Research Article
Towards Independency Using LMN4DISABLED System for Disabled

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We propose a wireless based system to localize, monitor, and navigate people with a single type of disability. The proposed system is called LMN4DISABLED. Smartphone devices are used as interfaces for disabled people to communicate with the surrounding environments. This paper studies two types of disabilities (1) blind people and (2) people on wheelchairs with no mental deficiencies. Experiments are performed on a three-floor university building. Sensor nodes and cameras are distributed in all rooms and hallways. Dijkstra routing algorithm is used to select the appropriate route for each profile. New localization algorithm is used in the experiments. Experiments show that LMN4DISABLED outperforms reference experiments that are not using LMN4DISABLED by about 50.8% for different types of disabilities. When separating the performance of the blind disabled people from the performance of the people on wheelchairs, experiments show that the blind performance improved by 55% while wheelchair users improved by 47% when using the LMN4DISABLED system compared to basic reference experiments for the same people that did not use the LMN4DISABLED.

1. Introduction

Being independent is an important issue for disabled people. Most of the disabled people rely on an escort to facilitate their navigation and to minimize risks caused by random wanderers. Common challenges to individuals with disabilities are how to be aware of the surroundings and recall routines and travel in new spots. To build an assistive system that has localizing, monitoring, and navigating facilities, special equipment could be utilized such as large numbers of sensors and cameras, in addition to recording information for processing. Different disabilities have different requirements to navigate safely in different environments. Disabled people who participated in the experimentation phase of the proposed system are blind individuals and people on wheelchairs that have no mental impairments.

A new system is proposed to localize, monitor, and navigate people with a single type of disability. The system is called LMN4DISABLED. LMN4DISABLED works in wireless sensor networks (WSNs) environment. A WSN is an infrastructure that is composed of many wireless sensor nodes that are scattered over a geographical area so as to monitor and respond to different events in this area. Sensor nodes are used in a variety of applications which require constant monitoring and detecting specific events. WSNs are used due to their low cost, collecting capabilities, computing power, and the ability to propagate data transparently.

Each node in the sensor network consists of four modules. (1) a sensor which connects the network to the physical environment, (2) a computation component which consists of controller that is responsible for controlling the sensors, (3) a transceiver that is responsible for the communication among nodes, and (4) the base station and the power supply module which is usually from batteries as shown in Figure 1. The WSN contains the processing module which is usually a microprocessor with a limited amount of memory. The processing unit is connected to the sensors through analog to digital modules. The transceiver unit transmits
data to the sensing unit for processing it. The transceiver unit integrates a localization algorithm that helps nodes to discover its position relative to the neighbour. The WSN architecture is shown in Figure 2.

LMN4DISABLED uses Bluetooth technology to facilitate communication retrieval from the smartphone to the sensors located at crucial points on the field under study. Bluetooth networking sends data via low power radio signals. LMN4DISABLED uses photos overlay arrow found in the field used for orientation. Received signal strength indicator (RSSI) is used to specify position of the disabled person in order to trigger monitoring cameras in the area. LMN4DISABLED used smartphones that acted like an interface for disabled people to communicate with the surrounding environment. The proposed system uses WSN networks for communicating with sensor nodes.

The paper is organized as follows: Section 2 discusses the literature survey. Section 3 describes the HAAT model. Section 4 discusses the proposed system. Section 5 has the experimental results and comparison between baseline reference and using the LMN4DISABLED system. Section 6 has the conclusion and the future work.

2. Literature Survey

Existing methods in public services for helping people with disabilities are extremely expensive. Rehabilitation institutes work with people with disabilities for the purpose of helping disabled people throughout the job hunting process and maintaining paid employment. Maintaining paid employment is performed through learning how to navigate to certain predefined points. In some cases a disabled person may require an escort for assistance. Several research groups have been working on developing navigation systems prototypes.

