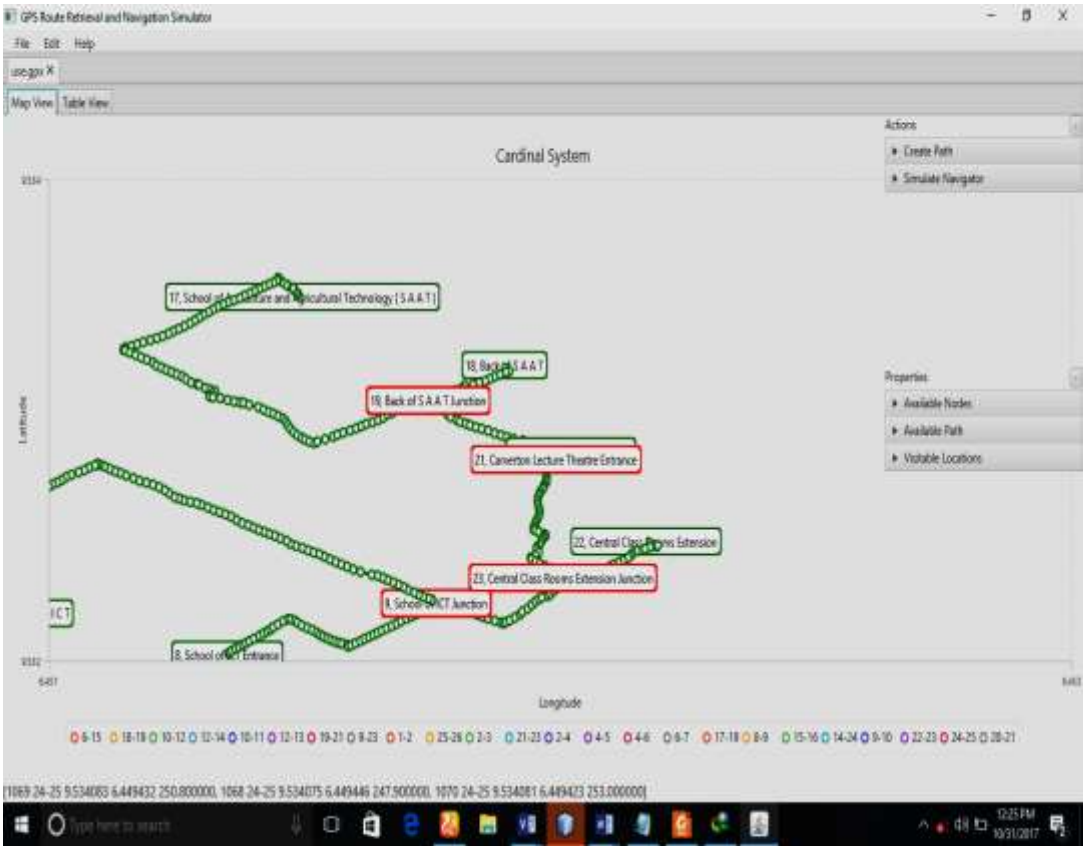

FIGURE 4. A Visual View of the Pedestrian Route Network for Federal University of Technology Minna, Gidan Kwano campus

Figure 5 shows the flowchart of the navigation module. Equations 1 and 2 were used in calculating the distance and angle between two coordinates respectively, during path finding and navigation assist.

$$d = 2r \times \sin^{-1}\sqrt{\sin^2\left(\frac{u_2 - u_1}{2}\right) + \cos(u_2)(u_1)\sin^2\left(\frac{l_2 - l_1}{2}\right)} \quad (1)$$

where,

$u_1 = latitude\ 1,\ u_2 = latitude\ 2,\quad l_1 = Longitude\ 1,\ l_2 = Longitude\ 2,\ d = Distance\ between\ to\ coordinate$

$$\varphi = \tan^{-1}\left(\frac{\cos(u_2)\sin(l_2 - l_1)}{\cos(u_1)\sin(u_2) - \sin(u_2)\cos(u_2)\cos(l_2 - l_1)}\right) \quad (2)$$

where $\varphi = Angle\ between\ two\ coordinate.$

Several setups and configurations were made on the raspberry pi micro controller before deploying the discussed software components onto it. Some of such setups and configurations are:

1. Installation of Raspbian Operating System, a Linux distribution, on the Raspberry.
2. Installation of Virtual Network Computing (VNC) software, a remote computing software, used for sharing the raspberry operating system on a Computer.
3. Installation of PI4J API library on the raspberry, it allows java to communicate with the Raspberry GPIO pins, serial interfaces, and other peripherals of the Raspberry.
4. Disable the Raspberry Serial console in other to enable its Universal Asynchronous Receiver-Transmitter (UART) interface use by the GPS receiver.

