Energy-Efficient Localization System for the Blind Based on an Awake/Sleep Scheduling Scheme

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Abstract. The mobility of blind individuals is restricted by their inability to perceive their surroundings. According to the World Health Organization (WHO), approximately 1 billion people suffer from blindness or poor vision that cannot be treated. Several techniques can use in the localization for the blind. Most localization system buildings use wireless sensor network (WSN) technology, but WSNs are a major source of energy consumption. Therefore, saving power in localization systems is a vital requirement. In this paper, a power-efficient portable localization system (PEPLS) based on WSN was implemented. In this system, location information was acquired via global positioning system (GPS) and transmitted via global system for mobile (GSM) and ZigBee protocols. These radio frequency modules increase power consumption. Therefore, an awake/sleep algorithm was used to decrease the power consumption of the PEPLS. The main components of the prototype PEPLS were GPS, GSM, ZigBee, and Radio Frequency Identification (RFID) units as well as an Arduino Nano Microcontroller. The proposed awake/sleep algorithm reduced the current consumption of the PEPLS to about 25 mA relative to classical operation, which consumes 156 mA. Consequently, a power savings of 84% was accomplished. Moreover, comparisons with other related works demonstrated that high power savings were achieved.

Keywords: Arduino microcontroller; Energy-efficient; GPS; GSM; localization; power savings; RFID; WSN; ZigBee

1. Introduction
The latest statistics from the World Health Organization indicate that there are at least 2.2 billion people around the world suffering from visual impairment or blindness, including more than 1 billion people who cannot be treated for these conditions [1]. Vision loss is a serious obstacle in our society due to its effects on the ability to move about freely. Consequently, the blind often need assistance when navigating open and closed places, such as streets, parks, government buildings, or even their homes [2].
Many researchers have used wireless network technologies for localization operations due to their advantages, including robustness, wireless connections, low cost [3], self-organization, high-precision monitoring, wide coverage, and fault tolerance [4]. The wireless sensor network (WSN) technologies have been used in many tracking and monitoring systems [5], an area in which they have gained more interest in recent years. WSNs can be employed in various applications in the agricultural [6], biomedical [7], industrial, sports [8], and commercial fields [9]. The past few years have witnessed an increasing interest in localization for blind people centred on WSN [10-13].

Radio transmission via WSN uses considerable power and is considered a major energy consumer [14]. The wireless modules are battery-powered, a major drawback that minimizes the lifetime of the system's battery [15]. The battery has a finite power capacity, so it often requires recharging times or perforations from time to time [16]. One way to boost the performance of such localization systems is to improve the performance of the wireless modules in the system [17]. Therefore, the major technical challenge confronting the field is to develop efficient solutions for instantaneous localization operations with reduced power consumption to assist blind people in moving about safely [18].

Localization systems based on wireless network technologies can be built using different techniques, including ZigBee, Wi-Fi, Bluetooth, GPS, RFID, and infrared LED technologies [19-21]. Most outdoor localization systems rely heavily on GPS [22], as a GPS module can provide accurate positions within centimetres in kinematic mode [23]. Instead of collecting data information from a limited number of network positions, GPS modules can capture locations continuously [24]. GPS modules are also smaller and less expensive than traditional data-gathering methods [24]. In addition, a GPS module can successfully monitor, track, and provide locations for short- or long-term operations [25]. Despite the advantages of GPS, it has some drawbacks, such as loss of signal inside buildings [26], multipath delays, atmospheric delays [27, 28], and battery drainage [29]. When compared with all other outdoor localization methods, GPS has been shown to be the most suitable tool for localization and tracking available [26]. Therefore, this study included a GPS module for outdoor localization.

