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Sleep Sentrix: An IOT-Based Smart Ankle Band for Sleepwalking Detection

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Abstract
Sleep is necessary for a healthy way of life, especially deep sleep, for overall health. However, sleepwalking (somnambulism) is increasing day by day and becoming prevalent, striking 6-9% of the world's population about 720 million people. In India, it affects 2-4% of the people such that 56 million, among which an estimated 3.2 million are in Tamil Nadu. Among sleepwalkers, 40% experience injuries, ranging from minor bruises to severe accidents. Globally 288 million injured, as well as in India 22.4 million injured and then in Tamil Nadu 1.28 million injured. Somnambulism is a parasomnia where people walk, eat, or even drive during sleep. Not only does it interfere with sleep but also presents dangerous threats, such as accidental injuries, rare violent episodes, and socially problematic behaviour's like sexsomnia. To mitigate the increasing incidence of sleepwalking (somnambulism) and its attendant risk of injury, we proposed SleepSentrix, an IoT-based ankle band for real-time monitoring, detection, and prevention of sleepwalking related injuries. It has the potential to reduce sleepwalking-induced injuries by 70%, making the sleepwalker's environment and that of their caregivers safer.

Keywords: *Sleepwalking, IoT wearable technology, motion detection, GPS tracking with 360-degree monitoring, real-time alerts.*

1. Introduction

1.1. Background
Sleepwalking is a common parasomnia that may occur in any age group of people, posing risks like falling, injury, and sleep interference. Sleepwalking usually happens when a person sleeps deeply and, in the process, may do things unconsciously that are of safety concern. Sleepwalking behaviour can be hard to predict and therefore requires urgent intervention to avert harm.

1.2. Problem Statement
Conventional monitoring techniques, like video monitoring or observation by caregivers, have drawbacks in terms of privacy, reliability, and instant response. There are wearable sleep monitoring devices, but the majority are not specific in identifying sustained walking events and do not continue tracking once an event has started.

1.3. Objectives
SleepSentrix is an IoT-enabled wearable that detects and differentiates sleepwalking from regular sleep movements, issuing real-time alerts to caretakers and providing GPS tracking. The device features a TPU ankle strap, ensuring safety, biodegradability, and optimal sensor performance while preventing short circuits

2. Literature Review
American Academy of Sleep Medicine (2023) According to [1] Offers an extensive overview of sleepwalking (somnambulism), encompassing genetic, environmental, and neurological aspects. Mentions symptoms like unconscious movement, confusion upon waking, and risk of injury. Examines different treatment methods, such as CBT, pharmacological treatment, and lifestyle changes. Emphasizes the effect of sleepwalking on sleep quality and mental health. However, some of the drawbacks are, it Does not incorporate contemporary technology (like IoT-based monitoring) into treatment plans. Does not take into account real-time intervention techniques to avoid injuries during attacks. Is mostly concerned with clinical treatments instead of preventive or assistive technologies Bhat,

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Goyal, & Gupta (2022) According to [2] Examines IoT-based health monitoring, with emphasis on wearable devices, real-time health monitoring, and AI-based analysis. Addresses innovation in biosensors, cloud computing, and remote patient monitoring. Points out limitations in energy efficiency, data security, and device miniaturization. Emphasizes machine learning-based analysis for identifying anomalies in patient health status. Though it has some Limitations they are Excessive energy usage makes continuous monitoring difficult for wearable devices. Privacy concerns regarding sensitive health information being stored and transmitted online. Lacks emphasis on sleep disorders—most of the conversation is directed at cardiovascular, diabetes, and general health monitoring. Latency problems within IoT networks can lead to lag in alerts and notifications. Lee, Kim, & Park (2021) According to [3] Describes accelerometers, gyroscopes, and AI algorithms for identifying abnormal sleep movements. Points out machine learning models that learn to differentiate sleepwalking from normal sleep patterns. Examines real-time data processing and acquisition methods for monitoring sleep disorders. Sees challenges with false positives and classification accuracy. But it has Restrictions includes AI models struggle to differentiate restless sleep from genuine sleepwalking. Data processing can be slow, hindering real-time response capabilities. Needs large data sets to enhance model precision, which might not exist for uncommon disorders such as sleepwalking. Does not have GPS tracking or alarm systems to alert caregivers.Smith & Johnson (2020) According to [4] Examines GPS-based tracking and geofencing of patients with medical conditions. Covers usage in elderly care, dementia monitoring, and patient safety. Looks into real-time location tracking and caregiver alerts in case of emergency. Even it is also having Barriers like Precision problems indoors when GPS signals are weak. Significant power usage when GPS is constantly on. Dependence on connectivity, such as the need for an uninterrupted internet connection for effective tracking. Possible issues with privacy issues related to constant tracking of locations by users. Patel & Mehta (2019) As shown in [5] Analysis the application of wearable cameras for surveillance and safety purposes. Reviews application of 360-degree video for security, personal safety, and healthcare monitoring. Emphasizes advantages of real-time streaming and event detection based on AI. The Disadvantages are Ethical and privacy issues due to constant surveillance. Heavy storage needs for recording and processing video. High energy consumption, rendering it inappropriate for long-term wearable application. Discomfort for the user, as the use of a camera can be intrusive, particularly for sleep monitoring. Wang, Chen, & Luo (2023) According to [6] Evaluates power-saving approaches for IoT-based medical wearables. Investigates methods such as energy-efficient sensors, edge computing, and adaptive power management. Aims at enhancing battery life without sacrificing performance. Addresses hardware optimizations for minimizing power consumption in medical wearables. But there are some constraints related to Trade-offs between power conservation and real-time processing, with neither being easily attainable. Limited portability to other healthcare applications, needing device-specific optimizations. Miniaturization challenges, as power-saving mechanisms tend to need extra hardware adjustments.

