







# A Resource-Efficient Approach of GNSS Activation for Pedestrian Monitoring

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**Abstract.** Remote monitoring provides effective solutions that bridge the gap between healthcare and where the elderly actually desire to live. In underdeveloped countries, the adoption rate of such platforms is exceptionally low due in part to the lack of resources that these systems take for granted. In other words, these systems are designed for rich countries but are also needed in resource-constrained environments. Global Navigation Satellite Systems (GNSS) are one of the main technologies for remote monitoring, though they consume relatively high amounts of energy. GNSS activation, i.e., varying the position update rate and turning the receiver on/off, is one of the main GNSS power optimization strategies, which has two existing methods: user activity-based and position-based. The former is usually too simple, suitable only for objects such as cars but not pedestrians. The latter requires installing beacons around users' premises, which is more expensive. We are looking for a method that is smarter than checking the acceleration and cheaper than using beacons for GNSS activation. This work proposes a position-based method using a Pedestrian Dead-Reckoning (PDR) system. PDR is a navigation method that uses inertial sensors (accelerometer, gyroscope, magnetometer) to estimate position.

Experimental evaluations show that this proposed GNSS activation method achieves higher power optimization (by more than 90% in and outside the safe zone) than acceleration-based ones without installing any beacon, making it better for resource-constrained environments. Also, since the proposed method depends on the user's estimated position, the

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effect of the PDR's performance is assessed by evaluating two different PDR implementations.

**Keywords:** GNSS activation · Pedestrian Dead-Reckoning · Resource-constrained environments

## 1 Introduction

The shift in a country's population distribution towards older ages started in highly developed countries, but now low and middle-income countries are also experiencing this change. By 2050, two-thirds of the world's population over 60 years will live in low- and middle-income countries [8]. This consistent increase in the number of elderly people represents a likelihood of a higher burden on healthcare, family, and social services and already resource-constrained low-income governments. Non-communicable diseases like cardiovascular diseases, diabetes, dementia, hypertension, and cancer are mainly a result of old age. [4]. Therefore, many of these older adults need support from caregivers as they cannot live independently. Several studies show that people with dementia are at least 60% likely to wander in open areas. Wandering as one of the challenges facing dementia patients can be dangerous and life-threatening. The stress of this risk weighs heavily on caregivers and families [19].

In order to save costs, health care policy should shift from institutionalization to aging in place (in the community). A recent American Association of Retired Persons (AARP) survey has confirmed that most people over 65 prefer to stay home, even if they require continuous assistance and health care [3]. Therefore, there is an increase in the demand for technologies to address the urgent service concerns of the aging population. Remote monitoring solutions using non-intrusive, non-invasive actuators, wearable sensors, and communication technologies offer efficient solutions. These technologies bridge the gaps between healthcare and where older adults prefer to live. When properly applied, such technologies will not only assure an appropriate quality of life among older people in their homes but will also support the family and caregivers in delivering adequate services to these older adults in society. [24].

Several remote localization platforms are available on the market, but their adoption rate is extremely low in low-developed countries and rural areas. One primary reason is the scarcity of resources that these systems take for granted. They presume the availability of resources and infrastructures such as cellular networks, Wi-Fi networks, the Internet, digital literacy, and access to the power grid. In other words, these systems are created for rich countries but are also vitally needed in poor and middle-income countries with resource-constrained environments [13].

Location information (positioning) is one the key variables as it allows us to remotely monitor the older person's behavior and infer some basic physical activity information relevant to their health status (step counter, walking speed, fall detection) [11]. Global Navigation Satellite Systems (GNSS) have been

the de facto standard for many remote outdoor infrastructure-free positioning applications for decades. GNSS can give dependable and accurate position data anywhere in the world, but it is not the ideal solution for all localization challenges. This is because GNSS technology has a very high energy consumption in its typical use case, which doesn't align well with the stringent constraints of battery-powered devices such as IoT devices, despite energy consumption being critical in resource-constrained environments. Additionally, remote location applications require the ability to monitor devices and data seamlessly. Therefore, a communication network is required, as the GNSS location must be communicated to the application server. From the systematic literature review conducted by authors in [13] about the state-of-the-art remote pedestrian monitoring systems for resource-constrained environments, it is evident that GNSS is still the best choice for remote long-range infrastructure-free localization. However, it is necessary to reduce the GNSS receiver energy consumption further. Therefore, research should aim to mitigate its challenges rather than eliminate its use in a resource-constrained environment.

Different GNSS power optimization strategies have been employed [2, 12]. On the one hand, techniques such as assisted GPS (AGPS) [6, 16], extended and autonomous ephemeris prediction or snapshot positioning [7, 17, 23] achieve great power reduction by using external information or delegating part of the GNSS processing, but require a communication channel (NB-IoT, GSM, LTE) to access the Internet with sufficient capacity and data rates, which are not available in resource-constrained environments.

The other type of power optimization strategy is varying the position update rate and turning on/off the receiver based on the user activity or position. By putting the receiver in sleep mode between location updates, the total energy consumption can be reduced significantly, especially in IoT use cases where a location update is only required every few hours, days, weeks, months, or even in instances where an event is triggered [9]. Two methods exist, i.e., user activity-based and position-based. Under activity-based, user activity parameters, such as acceleration or angular rate, have been used by different authors [1, 5, 10, 15] to control the position update rates and GNSS activation. This method may work on objects that are either static or changing their position, such as cars, but may not be an optimal solution to optimize power in the case of human users as subjects because, by nature, human beings exhibit frequent motions that can be easily captured and interpreted as an activity to trigger the turn-on of the GNSS and yet it is a false alarm.