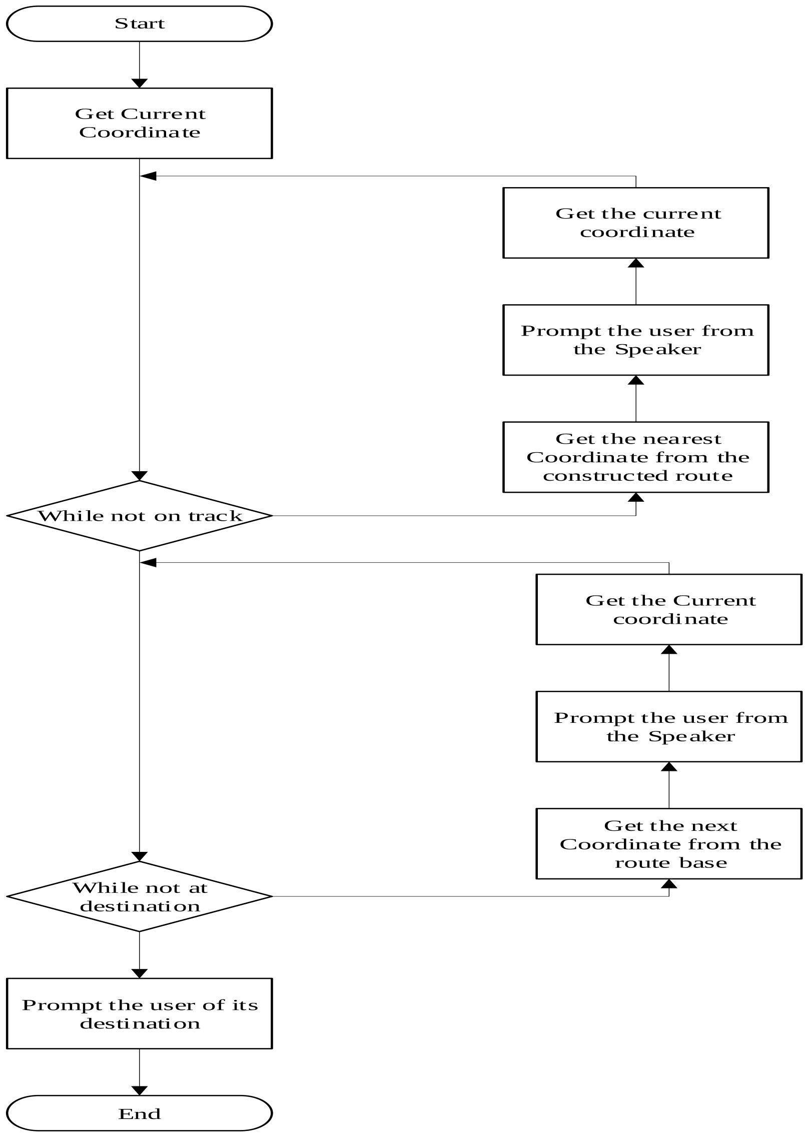

FIGURE 5. Flow Chart of Navigation Module

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3.3 PERFORMANCE EVALUATION

The performance of the algorithm used to develop the pedestrian route network, search and construct paths from the route network was evaluated to measure the search algorithm complexity using Big-O-Notation. Also, the system's ability to guide users through the correct route to a chosen node was evaluated using accuracy measured in percentage as shown in Equation (3).

$$Accuracy = \sum_{i=1}^{n} TP * \frac{100}{n} \quad (3)$$

where, True Positive (TP) is the correctly identified node, TP is 1 if a node is correctly identified and 0 otherwise: $TP \in \{0,1\}$, n is the number of nodes.

4. RESULT AND DISCUSSIONS

The complexity of the algorithm for searching for coordinates is $O(M)$, where M is the total number of coordinate. This is because the coordinates of each path does not change, since there are M coordinates that makes a chosen path, only M searches are required. In searching for shortest path in the route network, the algorithm complexity was found to be $O(N^2)$, where, N is the total number of paths on the route table of the network. In searching for the best route to take, the system compares a path with all other likely paths in the network of the desired node. Since, there are N paths, N^2 comparison will be required. These results indicated that the develop algorithm search speed depends on the number of coordinates and paths that are trained. The system was tested for all 26 nodes built into the system. The result show that the accuracy of the system is 100%, that is, it accurately guides the user to all the nodes in FUT Minna, Gidan kwano campus built in the campus network. The result was consistent after several trials which indicated an excellent performance.

5. CONCLUSIONS

This research work developed a smart standalone route recognition system for the visually impaired persons with a view to navigate their ways through the provided routes in an indoor and outdoor environment. The performance of the system based on the route recognition algorithm was evaluated using Big O Notation. The Big O notation for searching for searching for coordinates in the network was O(M) while the Big O notation for searching for the shortest path in the route network is $O(N^2)$. In addition, the accuracy of path recognition was computed to be 100%. This indicates that the developed system is reliable and the deployment of the system using Raspberry pi microcomputer makes the implementation faster in recognizing and navigating routes by the visual impaired persons. For further research, the system can be combined with an object recognition system for object and route recognition. Also, an efficient shortest path algorithm can also be applied like Dijkstra algorithm or Breath First or Depth First Search algorithms for shortest path selection.

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