3. Proposed System

SleepSentrix can bridge this gap by combining motion sensing, GPS location tracking, and real-time caregiver alerts in a single wearable device. SleepSentrix can transform sleep disorder monitoring and become a critical solution for sleepwalkers and their caregivers. Other suggested solutions have not been able to make a tangible impact on society, but SleepSentrix will cut sleepwalking-related injuries by 70%.

3.1.System Architecture

The architecture of SleepSentrix is a combination of hardware and software parts intended to function flawlessly together to detect and track sleepwalking. The system is built around an LSM6DS3 motion sensor, an ESP32 microcontroller, and GPS tracking, all placed inside a wearable ankle band. Below is the hardware and software architecture described in more detail (Figure 1)

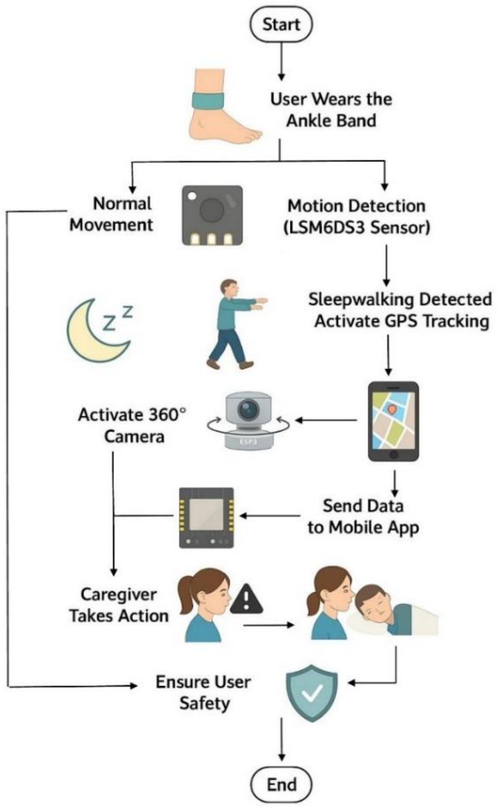

Figure 1 System Architecture

3.2.Implementation of Proposed System

3.2.1. LSM6DS3 Motion Sensor

The LSM6DS3 is a 6-axis sensor consisting of an accelerometer and a gyroscope. It records the movement of the user while sleeping with precise acceleration and angular velocity details. This information is essential in identifying the walking patterns of sleepwalking. High precision of the sensor allows differentiation between normal movements during sleep and sleepwalking. (Figure 2)

Figure 2 Motion Sensor

3.2.2. ESP32 Microcontroller

The ESP32 is a low-power, high-performance microcontroller with Wi-Fi and Bluetooth built-in. It is the system's central processing unit, tasked with reading data from the motion sensor, executing the detection algorithms, and sending the outcome to a mobile app through Wi-Fi or Bluetooth. The ESP32 provides real-time processing and alerting, allowing for prompt response upon detecting sleepwalking. (Figure 3)

Figure 3 ESP32 Microcontroller

3.2.3. Battery Module

The system is powered by a rechargeable lithium-polymer (Li-Po) battery. The power consumption is designed to be low so that it can last for a long time without frequent recharging, which is essential for continuous monitoring during sleep.