The position-based method uses the user position to eliminate unnecessary GNSS activations and/or position updates. Beacons such as Infrared and Bluetooth devices are commonly installed at the user's premises to determine the user's position around their premises. For example, authors in [5] used, in addition to an accelerometer to detect static periods, Bluetooth beacons and GNSS signal strength to determine if the user is indoors and then turn off the GPS. It should be noted that installing additional infrastructure comes at a higher cost

and works effectively well in planned, structured homes, commonly in urban centers.

By the nature of the resource-constrained environment use case, we are looking for a method smarter than just checking the acceleration and cheaper than using beacons for GNSS activation. We are, therefore, proposing a position-based method using the PDR system. This method does not need to install beacons at the user premises, making it the best fit for a resource-constrained environment, especially in poor rural areas in Africa with poor housing infrastructure. The proposed method is based on the definition of a geofence around the user's home such that the GNSS is only turned on when the user's position is estimated to be outside the geofence (safe zone). Our experiments were conducted in an open environment with limited interference to simulate the rural, low-resourced home scenario. LoRaWAN technology was used for ultra-low power requirements and long-range bidirectional communication of up to 15km or more in rural areas under Line-of-sight circumstances.

Experimental evaluations show that this proposed activation method achieves higher power optimization (by more than 90% in and outside the safe zone) than acceleration-based ones without installing any beacon. Also, in order to assess how position accuracy affects the performance of the proposed method, two different PDR systems have been implemented and evaluated.

The rest of this paper is organized as follows. Section 2 discusses relevant work related to the state of the art. Section 3 describes the proposed methodology. Details about the experiments and the results are presented in Sect. 4. Finally, this work is summarized and concluded in Sect. 5.

## 2 Related Work

The position update rate is the first thing to consider when attempting to lower a GNSS receiver's power consumption because some typical use cases only require position updates when an event is triggered, and thus, there is no need for continuous tracking [2]. This allows the GPS receiver to be turned off when not in use, minimizing the technology's power consumption.

Authors in [21] introduced unique techniques for cheaply determining whether and when GPS activations are required. At the heart of their approach is a method for estimating user velocity based on a history of previously measured velocities at the exact location and the same time of day; intuitively, this velocity estimation was leveraging consistency in user behavior, and when the estimated distance traveled approached a user-specified accuracy bound, their system (known as RAPS, the rate-adaptive positioning system) activated GPS. A duty-cycled accelerometer was used to estimate user movement/velocity efficiently. This proposal is designed for urban environments, where GNSS is generally less accurate, so it suffices to turn on GPS only as often as necessary to achieve this accuracy. In addition, the building of a location-time database makes the user device more complex and with higher communication requirements.

Similarly, authors in [20] developed an accelerometer-based algorithm for correctly detecting the user's mobility state. The novel algorithm was designed,

built, and tested on Android-powered mobile devices. It was used to control the process of turning on and off smartphone-based location-sensing technologies like GPS. Like in [21], just acceleration determines when to turn on/off the GPS, and as already explained in the introduction, it's not effective, especially with pedestrians.

The authors in [10] adopted and implemented a method called the Accelerometer Assisted GPS Model as designed by authors in [20]. The method utilized the embedded 3-axis accelerometer to distinguish whether the user kept stationary. To adjust the GPS sampling rate and reduce power consumption, the authors considered two motion patterns: movement and stationary. If a pedestrian is kept stationary, the system suspends the GPS sampling for positioning. In contrast, whenever a pedestrian started to move, their system adjusted the GPS sample rate based on the correlations between the maximum searching range, the service region, and the person's current location. Their work used the user position rather than just the mobility state. The user's position was determined in relation to the point of interest, which denotes a heritage, a landmark, a scenic spot, a neighboring restaurant, or a popular store, and to obtain neighboring information, pedestrians continuously update their current geographical locations via the cellular network, regardless of whether they are moving or stationary. Even though the authors use the idea of a geofence and user position, the system's design does not fit a resource-constrained environment as it requires a network and a reference point, like a restaurant or a popular store, to determine the user position, and these resources don't exist available in these rural resource-constrained environments.

The authors in [5] combined activity and position methods. An accelerometer was utilized to detect motion and count steps. If no motion was observed over a certain period, the pedestrian may have been stationary. To conserve power, the GNSS module was turned off unless it was activated by movement. Furthermore, Bluetooth beacon devices installed at the exit and entry of the house were used to determine the indoor position. The GNSS was turned off when the user was indoors with a poor signal. Installing beacons is not ideal for most resource-constrained environments because of the costs involved and the nature of the housing infrastructure found in these environments. Plus, the GPS receivers can continue getting a good signal even when the user is indoors because of the nature and materials used to set up those houses.

Therefore, to fill this open gap, a method smarter than user acceleration but cheaper than installing beacons is needed. We have reviewed the state of the art and identified the research gap; as far as we know, no work has been done on that.

## 3 Methodology

### 3.1 Pedestrian Monitoring System Overview

The proposed GNSS activation method will be included in a pedestrian monitoring system. This section describes the main blocks of that system as shown in

Fig. 1. Our proposed system has four blocks, i.e., power, sensor, control, and communication modules. The sensor module contains the positioning sensor (GNSS) and the inertial sensors (accelerometer and gyroscope). The communication module has a RAK11720 LoRaWAN, and the control module has an ESP32 microcontroller. A lithium-ion battery was used to power all the modules.