Blind people usually spending most of their time indoors. Therefore, localization in indoor environments is required. Localization in indoor environments faces several radio propagation issues, including shadowing, the multipath effect, delay distortions, and fading [30]. In addition to the high localization accuracy that indoor localization systems require, these systems must have low complexity, short process times, and long battery lives [31]. Since the accuracy of GPS modules is degraded inside buildings, active research is ongoing for indoor localization. Conventional techniques for localization in indoor environments are based on various types of wireless technologies, but most of these technologies have communication ranges of between 20 m and 5 mm (RFID) [32-34]. The exception is the ZigBee protocol, which has communication ranges of up to 30 and 120 m in indoor and outdoor environments, respectively [32]. The ZigBee module is preferred in localization systems due to its small size, low cost, low power consumption [32], and reliability [35]. A ZigBee network is flexible and can consist of a large number of nodes [35]. However, the ZigBee module has some limitations, such as limited bandwidth [36] and reduced accuracy arising from interference from other wireless networks [37]. Overall, indoor localization based on the ZigBee protocol is an effective method, and this protocol was used in the power-efficient portable localization system (PEPLS) developed in this study.

Some past studies [13, 19, 38-40] have not considered approaches for solving the power consumption problem when designing localization systems or devices. These devices drain considerable power because they work continually throughout the day. However, other researchers have looked at reducing WSNs' power consumption in localization systems through a media access control scheme [41], the sampling rate [42], reducing the number of active sensor nodes [43], low-power ZigBee modules [44], a power control algorithm [45], and a clustering algorithm [46].
In this study PEPLS was built with a GPS module, a ZigBee protocol, a GSM module, a Radio Frequency Identification (RFID) unit, an Arduino Microcontroller, a PC, and a Li-ion rechargeable battery. An awake/sleep algorithm was adopted for reducing the PEPLS’s power consumption and extending the battery life. The awake/sleep algorithm turned the GPS unit off (i.e., zero power consumption) in indoor environments and on in outdoor environments. On the other hand, the ZigBee protocol was turned off in outdoor environments and on in indoor environments. The RFID and GSM units worked only when sending signals, while the Arduino unit worked during both awake and sleep modes. The contributions of this study are outlined below:

1. An energy-efficient localization prototype for blind individuals using GPS and ZigBee protocols was designed and implemented to work in outdoor and indoor environments.
2. The PEPLS’s power consumption was minimized via an awake/sleep algorithm.
3. The PEPLS was compared with prior works to validate the performance of the proposed awake/sleep algorithm.
4. The PEPLS outperformed previous models in terms of power savings.

The rest of the paper is organized as follows. Section 2 presents previous work. In Section 3, the structure of the proposed PEPLS is explained. Results, discussion and comparison with the previous works are presented in Section 4. Finally, conclusions are made in Section 5.

2. Previous work

Localization processes designed to assist blind people have been implemented via various technologies. Sammouda et al. [47] suggested an outdoor and indoor navigation system for blind individuals. The system platform consisted of an RFID unit (UHF 900MHz GEN2), a GPS module, a Wi-Fi connection, a smartphone (Samsung S5), and voice recognition. The system did well in specifying the locations where the error was less than 2 m.

Fernandez et al. [48] developed an indoor localization system incorporating GPS based on vision data and 2D laser for visually-impaired individuals. The system prototype consisted of a monocular camera (9000 pro), laser scanner (SICK LMS 200), motor controller (Roboteq AX2850), and CPU (Intel Core i3 U380). The system applied an extended Kalman filter (EKF) to perform localization. The experimental results indicated that the localization error was 80 cm.

In [49], the authors presented a navigation system for visually impaired and blind people. The system prototype was made up of four Bluetooth units (Boni Company), a smartphone (Samsung J5), and 2700 mAh batteries. The localization error for the system was between 3 and 5 m.

Árvai [50] presented an indoor navigation system for visually impaired and blind people based on a mobile phone. Localization processing was achieved with sundry software modules. The system prototype consisted of a mobile phone and localization operations, backend service, and frontend web browser service. The system was appropriate for localizing blind people's positions in emergencies.

In [51], the authors presented an indoor/outdoor localization system for blind people based on Bluetooth. The system hardware consisted of a microcontroller (AVR / Mega 16p), Bluetooth (4.0 BLE), smartphone, and GPS module. Power savings were achieved by adjusting the broadcast interval to 1s and adjusting the power transmission to 3 - 4m. The experimental results indicated that the localization error was 2 m or less and that the power savings were about 54%.