Li et al. [1] designed a structural design to convey a just in time transit directions to a PDA device used by bus passengers. The system uses GPS and wireless technology installed on the buses under study. Stock et al. [2] examined the impact of a GPS-based system on people with disabilities to use public transportation systems. Stock et al. [2] used handheld devices for interaction. Authors proposed a GPS based system for delivering instant directions to passengers’ handheld devices based on GPS. The work presents an architecture that is composed of a personal travel assistant that uses GPS data to deliver instant triggers. The proposed system is composed of a mobile triggering client and collects task conditions from the mobile client to give warnings of potential problems. Sevillano et al. [3] built a simple wheelchair system with simple less on board sensors to interact with a smart environment. The navigation built into the wheelchair depends on a piece of software where external sensors are used for information gathering. Liu et al. [4] showed that the preferred media for giving directions are photos as opposed to speech and text. Authors in [4] used manual approaches to send photos based on location information given by the supporting team. Preplanned trips are the only trips that are used in the paper rather than route customization.

Chen et al. [5] studied signal strength indicator (RSSI) for localization purposes. The study planned to facilitate disabled people moving at home. The system was implemented in ZigBee modules. Experiments showed that the planned system can find the locations with minimum error rate. Chen et al. [5] presented a research in digital home and home management systems. Disabled people remotely managed home appliances through home network open service gateway that uses RSSI data. Santos et al. [6] proposed an approach for home automating appliances that targets elderly people with special needs. Marco et al. [7] presented a ZigBee and ultrasound solutions for people with special needs. All these systems mentioned above are expensive and cumbersome.

Cheng et al. [8, 9] compared between different localization techniques such as node selection criteria for localization in energy-constrained network, non-line-of-sight, scheduling the sensor node to optimize the tradeoff between localization performance and energy consumption, cooperative node localization, and localization algorithm in heterogeneous network. Chandra-Sekaran et al. [10] propose an empirical analysis and ranging using environment and mobility. The proposed system is adaptive and uses RSSI filter for patient localization during disaster management. Xiong et al. [11] propose a hybrid WSN and RFID indoor positioning and tracking system. Authors designed and evaluated a hybrid system which combines WSN and RFID technologies to
provide an indoor positioning service with the capability of feeding position information into a general-purpose Internet of Things (IoT) environment. Savioli et al. [12] propose an indoor localization in wireless sensor networks by ultra wideband (UWB) radio and inertial data fusion.

3. HAAT Model

The human activity assistive technology (HAAT) helps disabled people to maintain optimal functionality despite the fact that their capabilities are expected to decline. AT assessment collects the appropriate medical, educational, and work information. The team that performs the AT assessment consists of (1) disabled person, (2) family members, and (3) coaches as shown in Figure 3.

These three components are implemented in the proposed LMN4DISABLED. LMN4DISABLED has the disabled persons which are the volunteers that agreed to help out in these experiments. LMN4DISABLED has the family members that have signed the agreement to use the help of disabled persons in testing the proposed system.

LMN4DISABLED has the coach module that is directing the disabled persons and guide them through the reference experiments.

The HAAT model of AT assessment has three basic components: (1) human which refers to the disabled person; (2) activity that deals with what the disabled person wants to do; and (3) AT that deals with what the AT person uses to perform the activity. HAAT process identifies the performance difficulty that the disabled person would face.

The HAAT framework recommends that AT assessments should be performed during daily habits for more relevant application. The context is one of the factors affecting the activity.

Performing an activity within a commonly experienced context represents an output assessment of the AT strategy provided. As seen in Figure 3, the AT is considered as an input to the HAAT, which is classified into sensory, mental, and motor capabilities for the AT user, assistive technology effect, AT context and user’s environment, and AT user’s goal. Figure 4 shows the AT and its interaction with the educational technology, student environment required for students with special needs, matching person with technology to map the appropriate technology to the disabled person, access profile for disabled that determines the weaknesses and requirements including life space for each profile, and human activity assistive model (HAAT). Most disabled people remain unemployed and are socially isolated.