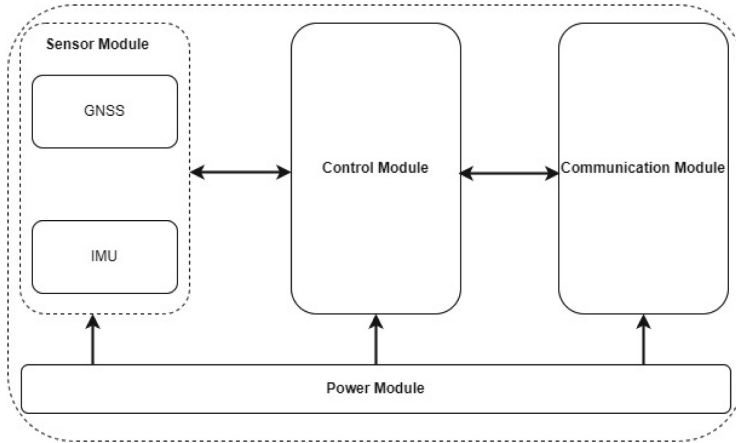


Fig. 1. Proposed system block diagram.

### 3.2 The Proposed Position-Based GNSS Activation Method

Figure 2 is the Workflow diagram of the proposed system. To easily monitor elderly persons around their homes, a geofence equivalent to a safe area is defined first. We assumed the user's home was at the center of the geofence (safe zone). When the user turns on the system, the inertial sensors and GNSS receiver are turned on and then off immediately after a reference point (reading of the coordinates for the initial user position) is acquired and stored permanently. The user is then requested to define the radius of the geofence (safe zone), and it's also stored permanently. We used the geofence idea to define the safe area around the user's home where less or no monitoring is needed. In our environment, we assumed the user could still get a GNSS signal even if indoors. A safe zone of a radius of 20 m around the user's home was assumed in this experiment.

In real-time, the user position is continuously monitored and estimated using a PDR system and checked to see if it is in the safe zone, and when the user position is estimated to be outside the safe zone radius, the GNSS receiver is turned on, and the reading is taken and compared with the initial position.

If the position is found to be inside the safe zone, the GNSS is turned off and marked as a false alarm. The user position on the PDR system is updated. Still, if the position is confirmed to be outside the safe zone, a message is sent through the LoRaWAN communication system to the caretaker for a quick response.

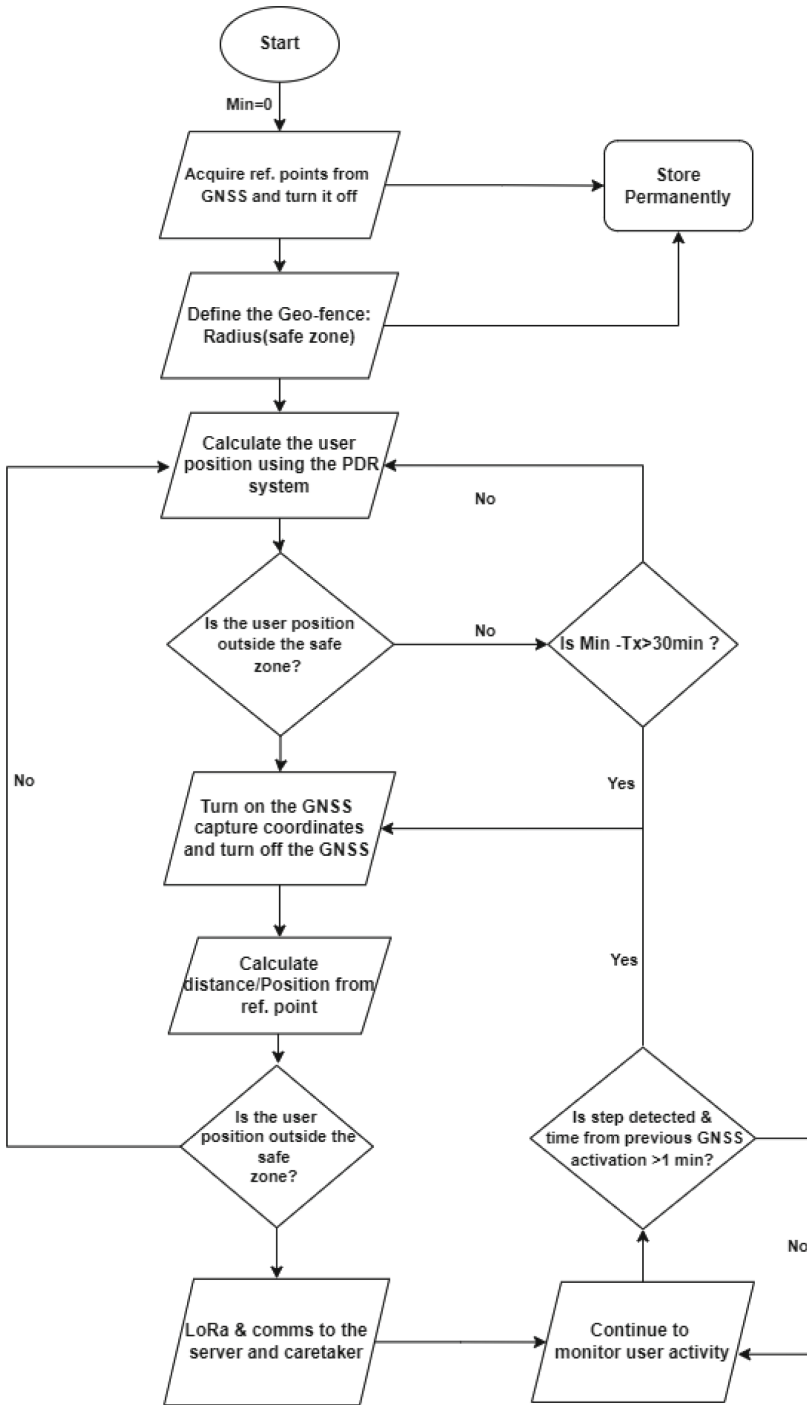


Fig. 2. Workflow diagram of the proposed system.

When the user is outside the safe zone and continues walking, the sampling rate for the GNSS receiver is set to 1 min, and the GNSS is turned off whenever the user is stationed to minimize energy consumption.