Meliones et al. [52] proposed an indoor localization system for the visually impaired. The system platform consisted of an accelerometer sensor, a smartphone (Samsung Galaxy A8), and a Bluetooth module. The blind museum tour application was employed to test localization. The experimental results indicated that the position error was equal to 1 m.
Nguyen et al. [53] developed a way-finding system to assist the blind and visually impaired. The system was divided into off-line and on-line phases and included a monocular camera, smartphone, Wi-Fi module, and robot (PCpot-914). Additionally, the system applied a loop-closure detection algorithm and an A* algorithm for localization operations and path finding. The test results indicated that the localization error was 0.75 m.

Trent et al. [54] developed a wearable smart navigation and localization system to detect visually impaired people’s positions in unfamiliar outdoor/indoor environments. The system platform was constructed with five modules: a Bluetooth low-energy (BLE) module (iBeacon transmitter), three ultrasonic sensors (HC-SR04), wireless transceivers (Wi-Fi and BLE), a computer (Raspberry Pi 2), and a feedback device (wireless headphones). The system applied a novel power-saving algorithm (NPSA) to achieve power savings. The experimental tests supported the proposed system and demonstration that it provided good localization information. Furthermore, the proposed system had power savings of 60%.

Lin et al. [55] proposed a localization system for visually impaired individuals for outdoor and indoor environments based on global optimization and the ConvNet descriptor. The system consisted of two successive parts: image reshaping, and matching optimization. The system platform included a multimodal camera, earphones, neural network (NN) module, GNSS module, ConvNet mode, and network-flow model. The testing results indicated that the localization precisions were 39.22 and 89.66% for GNSS-based localization and non-GNSS-based localization, respectively.

Xiao et al. [56] suggested an assistive navigation system for visually impaired and blind individuals. The prototype of the system consisted of wearable sensors, an RGB-D sensor (ASSUS Xtion PRO), a camera unit (C920 HD), a vibrotactile device, an inertial measurement unit, a Wi-Fi module, and a GPS module. This landmark localization method was used for processing position readouts. The preliminary pilot evaluation for the system indicated that the system faced some challenges, such as how to build and spin the accessibility database.

Fusco et al. [57] proposed a localization system based on computer vision in indoor environments to help blind and visually impaired people. The system framework was composed of a smartphone (iPhone 8), an inertial measurement unit, a Wi-Fi module, and a computer. The visual-inertial odometry (VIO) and transmitter power saving (TPS) algorithms were used to identify the user’s location and power savings, respectively. The system results indicated that the localization error was approximately 1 m and that the TPS saved 63% of the battery’s power.

Al-Khalifa et al. [58] presented a navigation aid system to guide blind individuals in indoor environments. The system was constructed from two smartphones (Samsung Galaxy S3 and Note 2), QR codes, a QR code reader, a Google Glass application, and Webserver. Dijkstra’s algorithm was used for localization operations. The experimental results showed that the localization error was a few meters.

Pandey et al. [41] presented a localization system based on distributed computing. The system proved helpful for people with special needs, such as those who were blind or had Alzheimer’s. This study aimed to modify position estimation methodologies and suggest a method for saving power. The system was composed of multi-hop networks based on IEEE802.15.4 and MAC protocols. The user’s position was computed via the multi-trilateration method. The system also employed a media access control role (MACR) to save energy. The initial results indicated that the average energy consumed was 2 J and that the average mean error was 0.4 m.

You et al. [59] proposed an energy-efficient localization system for tracking patients in medical facilities. The system platform was composed of a ZigBee network, MicaZ motes unit, accelerometer, and sampling rate adaptor. The user’s location was estimated based on a positioning algorithm, and the energy savings for the system were calculated via the sleep time method for mobile badges. The system's results indicated that the prediction accuracy was improved by as much as 56.34%, on average, when it
was compared to algorithms that did not utilize additional sensors. Also, the power consumption results shown a reduction of as much as 68.92%.

Niu et al. [44] designed an energy-efficient localization system for indoor environments based on ZigBee radio. The proposed system used a 802.15.4 ZigBee protocol, a Wi-Fi module, an Android tablet PC, and a mobile phone. The localization module consisted of two parts, namely, a fingerprint algorithm and the K-nearest neighbour (KNN) algorithm. The experimental results for the system showed that the localization accuracy was 87% and that the power savings were 68%.