Mapping the HAAT hierarchy to the shown in Figure 3 to LMN4DISABLED through sensory modules are represented in the paper by sensor nodes that are scattered in the building under study in corridors and in hallways in addition to rooms. These sensors communicate with the smart devices used by each disabled person. No mental impairment is assumed in this paper, it is kept for future work. Assistive technology effect module is represented through the smart devices and their communication with the sensors using Bluetooth. The AT context and user’s environment is the equipped environment that helps the disabled people to locate and find their target destinations. AT use goal for user is to reach the required destinations using the smart devices technology.

4. Proposed System

The proposed LMN4DISABLED system is used for localizing, monitoring, and navigating disabled people. When a disabled person uses the proposed LMN4DISABLED system and misses the right track, the system is responsible for making emergency calls to report that the disabled person missed or distracted from the right path. Teams from multiple disciplines with technology skills helped us in building the prototype. The LMN4DISABLED localizing, monitoring, and navigation system is composed of four main systems:

(i) smartphone system;
(ii) localization system;
(iii) monitoring system;
(iv) training system.

4.1. Smartphone System. Due to highly variable perceiving shortages, there are many research areas work on the percentage of mentally injured patients that are able to deal
properly with handheld devices (such as smartphones) even with proper training [2, 13, 14]. Empirically, smartphones have shown success and efficacy in field trials and society based experiments in both field trials and society based experiments. That is, smartphones have shown success and efficacy as appropriate interfaces for the disabled people [1].

Smartphones are used by disabled people to show instant directions and instructions by vibrating or displaying pictures or videos. This is achieved with or without verbal aid based on the appropriate profile of the disabled person and condition. At each point of interest, a photo is taken based on a configuration. Photos are used for possible relocation.

Smartphones used in the LMN4DISABLED are Samsung galaxy S that have Dual band CDMA2000/EV-DO Rev. A 800 and 1,900 MHz; WiMAX 2.5 to 2.7 GHz; 802.16e 2.5G (EDGE/GPRS/GSM/GPRS); 850, 900, 1,700, 1,800, 1,900, and 2,200 MHz; 3G (HSDPA 7.2 Mbit/s, HSUPA5.76 Mbit/s); 900, 1,900, and 2,100 MHz; running operating system Android 4.4.1 with TouchWiz UI 3.0/TouchWiz UI. Developing the environment is performed through downloading the Android SDK then installing the ADT plugin for Eclipse and downloading the SDK tools and platforms using the SDK Manager. The server used is an Intel-based PC server for authenticating the disabled people participating in the prototype, planning the route, and serving photos when requested by the smartphone at each time any location is visited.

In LMN4DISABLED, smartphones are designed with timeout values that should be maintained based on individuals, the position last visited, and the selected destination. Server gets alert when timeout collapses. The timeout values are implemented by java script code and personalized per profile. Disabled persons are instructed to back track if they missed the right track to the selected destination.

4.2. Localization System. Localization mechanism is required to give direction at the right place. Localization enabled WSN based on received signal strength RSS. However, in our case, we found empirically that errors can fluctuate significantly due to environmental changes such as (1) closed doors, (2) crowded people, and (3) temporary obstacles in the building. Even in the best cases, errors of the state of art WSN based utilization are still greater than 3 meters for a building scale application. Smartphone may receive prompts only after missing the decision points. Beacons emitted from sensor boards are used instead to trigger navigation instructions on the smartphone. In our implementation, Bluetooth is used as the source because modules are rather inexpensive to be used on the sensor boards and most smartphones are already Bluetooth equipped that can greatly simplify the task of picking up the beacons on the users’ side. Bluetooth is originally designed to cover local areas of diameter 10 meters. In order to provide sufficient resolution of location and reduce device cross talk, we modified the firmware to transmit power so that radiating radius is roughly 2-3 meters, a practical distance for navigation prompts. Reduction of transmission power translates to battery saving.

LMN4DISABLED uses WASPmotes. The WASP mote architecture has been designed to be extremely low consumption module. The WASP motes allow digital switches to turn on and off any of the sensor interfaces as well as the radio modules. The used sensors are in two modes that maintain the low power consumption. There are eight different interfaces for these devices: (1) long range, where it has 3G and GPRS capabilities; (2) medium range, where it has ZigBee capabilities and is used by the LMN4DISABLED to gather information about the location used; (3) short range that has Bluetooth capabilities used for triggering camera for monitoring patients. Each WASP mote connects 60 sensors and also supports encryption libraries to ensure authentication [15].