In that case, the user returns to the geofence as estimated by the PDR system; the GNSS is turned off until the user position is estimated to be outside the geofence or after 30 min. We used the 30-minute position update rate inside the safe zone for our work to prevent the GNSS receiver from going to the cold start. Power outages cause GNSS receivers to lose their position fix and all downloaded time and GNSS orbit data (ephemeris data), forcing them to undergo a complete cold start (up to 12.5 min) as soon as power is returned. Many GNSS receivers include a backup battery and a built-in EEPROM to boast the Time To First Fix (TTFF) [18]. So, by saving this data in backup RAM, GNSS receivers with a backup battery can recover faster (less than 30 s). This only works when the position update period is not longer than two hours, which roughly corresponds to the validity of the ephemeris data [2]. Therefore, the proposed method assumes that the GNSS receiver includes a backup battery and memory.

### 3.3 PDR System

The proposed GNSS activation and position update rate depend on the user position estimated by the PDR system. So, the accuracy with which the PDR system determines the position is key to the effectiveness of the proposed method. To assess this, two different PDR systems were implemented and evaluated. PDR systems are generally divided into four different blocks: step detection, step length estimation, heading estimation, and, finally, position integration. The two implementations differ only in the first two blocks, both in the algorithms and the input signal they use. The first one uses the pitch [22] of the inertial sensor, while the second one uses the magnitude of the sensor's acceleration. We chose those two implementations because the different step detectors are suitable for different mounting points. The performance of position estimation methods is determined by the accuracy of step detection and the pedestrian's step length (SL) estimation. The final blocks of this proposed algorithm, i.e., heading estimation and position integration, were implemented as explained in [22].

**Pitch-Based PDR Implementation.** Figure 3 represents the block diagram of the selected pitch-based PDR implementation, as explained in [22]. This proposed pitch-based approach detects steps using the pitch angle and estimates step length based on the pitch amplitude. We used a Kalman filter for accelerometer and gyroscope fusion [14] to calculate the roll and pitch of the inertial sensor. The step detection algorithm analyses the pitch and detects the step when local maximum and minimum pitch values occur in a certain interval. To avoid false step detection, the maximum and minimum values should be above or below a certain threshold, respectively.

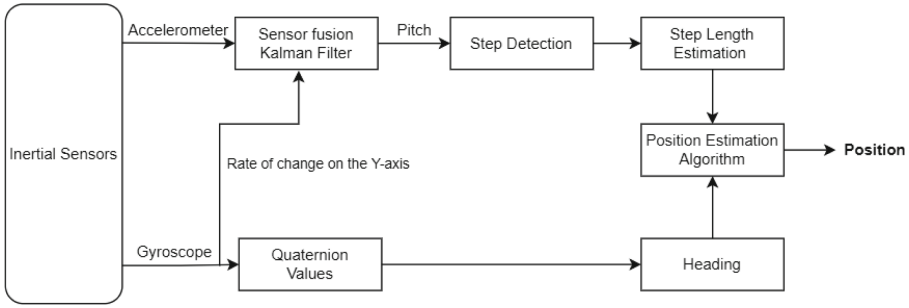


Fig. 3. Pitch-based PDR implementation.

Then, the step length is estimated using a first-order linear regression model on the pitch amplitude ( $\Delta\theta$ ):

$$SL = a \times \Delta\theta + b \tag{1}$$

where  $\Delta\theta$  is the difference between highest positive peak ( $\theta_{\max}$ ) and lowest negative peak ( $\theta_{\min}$ ), in degrees. The constants  $b$  and  $a$  are the personalized parameters fitting each regression line.

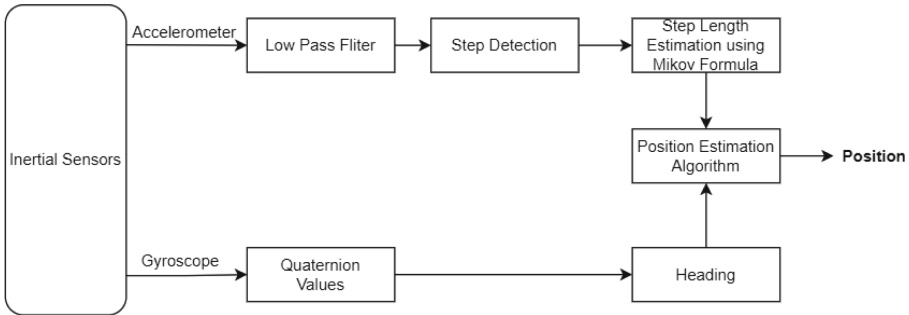


Fig. 4. Acceleration-based PDR implementation.

**Acceleration-Based sPDR Implementation.** Figure 4 shows the second selected PDR implementation, which utilizes the acceleration values of the accelerometer sensor’s X, Y, and Z axes to count steps in real time. Then, the magnitude value is computed as the square root of the three accelerometer values, as shown in the equation below [22].

$$mag = \sqrt{x^2 + y^2 + z^2} \tag{2}$$

The magnitude value represents the vibration on the three-axis coordinates. The accelerometer sensors are inaccurate and suffer from various problems. Therefore, the derived data must be filtered to exclude the noise and the outliers' values. The derived data were filtered in this work using a low pass filter. Smoothing the data helps improve the system's accuracy, as the accelerometer sensor is very sensitive to the movements.

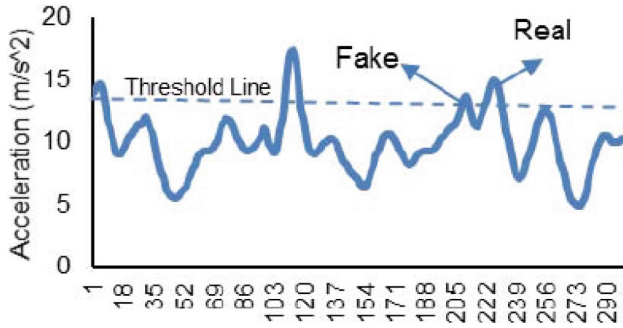


Fig. 5. Fake vs Real peaks.