Yuan et al. [45] presented an energy-efficient localization system for personnel safety based on heterogeneous WSNs. The system platform consisted of a ZigBee protocol (IEEE 1588), a computer, two microcontrollers (STM32F207 and STM32L151), a transceiver unit based on nanoLOCTRX /NA5TR1, and an accelerometer sensor (MMA8652fc). The system adopted a power control algorithm to prolong the network lifetime and improve system performance. The test results indicated that the localization error was 1.128 m and that the power savings amounted to 53%.

Zheng et al. [60] presented an energy-efficient tracking and localization system for numerous services in hospitals, homes, and retail outlets. The initial system was composed of a ZigBee (IEEE 802.15.4), multi-radio module (CC2530), computer, and power supply. A sleep mode strategy was used for power savings. The results demonstrated that the average localization error was 0.53 m and the power savings were about 20%.

Based on these previous works, it can be seen that the localization operations have been carried out using different techniques and algorithms and that some of these studies considered the energy conservation issue. Therefore, the energy consumption of the PEPLS is addressed in the current study.

3. PEPLS Architecture

The PEPLS is designed and implemented to detect the location of people who are blind or have a visual impairment in external and internal environments without draining the battery of the system. The PEPLS consists of hardware and software modules and was designed to be low cost, small in size, low weight as well as have a long battery life and great reliability. The awake/sleep method is used to reduce PEPLS’s power consumption.

3.1 Hardware Design

The PEPLS platform is composed of a GPS module (neo-M8N, China), ZigBee network (XBee S2C, USA), an Arduino Nano Microcontroller (ATmega328p, China), an RFID unit (MFRC 522, China), a GSM unit (SIM 800L, China), a PC (Lenovo T540p, China), and a rechargeable battery (3.7V/3,400mA). The GPS module provides geolocation information (longitude and latitude) to the microcontroller unit. The proposed PEPLS’s n RFID unit is used to record the building number of the building in which the blind individual is located. Also, the ZigBee network consists of five nodes, one of which is the coordinator node (CN), while the others are anchor nodes (ANs). The ANs are attached to the four corners of the 25×28 m building used in the experiments. The CN was attached to the blind person’s belt, which has been identified as the most suitable placement in previous works [61, 62]. ANs send a beacons signals, while the CN receives the received signal strength indicators (RSSIs) and transmits them to the PC to be inserted into an artificial neural network (ANN) via Matlab software for x,y positioning. The microcontroller unit sends the location information, along with the building number, to the smartphone of the caregiver via the GSM module. The PEPLS block diagram and hardware are presented in Figure 1. The device dimensions measured 5 × 6 × 5 cm (width × length × height). Moreover, the PEPLS cost $253.50.
3.2. PEPLS Power Consumption Mode

To minimize power consumption, an awake/sleep mode is utilized. The PEPLS building based on five components: (i) the GPS module, (ii) the ZigBee protocol, (iii) the GSM module, (iv) the RFID module, and (v) the microcontroller. The battery life can be estimated by gauging the current drain of all the PEPLS components against the system's battery capacity. Equation (1) below can be used to compute the total current drain \( (I_{total}) \) for the PEPLS.

\[
I_{total} = I_{GPS} + I_{GSM} + I_{RFID} + I_{ZigBee} + I_{Arduino}
\]  

Equation (2) below can be used to estimate the battery life \( (B_{life}) \) for the PEPLS.

\[
B_{life} = \frac{Battery \ Capicity \ in \ mAh}{I_{total}}
\]

In the PEPLS, the GPS and GSM modules consume 100 mA to acquire and send location information. Therefore, the GSM and GPS modules are the main power consumers [63-65]. The microcontroller,
RFID module, and ZigBee protocol consume 28, 8, and 20 mA, respectively, which means that the total PEPLS drain is 156 mA. Therefore, when the PEPLS is equipped with a 3,400 mAh capacity battery, the battery life is about 22 hours at continuous operation mode, i.e., effectively at 100% duty cycle. So, the power consumption for the PEPLS’s components should be minimized to lengthen the battery life and improve the performance. Therefore, to save energy, each component of the device works in a specified format. The GPS unit works in the external environment only, while the GSM unit is activated only to send location information to the care provider. The ZigBee unit turns on in indoor environments, whereas the RFID unit is active when the blind individual’s card passes the reader.