In LMN4DISABLED, a node is plugged on each floor at each destination point. A destination point is any location the disabled person requests to navigate to. Using smartphones in the LMN4DISABLED shows instant directions by displaying photos initiated by sensor nodes. This occurs when communicating with in-field smartphones is used by the disabled person. Sensors are placed so users can make decisions on which direction to take at crucial points such as at a door, at a turn, or at an elevator.

In indoor straight hallways, there are no sensor nodes to be located in the middle, since no changes of directions are expected. Sensor nodes are located in areas where they are needed without being hugely distributed everywhere. Figures 5, 6, and 7 show the plan view of the first floor, second floor, and third floor, respectively.

Localization is one of the main functions used in WSNs. Each sensor node knows its location and couples it with the data it transmits through messages. A low power, a low cost, and an accurate technique is needed for locating objects. A global positioning system (GPS) is not always feasible since it has indoors reachability problems. Besides, it consumes high power and makes sensor nodes more complex. Localization algorithms are classified into relative and absolute, centralized and distributed, and range-based and distance-based estimation algorithms [16].

Relative localization algorithms estimate relative positions of nodes to a reference coordinate node. A coordinate node is chosen by a group of nodes. Relative localization algorithms do not need any anchor nodes. Absolute localization algorithms compute absolute positions of nodes by using anchor nodes that send location information to the other nodes. The accuracy of the algorithm increases as the number of anchor nodes increases in the system. In the centralized localization based algorithms, nodes forward data measured to a central base station for final computation. In distributed localization algorithms, every node computes and derives its position. In range based algorithms, distance between nodes is used to compute location of nodes.

The received signal strength information (RSSI) derives the distance between the receiver and the reference point as a function in the value of the increase in the attenuation of the radio signal between the receiver and transmitter. Distance estimation relies on received signal strength measurements which is a built in feature found in smartphones devices. The RSSI techniques are attractive since they do not require extra
hardware; hence they consume low power and have no effect on sensor size and cost. $P_{Rx}(d)$ is the receiver power obtained. The received power is a function in the distance $d$ as discussed in the Friis equation as shown in the following:

$$P_{Rx}(d) = \frac{P_{Tx}G_{Tx}G_{Rx}\lambda^2}{16\pi^2d^2}. \quad (1)$$

$P_{Tx}$ is the power at the transmitter. $G_{Tx}$ is the antenna gain at the transmitter. $G_{Rx}$ is the antenna gain at the receiver. $\lambda$ is the transmitter wavelength measured in meters.

Free space model, however, is an ideal case. To be realistic, reflection, diffraction, and scattering should be taken into account. The RSS $P_{Rx}(d)$ is modelled at any value of $d$ at a particular location as a stochastic value using log normal distance mean value as given in the following:

$$P_{Rx}(d) [\text{dB m}] = P_0(d_0) [\text{dB m}] - 10n_p\log_{10}\left(\frac{d}{d_0}\right) + X\sigma. \quad (2)$$

$P_0(d_0) [\text{dB m}]$ is the power value used as reference at a distance $d_0$ from the transmitter. $n_p$ is the path loss value that measures the rate at which the RSS reduces with distance.
Using the RSS measurement, assume that $P_{ij}$ between transmitter $i$ and receiver $j$, an estimate of the distance $d_{ij}$ between transmitter $i$ and the receiver $j$ could be given by the following:

$$d^*_{ij} = d_0 \left[ \frac{P_{ij}}{P_0(d_0)} \right]^{-1/n_p}. \quad (3)$$

Using (2) and (3), the estimated distance $d^*_{ij}$ could be measured as a function in the real distance as given by