Most current step detection algorithms rely on counting the peaks, as each peak represents a user's stride. A significant problem is the fake peaks. A fake peak is a peak caused by an irrelevant movement. Figure 5 shows the real and the fake peaks. Counting the fake peak as a real peak increases the error in the distance estimation. In this research, a peak detection method for the detection of the steps, as explained in [25], was used, and the following Mikov formula was used to compute step length.

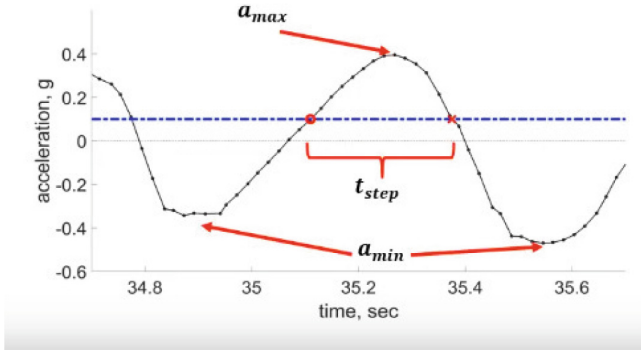
$$L_{Mikov} = K_5 \cdot t_{step} \cdot \sqrt[4]{a_{max} - a_{min}} \tag{3}$$

where  $a_{min}$  and  $a_{max}$  are the minimum and maximum acceleration values as shown in Fig. 6, respectively, measured on the Z-axis in a single stride,  $t_{step}$  is step duration, and  $K_1$  is a constant for unit conversion (i.e., feet or meters traveled).

## 4 Experimental Evaluation

### 4.1 Experiments Description

In our experiments, we try to show that using just acceleration or steps to activate the GNSS is not good enough, especially with human subjects. So, this work proposes a smarter and more efficient algorithm for GNSS activation, using the user position around their home, as demonstrated in the experiments we conducted. In our experiments, we assumed that the user's home was at the center of our defined geofence.



**Fig. 6.** Acceleration chart.

We conducted different experiments to assess the effectiveness of our proposed method, including experiments to evaluate the GNSS activation and the effect of position performance for the two PDR implementations. Two mounting positions were used to collect data, i.e., on the chest and in the swinging hands while walking.

(a). GNSS Activation evaluation

Here, our GNSS activation method was compared with a basic method we implemented inspired by work from the literature [20]. This simple system activates the GNSS whenever a step is detected. In this test, two evaluation metrics were used, i.e., when the GPS is activated/deactivated and power consumption.

(i). Experiment one:

Walking continuously inside, outside, and back inside the safe zone: This experiment aims to show that in our method, GPS is activated only outside the safe zone, hence getting some power saving against the other method.

(ii). Experiment two:

Walking continuously inside the safe zone for at least more than 30 min (to simplify the experiments, we used 5 min), and the objective of this experiment is to show that our method periodically activates the GPS if the user stays inside the safe zone, i.e., every after 30 min to refresh the position error accumulated by the PDR, and the satellite data to avoid a cold start.

(iii). Experiment three:

Walking and stopping inside, outside, and back inside the safe zone: This experiment aims to show that whenever the user stops outside the geofence, the GPS gets off until a motion/step is detected again.

(b). Effect of position performance

In this experiment, data were collected using two mounting positions: on the chest and in the hands.

- (iv). Experiment four: Effect of length estimation and step detection.  
In this experiment, the volunteer walked in a straight line inside, outside, and back inside with each PDR implementation for two different mounting points. This experiment aims to assess how the performance of step detection, step length estimation, and, therefore, position estimation affects the GNSS activation method performance.
- (v). Experiment five: Effect of heading estimation  
In this experiment, the volunteer walked in a zigzag motion from the center of the geofence to the outside and back. This was intended to assess the effect of the heading estimation on the final user position and, therefore, on the GNSS activation. The acceleration-based PDR implementation mounted on the chest was used for this experiment.

## 4.2 Data Collection

An embedded system on a custom-designed Printed Circuit Board (PCB) was designed and assembled for the tests as shown in Fig. 7a. A custom design allowed for miniaturization of the system as it was intended to be carried or worn by the user. The PCB integrated the **ESP32 microcontroller** (ESP32 integrates a power amplifier, RF balun, an antenna switch, filter, low-noise amplifier, and power management module. The chip's sleep current is less  $5 \mu\text{A}$ , making it suitable for battery-powered wearable electronic devices), **MPU6050 IMU** (a low-cost, low-power 6-axis motion tracking chip that integrates a 3-axis accelerometer, 3-axis gyroscope and a Digital Motion Processor (DMP) into a tiny  $4 \text{ mm} \times 4 \text{ mm}$  package), **NEO6 GPS** module (A u-blox module that was used to get the positioning information. This module only supports GPS, and its compact architecture, memory, and power options make NEO-6 modules excellent for battery-powered mobile devices with very strict cost and space constraints. It also comes with a small battery for hot-start and built-in EEPROM to save configuration settings when turned off), and **RAK3172 LoRaWAN** module in a tiny 40 mm diameter board and configured to operate at 868 MHz. It's an Ultra-low-power consumption module with an active power consumption of less than  $6 \mu\text{A}/\text{MHz}$  and  $2.7 \mu\text{A}$  in sleep mode. The PCB also supports lithium-ion battery charging from the onboard USB connector for programming the microcontroller.