It is assumed that a blind individual spends 8 hours of his day sleeping and carries out his daily activities in the remaining 16 hours of the day. It is also assumed that the blind person spends 6 out of 16 hours in the external environment and spends the remaining time in an internal environment (i.e., 10 of the 16 hours). On the other hand, it can be assumed that the GSM unit needs 10 seconds every hour (i.e., 160 seconds of the 16 hours) to send information and that the RFID requires 5 seconds to read the card. The GPS unit is activated for tracking the location of the blind person in the outdoor environment and is assumed to work for 1 minute and sleep for 1 minute while in that environment (i.e., active for 3 hours and sleeps for the rest of the time) to save power. On the other hand, in the indoor environment, the ZigBee protocol must be active and is assumed to work for 1 minute and sleep for 1 minute t (i.e., active for 5 hours and sleeps for the rest of the time). The same operating theory is applied to the Arduino (i.e., active for 8 hours; 3 hours outdoors, and 5 hours indoors). According to the awake and sleep strategy outlined above, the average current drain ($I_{avg}$) can be expressed in Equation (3) below [66].

$$I_{avg} = \frac{t_{active}}{T_{total}} \times I_{active} + \frac{t_{sleep}}{T_{total}} \times I_{sleep},$$

(3)

where $T_{sleep}$ and $T_{active}$ refer to the sleep and active times for the PEPLS’s elements, respectively, and $T_{total}$ refers to the total time of operation for the PEPLS (i.e., 24 hours). Here, the duty cycle (DC) is equal to $T_{active}/T_{total}$, and $T_{sleep}=T_{total}-T_{active}$.

The DCs for the PEPLS components differ according their active and sleep periods.

1. The DC of the GPS module is equal to 0.125 (DC1=3/24).
2. The DC of the ZigBee module is equal to 0.2 (DC2=5/24).
3. The DC of the Arduino unit is equal to 0.333 (DC3=8/24).
4. The DC of the GSM module is equal to 1.85×10⁻³ (DC4=160s/86,400s).
5. The DC of the RFID module is equal to 5×10⁻² (DC5=5 s/86,400s).

Therefore, the PEPLS average current drain in Equation (3) can be computed with DC1, DC2, DC3, DC4, and DC5, see Equation (4) below.

$$I_{avg} = DC1 \times I_{GPS,active} + (1 - DC1) \times I_{GPS,sleep} + DC2 \times I_{ZigBee,active} + (1 - DC2) \times I_{ZigBee,sleep} + DC3 \times I_{Arduino,active} + (1 - DC3) \times I_{Arduino,sleep} + DC4 \times I_{RFID,active} + (1 - DC4) \times I_{RFID,sleep} + DC4 \times I_{GSM,active} + (1 - DC4) \times I_{GSM,sleep}.$$ (4)

The RFID reader module consumes only 5 mA and is activated only when the card passes it. Hence, DC5 is very small (i.e., DC5=5 seconds/24 hours×60 minutes×60 seconds=5×10⁻⁵) compared to the DCs of the other PEPLS components. Because the current drain for the RFID tag module is very tiny, it can be neglected. Therefore, Equation (4) can be written in the following form.

$$I_{avg} = DC1 \times I_{GPS,active} + (1 - DC1) \times I_{GPS,sleep} + DC2 \times I_{ZigBee,active} + (1 - DC2) \times I_{ZigBee,sleep} \times I_{Arduino,active} + (1 - DC3) \times I_{Arduino,sleep} + DC4 \times I_{GSM,active} + (1 - DC4) \times I_{GSM,sleep}.$$ (5)

To examine the device’s power savings (Ps), the device’s drain currents under normal working conditions (Equation (1)) and using the sleep/awake strategy (Equation (5)) are taken into consideration, as illustrated in Equation (6) [66].
\[
P_S(\%) = \frac{I_{\text{total}} - I_{\text{avg}}}{I_{\text{total}}}
\]