$$d^*_{ij} = d_{ij} \left[ 10^{-X_{ij}/10n_p} \right] = d_{ij}10^{\ln(10)X_{ij}/[10n_p\ln(10)]} = d_{ij}e^{X_{ij}/(\beta n_p)}, \quad (4)$$

$$\beta = 10/\ln(10).$$

The expected value of $d^*_{ij}$ could be given by

$$E(d^*_{ij}) = \frac{1}{\sqrt{2\pi}\sigma}d_{ij}10^{-X_{ij}/10n_p} = d_{ij}10^{\ln(10)X_{ij}/[10n_p\ln(10)]} = d_{ij}e^{X_{ij}/(\beta n_p)}. \quad (5)$$

Equation (3) is a biased estimate version of the true distance. The unbiased version is given by

$$d^*_{ij} = d_0 \left[ \frac{P_{ij}}{P_0(d_0)} \right]^{-1/n_p}e^{\beta^2/2n_p^2}. \quad (6)$$

RSS profiling based localization techniques build maps of signal strengths in the coverage area. In this technique, there are anchor nodes and nonanchor nodes. For each point, a signal vector is obtained. The collection of data forms the RSS model and is unique with respect to the anchor locations and its environment. The model collects data and resides it in a central base station. Nonanchor nodes can estimate their location using the RSS measurements. Angle of arrival localization based and propagation time measurements have better accuracy compared to RSS localization based measurements in the expense of using expensive equipment. Using the RSS technique, every nonanchor node that does not know its location uses signal strength values it assembles from the anchor nodes to create its own RSS pattern. The values are transmitted to the base station that compares the signal strength vector values to the RSS model. In the proposed LMN4DISABLED, the base station sends the non-anchor node the estimated value periodically.

### 4.3. Monitoring System

LMN4DISABLED used Bluetooth and directions pictures to overly the arrows that exist in the building. The direction pictures are designed to be read using the smartphone devices. Server observes the person who diverges from the correct path of the appropriate route. In case a disabled person misses the route, standard procedures are used such as making phone calls to the appropriate personnel. Tracking functions in LMN4DISABLED are performed through smartphone by recording the disabled person’s ID, recording the time the location was visited, recording the time after departing the previous location, and sending all the information wirelessly to the server that performs the tracking operation.

In the LMN4DISABLED model, the RSSI is utilized and operated using smartphones. RSSI scheme is used to activate the monitoring through cameras scattered in different locations; different responses are recorded. The main purpose of the RSSI measurements is to trigger the cameras based on the moving objects. To find the movement of disabled persons in the field, the change in the received signal strength indicator values is used. Different values of the RSSI depend on the behaviour of the person under study.
Table 1: Volunteers profiles.

| ID | Gender | Age | Disability    |
|----|--------|-----|---------------|
| 1  | M      | 9   | Blind         |
| 2  | F      | 8   | Blind         |
| 3  | M      | 20  | Blind         |
| 4  | F      | 18  | Blind         |
| 5  | M      | 69  | Blind         |
| 6  | F      | 70  | Blind         |
| 7  | M      | 11  | Wheelchair    |
| 8  | F      | 9   | Wheelchair    |
| 9  | M      | 22  | Wheelchair    |
| 10 | F      | 20  | Wheelchair    |
| 11 | M      | 65  | Wheelchair    |
| 12 | F      | 71  | Wheelchair    |

4.4. Training System. This phase is to prepare patients to use smartphone devices. It is not easy to find and recruit appropriate participants since this population is a vulnerable population. Patients with different disabilities, ages, and genders are difficult to find. Contacting rehabilitation institutes helped finding volunteers. Priorities are given to functioning patients that have the ability to operate the smartphone and understand its feedback. If a qualified patient agreed to volunteer, his/her guardian is required to sign a consent form. Table 1 shows the profiles of twelve volunteers. Disabilities vary with different genders, ages, and types of disability.

The training system is designed to help coaches to summarize the blind disabled people about the appropriate routes to the source. Based on the platform that works in private mode, training materials are posted and listed in a sequential order. Training materials could be navigation photos and their associated sensors for the meeting points. This is performed with regards to specific destinations. Coaches are able to brief their associated disabled person.