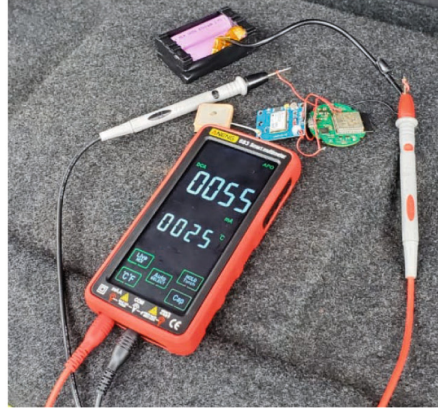
We conducted our experiments in an open ground (Makerere University rugby ground) to simulate rural resource-constrained environments with scattered, inadequate semi-structured buildings and less interference with GNSS signals.

During data collection, the Volunteer mounted the embedded system in the two mentioned mounting points and walked in the reference paths. This was done to test if the device could track the number of steps made, distance traveled, and user position accurately, regardless of the device's mounting position. Our test set a radius of 20 m as the required geofence radius (safe zone), outside which the GNSS module would be turned on and coordinates retrieved. Note that the safe

zone radius is not fixed but is determined based on the user's safe surroundings. Only the MPU6050 IMU sensor was used for tracking inside the geofence radius.



(a) PCB.



(b) Current reading from multi-meter.

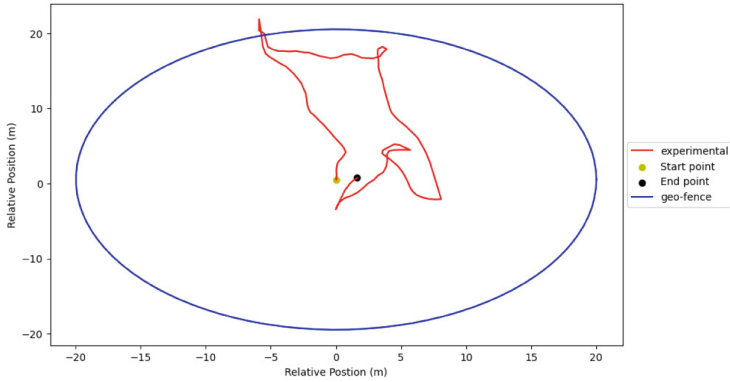
**Fig. 7.** Designed embedded system.

The system printed out logs over a serial monitoring application; an Arduino serial monitor was used, after which the data was saved as a log of the experiment for analysis purposes. The logged data included current, relative location, number of steps made, heading of the person, and distance moved by the person. If the person has moved out of the specified geofence radius, the logs then include the status of the GPS and the current coordinates from it.

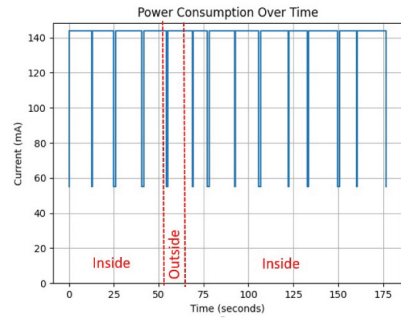
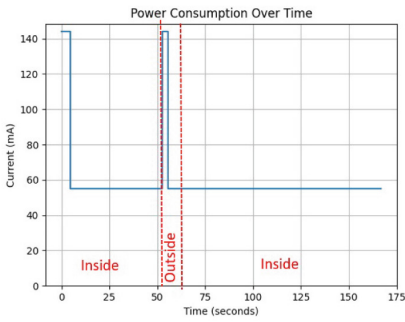
To assess the power consumption, current readings were taken using a multi-meter in series with the system and the battery. Measurements showed that with the GPS off, an average of 55mA was drawn from the battery and 144mA when the GPS was turned on, as shown in Fig. 7b.

### 4.3 Results and Discussion

To evaluate the energy performance of our proposed GNSS activation method, five experiments were conducted. Three were conducted to evaluate the GNSS activation, and two to assess the effect of position performance. The data was collected as explained in 4.2. The following represents the results and analysis of the conducted experiments.



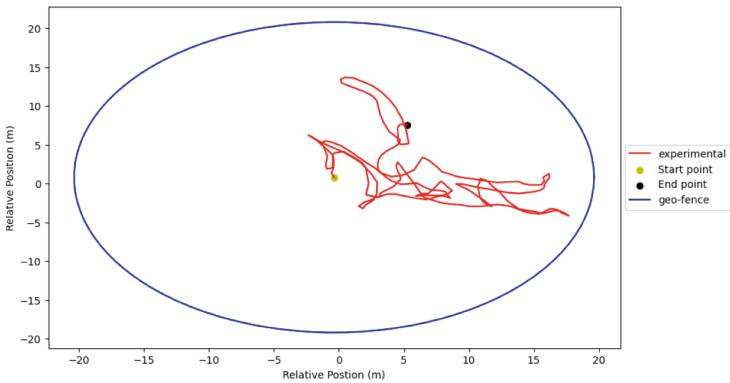
**Fig. 8.** Shows the path taken by the volunteer during the experiment one.



(a) Power consumption of the proposed method.

(b) Power consumption of the activity-based method.