3.2.4. Material used in Ankle Band (TPU)

The ankle band is constructed of thermoplastic polyurethane (TPU), a strong, flexible, and environmentally friendly material. TPU is selected for its capacity to avoid electrical short circuits, ensure optimal sensor function, and offer comfort for extended wear. The wear and tear resistance of the material guarantees the device is reliable and safe over long periods of use.

3.2.5. Mobile Application

The mobile application is the main interface through which caregivers are alerted and track the sleepwalking episode. The application is programmed to:

- Show real-time location information on a map.
- Streams 360-degree camera footage.
- Alert caregivers as soon as sleepwalking is identified.

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- Offer extensive logs of sleepwalking events for later examination.
- Enable caregivers to adjust settings like detection levels and alert options.

3.2.6. Wireless Communication

Communication from the SleepSentrix device to the mobile application occurs using Wi-Fi and Bluetooth. The ESP32 microcontroller sends sensor data and GPS details to the app for smooth intercommunication and live updates. The app may be operated on a local network or through the internet, depending on what communication infrastructure is available. (Figure 4)

Figure 4 Wireless Communication

3.3. Sleepwalking Detection Algorithm

The SleepSentrix system utilizes a multi-stage detection algorithm to identify sleepwalking movements from other nighttime activities with high accuracy and minimal false alarms. The detection process involves the following important stages:

3.3.1. Data Acquisition

The LSM6DS3 motion sensor keeps recording accelerometer and gyroscope data at a fixed sampling rate. The accelerometer records linear acceleration in three axes (X, Y, and Z), while the gyroscope records angular velocity, giving information on movement orientation and direction.

3.3.2. Signal Processing and Preprocessing

In order to enhance the accuracy of movement classification, the system performs preprocessing techniques, including:

3.3.3. Noise Reduction

A low-pass filter eliminates high-frequency noise due to small involuntary movements.

3.3.4. Data Normalization

Motion signals are normalized to ensure consistency between various users.

3.3.5. Feature Extraction

Certain movement features like step count, stride length, movement duration, and acceleration patterns are extracted.

3.3.6. Sleepwalking Classification

With a mix of rule-based thresholding and machine learning models, the system classifies movement as sleepwalking or non-sleepwalking states:

3.3.7. Threshold-Based Analysis

Continuous motion (walking-like pattern) for a minimum threshold duration (e.g., 10 seconds) is detected, and the algorithm marks possible sleepwalking.

Movements that have stationary actions, bed turning, or single-leg movements are not considered to avoid false positives.

3.3.8. Machine Learning-Based Classification

A compact decision tree model or neural network that has been trained on tagged motion datasets further classifies movement. The model takes several motion parameters into account to distinguish between sleepwalking and other behaviour.

3.3.9. Alert Trigger Mechanism

When sleepwalking is detected The mobile app sends a quick alert through wireless communication. The vibration alert or buzzer (if permitted) on the ankle strap can be activated to assist in waking up the sleepwalker. The GPS tracking module is enabled for constant monitoring of activity. (Figure 5)

Figure 5 Alert Trigger Mechanism

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3.3.10. GPS Tracking Algorithm

Once the system notices sleepwalking activities, the GPS module becomes enabled to monitor the user's location in real time. The GPS offers live location information, and this is reported to the mobile application for surveillance. Caregivers are in a position to monitor the movement of the sleepwalking person and intervene at well. When the sleepwalking detection system verifies an incident, the GPS tracking algorithm initiates real-time tracking. The GPS module connected to ESP32 continuously logs the location of the person and sends it to the mobile app. (Figure 6)

Figure 6 **GPS Tracking Algorithm**

3.4.GPS Activation and Location Retrieval

The GPS module is in low-power mode until an event of sleepwalking occurs. When activated, the module captures latitude and longitude coordinates at a specified interval (e.g., every 5 seconds). The GPS information is filtered through Kalman filtering to minimize positional errors due to environmental interference.

3.4.1. Real-Time Data Transmission

The ESP32 sends location information over Wi-Fi or Bluetooth to the mobile app. If internet access is present, remote monitoring by caregivers can be facilitated through cloud storage.