Photos help disabled persons by giving them directions to take. Those directions could be straight forward, right or left directions or by taking the elevator. Coaches train disabled to become experienced at operating the designed system. Photos are downloaded to the smartphone. LMN4DISABLED training system is based on participants with various disabilities as shown in Table 1. Empirical studies showed that blind people have navigation difficulties due to insufficient information required for navigation. When blind people plan a trip in an indoor environment they need a clear environment excluding without interrupting sounds. People on wheelchairs have physical problems in accessing information, opening doors, and dealing with stairs.

We use LMN4DISABLED to route disabled people to select the best path. Considered routes that depend on physical distances of the links are not always adopted, since safer routes are used rather than shortest ones. When the disabled person reaches a decision point, the smartphone picks data such as the degree of light levels and sound amplitude from the sensor nodes. That information is used to help in navigation or could warn of stairs, possible power shutdown, or maintenance in progress. Disabled person could move around conditions that could change dynamically, a meeting node that is known by other nodes. Meeting nodes store data received from other sensor nodes. Once the updates are received by smartphones, they are sent to a neighbour node, which builds a route to the meeting node. Minimum cost routes are selected using Dijkstra algorithm based on a weighted criteria.

Routing mechanism is used to give directions to the right place. WSN depends on the received signal strength (RSS) to locate objects. LMN4DISABLED system finds that errors can change due to fluctuations that occur in the environment such as doors, density of people, and the ways obstacles are located in the building. Disabled people may miss navigation information or misinterpret it. For a system to be realistic, it must handle errors if they occur. Given the computed route, disorientation can be detected instantaneously. If the disabled person is on the right track, a central node should match a node on the path towards the destination. In case of a miscalculated signal, it shows that the user has deviated from the right path. Recalculation of the correct route is performed on the disabled smart phone as a function of the current position that works as a starting point for recalculation process. When the disabled person is detected by the sensor node, a camera takes order to start recording in order to give chance for an escort to view the condition of the disabled person in case help is needed.

5. Reference and LMN4DISABLED Results

5.1. Experimental Testbed. Ten trips were formed for experimentation. Trips have different starting and ending points in order to study different scenarios testing the LMN4DISABLED model. The ten trips scenarios are shown in Table 2.

In the following two subsections, two types of experiments will be discussed. The first type is conducting reference experiments. Reference experiments are conducted to motivate the need for the LMN4DISABLED system. In the reference experiments, disabled people were on their own without using the LMN4DISABLED. The second type of experiments is by using the LMN4DISABLED system. Results for the two types of experiments were compared.

The plan views for the three floors studied are shown in Figures 5, 6, and 7, respectively. The first floor has two classrooms, coffee shop, restaurant, conference room, disabled washroom, and two regular washrooms in addition to the stairs and elevator. The second floor is composed of eight classrooms, regular washrooms, stairs, and elevator. The third floor is composed of six classrooms, a coffee shop, a disabled washroom, and regular washrooms. Each room is 3 m²; we experimented with twelve individuals with different ages, genders, and disabilities as shown in Table 1. Disabilities studied in this paper are blindness and people on wheelchair. Six disabled persons from each category. Three age categories are studied in the experiments. Very young fast and immature, middle age teenagers and elder disabled people conducted the reference experiments. Older users are slower than younger users. RSSI is measured for each case.
and learns its associated allowed range. In this paper, we have adopted Li et al. [1] approach for locating the cameras in each room in addition to the sensor nodes for full coverage.

A trip was considered a successful trip if the participant was able to make it to the destination without even a single outside request or help. Otherwise, if the participant got lost somewhere in the middle or requested a help, it was considered a failed trip. Experimental outcomes were deduced based on the observations. The baseline reference experiments suggested that blind people with disabilities could not navigate without a person by their sides. We found that LMN4DISABLED was able to assist them efficiently.