**Fig. 9.** GPS activation outside the geofence



**Fig. 10.** Shows the user movements and position for the 14 min walk in experiment two.

(i). Experiment one:

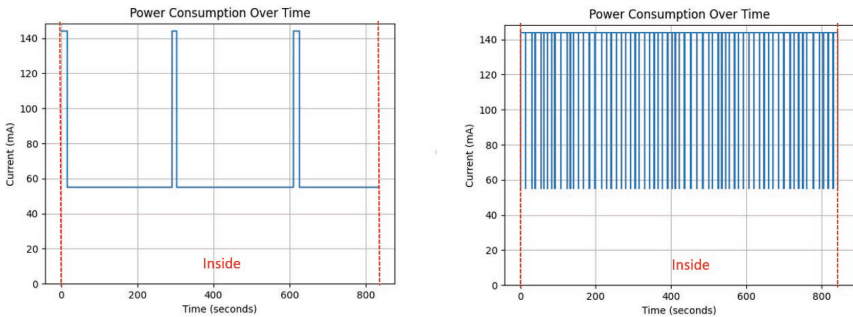
Figure 9 represents the analysis of data collected in experiment one for a user walking continuously inside, outside, and back inside the safe zone, as illustrated in Fig. 8. Figure 9a shows that the GPS was activated only once when the user briefly stepped out of the safe zone (section marked outside on the graph) and remained turned off for the entire period the user was walking in the safe zone (section marked inside). This demonstrates that our system turns on the GPS only when the user walks out of the geofence, maximizing the device’s battery life. Contrary, Fig. 9b shows GPS continues to be turned on while the user moves, regardless of his/her position for the activity-based method.

(ii). Experiment two:

Figure 11 represents the analysis of data collected in experiment two, where the user walked continuously inside the safe zone, as illustrated in Fig. 10. Figure 11a shows that the GPS was activated only two times each after approximately 5 min for 14-minute continuous walks within the safe zone. As already explained in 4.1, we used 5 min instead of 30 min to simplify the experiment. This periodic GPS activation is done to avoid a cold start of the receiver, as already explained in 3.2. Because of this periodic activation, GPS took an average of less than 14s to get a position fix in most cases, hence less power consumption. Contrary, Fig. 11b shows that the GPS continues to be turned on while the user moves, even though the user is inside the safe zone, hence unnecessary power consumption.

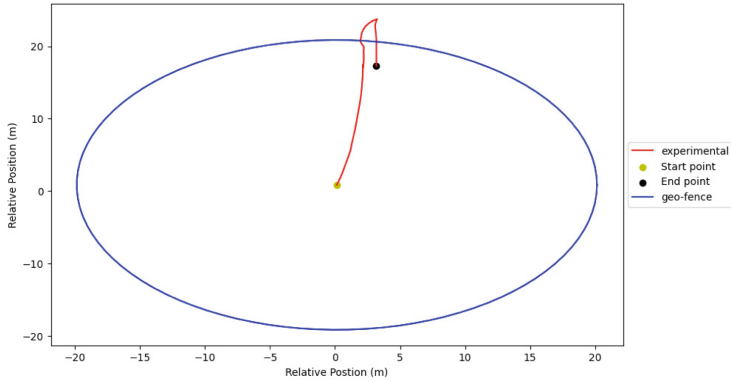
(iii). Experiment three:

Figure 13 represents the analysis of data collected in experiment three, where the user walked and stopped inside, outside, and back inside the safe zone, as represented in Fig. 12. This experiment demonstrates that in

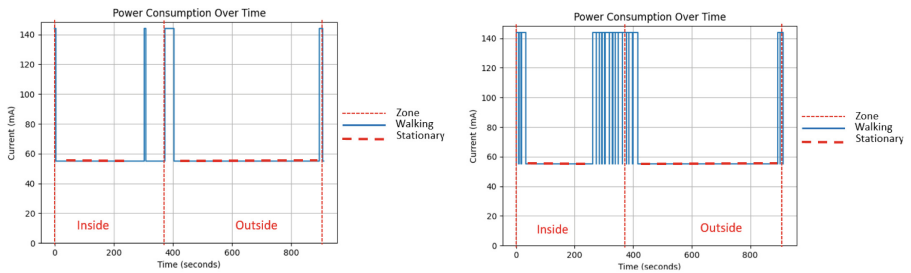


(a) Our method periodically activates the GPS if the user stays inside the safe zone to avoid a cold start (b) GPS continues to be turned on while the user moves in the safe zone for the activity-based method.

**Fig. 11.** Periodic GPS activation within the geofence



**Fig. 12.** Shows the path taken by the volunteer during the experiment two.



(a) Shows that GPS is turned off whenever the user is stationary even though outside the safe zone, as illustrated in 13.

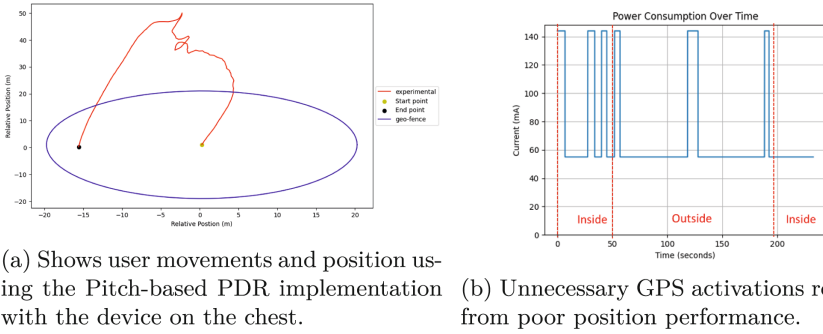
(b) Shows that GPS is turned on and off for all times apart from when the user is stationary

**Fig. 13.** GPS activation outside the geofence

our method, the GPS is turned off whenever the user is stationary until a step is detected again when the user is outside the geofence, as shown in Fig. 13a. Power consumption for both systems is comparable when the user is stationary regardless of user position but very high for the activity-based system when the user moves even though inside the geofence, as illustrated in Fig. 13b.