3.3. Power Consumption Algorithm and Location Measurements

The power consumption algorithm and the location measurements for the PEPLS when outdoors are based on the C/C++ language, whereas an artificial neural network (ANN) in the Matlab software is used in the indoor environment. The libraries SoftwareSerial.h, TinyGPS++.h, MFRC522.h, SPI.h, and others are used in the microcontroller programming process. The localization algorithm uses the GPS, ZigBee, and RFID modules and transmits the location information to the caregiver’s smartphone via the GSM unit. The biases of this power reduction strategy are illustrated in Figure 2. The process used in this algorithm can be represented as follows:

1. The PEPLS ON/OFF switch is controlled by the blind user. When the blind person goes to sleep, the device is turned off (assuming he/she sleeps for 8 hours). When this individual wakes up, the device is turned on and is assumed to operate for about 16 hours. In this case, it is assumed that the PEPLS can work in the outdoor environment for 6 hours while the module is active for 1 minute and sleeps for 1 minute (i.e., active for 3 hours only). Otherwise, the blind person in the indoor environment, in which it is active for 1 minute and sleeps 1 minute (i.e., active for 5 hours only) to reduce energy consumption.

2. The microcontroller activates the GPS module when the blind person is outdoors, whereas the RFID module and ZigBee protocol are in sleep mode. The RFID module and ZigBee protocol switch to their active state when the blind individual’s card is put in front of the RFID reader. The microcontroller puts the GSM unit in sleep mode at the same time.

3. In outdoor environments, the GPS unit finds the blind person's location and provides the longitude and latitude of that location. When the blind individual is indoors, the ZigBee (CN) reads the RSSI signals and sends them to the ANN to identify the \(x, y\) coordinates.

4. The location information obtained with the GPS and ZigBee units is sent to the microcontroller.

5. The microcontroller transmits a control signal to activate the GSM unit and allow it to receive location data.

6. The location information is sent to the microcontroller via a serial communication port with a baud rate of 9600 bits/sec.

7. The GSM unit transmits the blind person's location information (longitude and latitude if the blind person is outdoors or the \(x\) and \(y\) coordinates with building number if they are in the indoor environment) to the caregiver’s phone over the mobile network.

8. A control signal is sent from the microcontroller to the GSM module to make it sleep case for 50s every minute to save energy.

9. When the blind individual changes location, the microcontroller checks if the new site is tracked or not. If the site is tracked, steps 4 through 8 are repeated. In the event that the spot is not tracked, steps 3 through 8 are repeated.

10. The localization process is terminated if the blind person does not change their location.
Figure 2. Flow chart of the PEPLS and power consumption algorithm.
4. Results and Discussion

4.1. Measurement of Power Consumption

In general, most of the related works discussed in this paper focused on the localization accuracy issue but ignored the problem of energy consumption. Therefore, the power consumption issue is tackled in this paper via the proposed awake/sleep strategy for each component in the PEPLS. When the PEPLS components start working and once the awake/sleep algorithm that illustrated in Figure 2 is started, the power consumption in the PEPLS is minimized by more than three-quarters. For the ZigBee, GPS, Arduino, RFID, and GSM units, the average current draws improved to about 4, 9.3, 9.5, 0.0054, and 2 mA, respectively, using the awake/sleep strategy. Accordingly, the total average PEPLS’s current drain is 25 mA instead of the 156 mA utilized during conventional operation. Figure 3 demonstrates, for each PEPLS component, the comparison between the drain current in the traditional mode and that when applying the proposed awake/sleep algorithm. Looking at Figure 3, it is easy to see that the GSM drain current is improved considerably by the awake/sleep algorithm. The GSM current drain decreases because this unit is activated only when sending information; otherwise, it is asleep. The GPS unit loses its line-of-sight in indoor conditions [67], so this unit can work in the external environment only. Therefore, the GPS module works only in outdoor circumstances and sleeps in an indoor environment. The ZigBee module works only in indoor environments and sleeps in outdoor environments. Figure 3 presents the power savings for each component of the PEPLS. The GSM comes after the GPS module in power savings due to its low DC of 0.125. The Arduino Nano Microcontroller and ZigBee unit have DCs between 0.2 and 0.333.

![Figure 3](image-url)

**Figure 3.** Current consumptions of the PEPLS components during conventional operation and when using the awake/sleep algorithm.