5.2. Reference Experiments. Baseline reference experiments are conducted on paper maps and free walks. Reference experiments were conducted for disabled people to take different trips without using the LMN4DISABLED system. This type of experiments was conducted as reference experiments to assess the efficiency of the helping environment and to have baseline navigation ability. If the same tracks are to be taken successfully without using the LMN4DISABLED, this implies ambiguity of the proposed system. Two cases would have led to the successful routes without the need for the LMN4DISABLED system; there is no need for the LMN4DISABLED system for this participant or he/she has memorized the route and hence the results depend on his/her memory not on the navigation process.

Reference experiments were conducted where the participants got verbal instructions only and then carried a paper map to navigate their trips. Participants were then asked about the preferred preference to use. The preferences that the participants considered included (1) verbal aids only, (2) only picture, and (3) picture with verbal aids. For the rest of the experiments, disabled people carried their smart phones and made use of the LMN4DISABLED system resulting. This experimentation phase constituted a total of 120 sessions. Figure 8 shows the results obtained when applying the reference experiments. The success/fail column shows the number of successes as opposed to the number of fails. The total is always equal to ten with different values based on the disabled ID profile.

In the 120 trips performed by 12 different disabled persons, the percentage of success trips is 39.2% as opposed to 60.8% failed trips. Disabled persons 1, 2, 6, and 12 failed to complete the route involving stairs. It seemed like they did not respond well to the instructions of the prototype. Disabled person number 7 passed by the sensor without sensing it on the appropriate route which caused a deviation from the correct path.

5.3. LMN4DISABLED Experimental Results. This section describes using the LMN4DISABLED by the twelve disabled people who volunteered to try the proposed LMN4DISABLED system. Using the LMN4DISABLED has improved wandering by 10 times compared to the reference baseline experiment. Recalculation of the path is performed using Dijkstra routing algorithm. RSS localization was implemented in the LMN4DISABLED. Experiments conducted using the routing algorithm took mean run time processing times of 0.00097 seconds and maximum processing times of 0.0125 seconds when used on the two-floor building. This is accepted to be used for real time pedestrian navigation for its low response time. Experiments were repeated 3 times for verification purposes. LMN4DISABLED used ZigBee modules with a 64-bit CPU, a 2.4 GHz radio transceiver, and a built-in light sensor.

Experiments show promising results for using LMN4DISABLED as shown in Figure 9. Results show evidence with regard to the applicability of the proposed autonomous indoor navigation system. Volunteer persons used the devices and trained before the experiments. Volunteers were trained to use LMN4DISABLED.

In the 120 different experiments performed by the 12 disabled persons, the percentage of success was around 90% as opposed to 10% failed trips. This is a magnificent improvement concerning the use of the proposed LMN4DISABLED system.

For the people participants who used the verbal aids only used different routes that excluded the dim corridors and/or stairs. For the wheelchair disability, both picture and verbal aids were supported. This resulted in longer but safer trips.
### Table 3: RSSI range.

| ID | Test object | Test 1 From | Test 1 To | Test 2 From | Test 2 To | Test 3 From | Test 3 To |
|----|-------------|-------------|-----------|-------------|-----------|-------------|-----------|
| 1  | Blind       | −10         | −36       | −11         | −37       | −9          | −36       |
| 2  | Blind       | −9          | −38       | −12         | −36       | −10         | −38       |
| 3  | Blind       | −10         | −37       | −10         | −36       | −10         | −37       |
| 4  | Blind       | −10         | −36       | −9          | −37       | −10         | −36       |
| 5  | Blind       | −11         | −33       | −8          | −34       | −10         | −32       |
| 6  | Blind       | −12         | −34       | −7          | −33       | −10         | −35       |
| 7  | Wheelchair  | −15         | −42       | −15         | −40       | −16         | −41       |
| 8  | Wheelchair  | −16         | −41       | −15         | −41       | −17         | −40       |
| 9  | Wheelchair  | −17         | −38       | −15         | −39       | −18         | −39       |
| 10 | Wheelchair  | −14         | −40       | −15         | −41       | −16         | −39       |
| 11 | Wheelchair  | −18         | −36       | −15         | −37       | −17         | −37       |
| 12 | Wheelchair  | −19         | −37       | −17         | −35       | −18         | −36       |
|    | No movement | −9          | −20       | −9          | −17       | −10         | −19       |