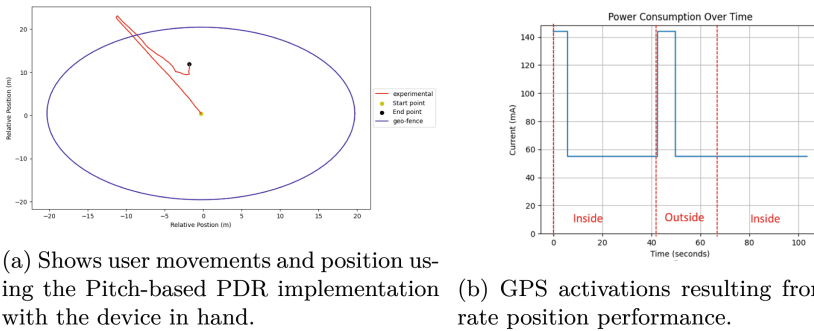
(iv). Experiment four:

Figure 14 shows the user positions estimated using pitch-based PDR implementation mounted on the chest. In this experiment, the user walked straight inside, outside, and back inside, as illustrated in Fig. 14a. This was done to demonstrate the effect of step detection and length estimation performance on the GPS activation method. Figure 14b shows several unnecessary GPS activations inside the safe zone resulting from wrong PDR positioning because of the mounting point used. Contrary, the same



**Fig. 14.** User position and power consumption using Pitch-based PDR implementation with the device on the chest

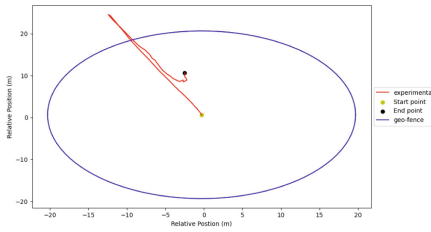
PDR implementation has a better positioning and even better power optimization when a different mounting point is used, as demonstrated in Fig. 15. Similarly, better positioning and power optimization are achieved as illustrated in Fig. 16 where acceleration-based PDR implementation is mounted on the chest, but contrary for the same implementation when the device is carried in the hands as shown in 17 From analysis it is clear the pitch-based PDR implementation works best with the body’s swinging parts, but the acceleration-based method does not.



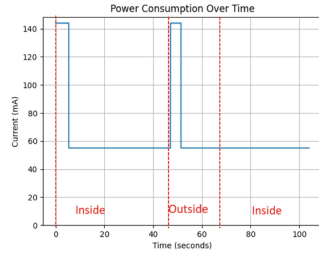
**Fig. 15.** User position and power consumption using Pitch-based PDR implementation with the device in hand

(v). Experiment five:

Figure 18 shows the effect of heading estimation on the user’s final position estimation and power consumption. The acceleration-based PDR implementation mounted on the chest was used in this experiment, and the user walked in a zigzag from the center of the geofence to the outside and

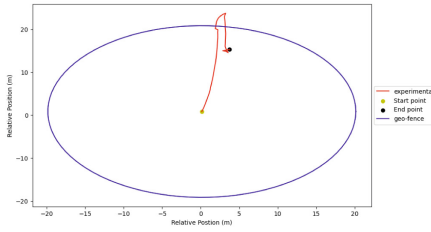


(a) Shows user movements and position using the Acceleration-based PDR implementation with the device on the chest.

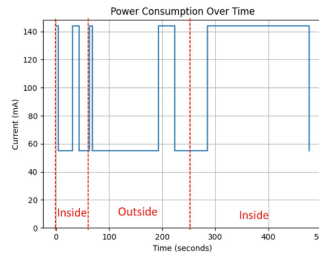


(b) GPS activations and power consumption resulting from accurate position performance.

**Fig. 16.** Shows the user position using Acceleration-based PDR implementation with the device on the chest

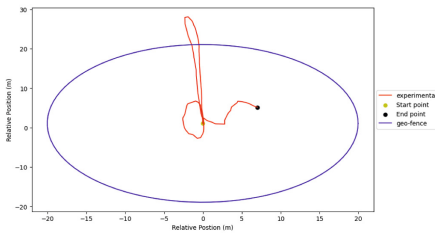


(a) Shows user movements and position using the acceleration-based PDR implementation with the device in hand.

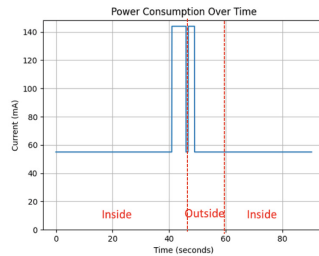


(b) Unnecessary GPS activations resulting from poor position performance.

**Fig. 17.** Shows the user position using Acceleration-based step detection method for different mounting points



(a) Shows the effect of heading estimation on the final user position.



(b) shows the GPS was activated when the user was still in the safe zone.

**Fig. 18.** Shows the effect of heading estimation on the user's final position estimation and power consumption

back to the center, but because of the effect of heading estimation, the user position is off by more than 3 m. Figure 18b shows the GPS was activated when the user was still in the safe zone, hence unnecessary power consumption.

## 5 Conclusion

This paper presents a position-based GNSS activation method using a PDR system as the main input source. The aim is to design an activation method better than usual activity-based methods for pedestrians (commonly acceleration-based) and cheaper than common position-based methods requiring beacons. From all experiments and results, our proposed method shows better power optimization (by more than 50%) compared to the activity-based method, as demonstrated using the current draw.

The proposed GNSS activation and position update rate method depends on the user position estimated by the PDR system. So, the accuracy with which the PDR system determines the position is key to the effectiveness of our proposed method. To assess this, two different PDR systems were implemented and evaluated, i.e., acceleration-based and pitch-based PDR implementation. Two mounting positions were used to collect data, i.e., on the chest and in the hands. The experimental evaluation confirmed that the PDR's estimated position directly affects the proposed GNSS activation method, reducing its performance.

The approach defined in this study can be applied to children and pet monitoring in open-space scenarios such as homes, sports fields, and recreation parks.

In future work, we plan to improve the power measurement by adding a fuel gauge to get the exact power consumption reading. We also plan to explore improved GNSS activation methods by using machine learning to distinguish motion mode by users at home vs. moving to a different place. This way, we could avoid the error accumulation limitation of the PDR strategy.

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