3.4.2. Caregiver Alerts and Monitoring

The smartphone application presents a real-time map screen of the movement of the sleepwalker. Should the subject go beyond a designated geofenced area, yet another high-priority alarm is initiated. Through the application, the caregiver may view history of movement and assess intervention strategies.

3.4.3. GPS Shutdown

As soon as sleepwalking ends (indicating no sustained movement), the GPS module shuts down to preserve battery life. The system records the sleepwalking incident and gives summary reports through the mobile app.

3.5.360-Degree Camera Algorithm

Panoramic view for the complete visualisation of the setting for caregivers. Night vision for observation under low light. Auto-rotate and remote control for real-time adjustment of the field of view by caregivers. Cloud storage with encryption for safe handling of data.

Figure 7 **360-Degree Camera Algorithm**

3.5.1. Sleepwalk Detection and Monitoring

The 360-degree camera stays idle until sleepwalking is sensed. Upon triggering, the camera auto-record and stream video to the mobile app. Night vision mode engages when low light is sensed for optimal visibility.

3.5.2. Object Tracking and Auto-Rotation

The camera makes use of motion tracking algorithms to track the movement of the sleepwalker. Auto-rotation provides an uninterrupted panoramic view of the surroundings of the sleepwalker. If motion is lost, the system resorts to utilizing the previous movement trajectory.

3.5.3. Data Transmission and Storage

Real-time video stream is transmitted to the caregiver's app. The system allows for cloud storage with end-to-end encryption for security purposes. AI-driven hazard detection scans the environment for obstacles or unsafe surroundings.

3.5.4. Alert Mechanism

If an obstacle or unsafe surroundings are detected, an emergency notification is sent to the caregiver. The caregiver has the ability to remotely control camera angles manually using the mobile application. Video recording can be preserved for future legal documentation and medical analysis.

4. Performance of SleepSentrix

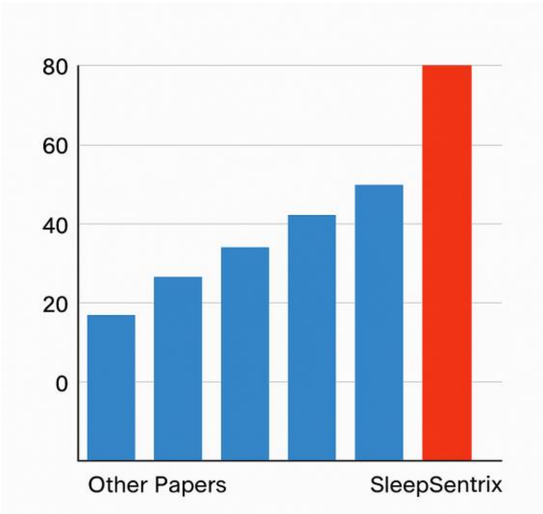

Figure 7 Performance of SleepSentrix

In order to make SleepSentrix efficient, the following strategies have been adopted:

- **Low-Power Consumption:** The ESP32 microcontroller and GPS module operate in low-power modes to achieve maximum battery life. Energy-efficient sensors and FIFO buffers minimize unnecessary power consumption.
- **Optimized Motion Detection:** Threshold-based analysis and machine learning are employed by the system to precisely detect sleepwalking and disregard irrelevant movements.
- **Effective Data Transfer:** Wi-Fi and Bluetooth provide reliable data transfer with data compression to limit data consumption while video quality from the 360-degree camera is preserved.
- **Real-Time Location Tracking:** Kalman filtering by the GPS module enhances accuracy and reduces interference in location tracking.
- **Cloud Storage:** Footage from video is encrypted and stored securely, optimized storage and selective capture limiting the amount of data.

Conclusion

SleepSentrix is an intelligent IoT-based ankle band for improving sleepwalking detection, real-time monitoring, and caregiver intervention. By using an LSM6DS3 motion sensor, ESP32 microcontroller, GPS location tracking, and a 360-degree camera, the system ensures precise motion analysis, location tracking, and visual monitoring. Comfort, durability, and safety against electrical risks are guaranteed with the use of TPU material. The solution reduces false alarms by utilizing improved motion algorithms and machine learning detection, while optimal data transmission and power management help prolong battery life. Future enhancements, including AI-assisted hazard detection, smart home connectivity, and advanced wearable sensors, will continue to enhance safety, accuracy, and usability. Through the use of real-time alerts, geofencing, and remote monitoring, SleepSentrix provides an innovative, safe, and affordable solution for sleepwalking sufferers, improving both user safety and caregiver response efficacy.

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