**Figure 9:** LMN4DISABLED based experiments.

However, this was a safe route. Disabled participant followed a different longer route to avoid stairs in the suggested route and an elevator was suggested. So the disabled person had to wait some time there before catching the elevator. LMN4DISABLED guided the disabled volunteers to follow a route of seven sensor nodes. Among the seven nodes, two nodes were end nodes of the corridor and the two other nodes were points located in a room with a low light level.

As shown in Table 3, it was found that if the RSSI is lower than −20, this means that a disabled person is moving for detection. These values were used to trigger cameras used for monitoring the disabled person [17]. Older disabled persons are usually slower than younger ones as shown in Table 3. Young blind disabled persons such as users with IDs 1 and 2 are the fastest category when compared to older blind ones such as users that have IDs 3 through 6. Similarly, young wheelchair users are faster than older ones. Hence, wheelchair users with IDs 7 and 8 are the fastest category when compared to the ones that carry IDs 9 through 12.

5.4. **Comparing Reference and LMN4DISABLED Experimental Results.** By comparing results of the two types of experiments, the number of successful trips of not using the LMN4DISABLED is 47 out of 120 different trips. However, using the LMN4DISABLED led to 108 successful trips out of the total 120 trips. So the improvement was about 50.8% for the overall average of success trips in the two types of experiments. Figure 10 shows the comparison between the overall experiments without using the LMN4DISABLED and with using it.

When separating different types of disabilities, by studying the performance of blind disabled persons with and without using the LMN4DISABLED, we find that the number of failed experiments for blind users were 68% of the total number of attempts, as opposed to only 32% succeeded attempts. However when the blind persons used the LMN4DISABLED, they failed 13% of the total number of attempts as opposed to 87% of the number of attempts with an improvement of 55% for the successful attempts as shown in Figure 11.

When comparing only wheelchair disabilities with and without using the LMN4DISABLED system, results in Figure 12 show that the people on wheelchair failed by 54% when not using the LMN4DISABLED system and successes was only 46%. But when they used the LMN4DISABLED, the performance increased to achieve a failure percentage of 7% as opposed to 93%, a successful rate with an improvement of 47%.
6. Conclusions and Future Work

This paper proposes a localizing, monitoring, and navigating system for the disabled people. The proposed system is called LMN4DISABLED to help people that have one of two types of disabilities, blind people and people on wheelchairs without mental deficiencies. The proposed system is based on wireless sensor networks (WSN), where sensor nodes and cameras are scattered in the hallways and at each room in the building under study.

Experiments were conducted with twelve real participants with different age categories, different genders, and different types of disabilities. Six of participants are blind and six are on wheelchairs with different genders and ages. Twenty different trips were experimented for each participant. A total of 240 different experiments were conducted for the twelve participants. 120 experiments of which were baseline reference experiments. Baseline reference experiments were performed using only paper maps and guiding escort to help disabled people without using the LMN4DISABLED system. In the other 120 experiments the disabled people were using the LMN4DISABLED system. Comparison study was made to measure the performance difference between the two approaches. Experiments show that using the LMN4DISABLED outperforms reference experiments that are not using LMN4DISABLED by about 50.8% for different types of disabilities. When separating the performance of the blind disabled people from the performance of the people on wheelchairs, experiments show that the blind performance improved by 55% while wheelchair users improved by 47% when using the LMN4DISABLED system compared to basic reference experiments for the same people that are not using the proposed system.

This is an ongoing research and more experiments are to be conducted with more types of disabilities. Interaction between more than one type of disability is to be studied as a future work of this work. Also people on wheelchairs were assumed not to have mental deficiencies; different types of mental deficiencies for the blind people and people on wheelchair are to be studied as a future work of this work.

Conflict of Interests

The author declares that there is no conflict of interests regarding the publication of this paper.

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