Table 1 shows the current consumptions of the PEPLS components during the awake and sleep modes, along with their total operation times. The table also contains the power savings and battery lives for the traditional mode and the awake/sleep algorithm. The awake/sleep strategy can save 84% of the battery capacity, prolonging the battery life to 136 hours without a charge (i.e., more than 5 days). The battery life is plotted against battery capacity in Figure 4. From the figure, it can be noted that the current consumed by PEPLS decreases when the awake/sleep algorithm is applied. It is worth noting that the PEPLS’s power consumption and savings are fundamentally dependent on its operating schedule. In addition, the PEPLS operating life will increase as the battery capacity increases, and vice versa. Finally, the proposed algorithm has succeeded in reducing the PEPLS’s current depletion.
Table 1. The PEPLS active and sleep currents for the various components.

| Units       | Active measured current (mA) | Sleep current (mA) | Active time (Second) | Sleep time (Second) | Total operation time (Second) | DC                  |
|-------------|------------------------------|-------------------|----------------------|---------------------|-----------------------------|---------------------|
| GSM         | 60                           | 2                 | 160                  | 50                  | 86,400 (24 h)               | 1.85×10^-3          |
| GPS         | 40                           | 5                 | 10,800 (3 h)         | 75,600 (21 h)       | 86,400 (24 h)               | 0.125               |
| RFID        | 8                            | 0.005             | 5                    | 86,395              | 86,400 (24 h)               | 5×10^-5             |
| ZigBee      | 20                           | 0.001             | 18,000 (5h)          | 68,400 (19 h)       | 86,400 (24 h)               | 0.2                 |
| Arduino Nano| 28                           | 0.3               | 28,800 (8 h)         | 57,600 (16 h)       | 86,400 (24 h)               | 0.333               |

Total current in traditional operation mode \(I_{total}=156 \text{ mA}\) (calculated based on Eq. 1)

The battery life of the PEPLS in traditional operation mode \(B_{life}=21.79 \text{ hours}\) (calculated based on Eq. 2)

Average current consumption of the PEPLS based on the awake/sleep algorithm \(I_{avg}=25 \text{ mA}\) (calculated based on Eq. 5)

The battery life of the PEPLS based on the awake/sleep algorithm \(B_{life}=136 \text{ hours}\) (calculated based on Eq. 2)

Power savings \(P_s=84\%\) (calculated based on Eq. 6)

PEPLS battery current= 3,400 mAh

Figure 4. PEPLS battery lifetime versus battery capacity for the conventional and awake/sleep strategies.

4.2. Comparison of the PEPLS Results with the Results of Previous Works

The power savings for PEPLS using the GPS and ZigBee modules are compared with the savings obtained by earlier positioning systems. Generally, most of the works utilized WSN technologies to track location, but a small number of these works also dealt with the issue of energy conservation. PEPLS achieved a power savings of 84\%, which surpassed the savings achieved in previous studies [44, 45, 51, 54, 57, 59, 60], as presents in Figure 5.
Figure 5. Comparison of the power savings obtained by PEPLS with savings in related works.

5. Conclusion
In this paper, the PEPLS was designed and performed in practical manner. PEPLS was built to help blind and visually impaired people move safely and independently without becoming lost in both external and internal environments while saving battery power. The location of the blind individual was based on latitude and longitude information in outdoor environments provided by the GPS and on x, y coordinates in indoor environments provided by the XBeeS2C protocol. The PEPLS was attached to the individual at their waist, which was deemed a comfortable place for the person in prior studies. Mathematical models for energy consumption were presented and discussed, and the awake/sleep algorithm saved approximately 84% of the PEPLS's battery power. Consequently, the proposed algorithm can prolong battery life to about 136 hours (i.e., more that 5 days) without recharging. The proposed algorithm is designed to ensure that the PEPLS's components are in a sleep state when they are not needed. The GSM module drains most of the current in the traditional work mode. Therefore, the awake/sleep strategy was designed to minimize power consumption. The power consumption can be increased or decreased by altering the on/off or the awake/sleep schedule. In future work, a road planning system based on WSN technologies will be suggested to guide a blind person while walking.

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