A System for Sleepwalking Accident Prevention Utilizing the Remote Sensor of Wearable Device

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ABSTRACT

Sleepwalking is a type of sleep disorder which originates during deep sleep and results in a walking state with people performing a series of complex behaviors or actions while sleeping. In some cases, sleepwalking patients can injure themselves from their actions, such as by driving a car or by climbing out of a window. In addition, waking up the sleepwalkers can be difficult. The sudden waking up can cause them to be confused, and they may even attack the person who wakes them. Therefore, detecting sleepwalking incidents in an early state can help the caretaker or family members stop the patients before they harm themselves from any strange, inappropriate, or violent behaviors. In this research, we present a prototype sleepwalking detection algorithm and a notification system using smart device which work coordinating with a wearable device. There are two main groups of users: patients and caretakers. A User Activity Sensor (UAS) in the wearable device is utilized for detecting User Activity Data (UAD), unusual activities, of a sleepwalking patient. This data is collected using software provided by the Remote Sensor software development kit (SDK). The system returns the patient UAD states consisting of standing, walking, and running. The smart device accepts the UAD states from the wearable device, performs sleepwalking detection algorithms, then informs caretakers when the sleepwalking state has already evoked. The system has been implemented, built, tested, and deployed. Experimental measurements of physical user activities have been performed to validate our proposed sleepwalking detection algorithms. The system correctly detects the sleepwalking states and notifies the caretaker.

Keywords: Detection notification, sleepwalking detection, smart device, wearable device, user activity sensor, user activity data

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1. INTRODUCTION

Sleepwalking is a sleep disorder in the category of parasomnias that involves abnormal movement or behavior that occurs while a person is sleeping. Usually, the sleepwalking initiates during partial arousal from slow-wave sleep [1]. Sleepwalking is commonly found in children. However, it is also found in adults.

Worldwide, millions of people are affected by sleep walking incidents on a regular basis. About 25 percent of sleepwalkers may harm themselves during their sleep [2]. Sleepwalking involves basic actions such as walking or a series of other complex activities such as cooking, cleaning, driving, or violent gestures. Sleepwalking most often occurs during the slow-wave cycle of sleep, either in the first third of a night's sleep or during other long sleep periods.

Sleepwalking is often observed with children where older children may speak and make body movements. Although, this behavior can disappear with age, for some it still occurs in adulthood [3] [4] [5] [6] [7].

Sleepwalkers, especially adults, can injure themselves or others from their impaired perception or actions during sleepwalking. For example, consider a case in 1978 [3], where a man drove a car 23 kilometers to his wife's parents house and all the way into the house. This man was found not guilty of murder. He could not be held responsible for his actions in that situation.

Therefore, it would benefit the sleepwalker or the family members to have a tool that can help them detect sleepwalking incidents and to stop or prevent any potential adverse health outcomes from the sleepwalking.

This paper proposes a prototype sleepwalking detection application on a smartphone which works coordinating with a smartwatch. The caretaker monitors the sleepwalking patient via the application on their smartphone. The phone application processes data from the user activity sensor provided the smartwatch worn by sleepwalking patient. The detection system sends an alarm to the caretaker when it detects any walking and running activity while monitoring activities via Bluetooth and a wireless connection. In this work, an architecture of the system and sleepwalking detection algorithms are investigated and designed, built, and experiments to test it are performed.

In the next section, related work and background information about the Remote Sensor software development kit (SDK) are reviewed and described. Analysis and design are presented in Section 3. Implementation and verification of the proposed algorithms are described in Sections 4 and 5 respectively. Results and discussions, and conclusions are presented in Sections 6 and 7 consecutively.

2. RELATED WORK AND BACKGROUND

2.1 Monitoring System

Bhattacharya [8] proposed a multi-sensor room system for monitoring patients. The room was called “a smart room” and was designed for sending an alarm to a follower when a patient has already moved out of the room. This system can detect only a single patient living in the smart room. In case of people sharing the room, the system cannot detect the patient’s activities precisely. This is similar to the work of Singhal [9], who presented a prototype for monitoring and protecting sleepwalking patients using motion sensors and accelerometers. The motion sensors are installed in the room and at openings such as doors or windows. Whenever an event occurs, an alarm sounds, a call is made to the registered mobile, and a message will be sent to the caretaker. The accelerometer in the proposed system has a small size and uses low power to operate.

In 2007, P. K. Atrey at el. [4] proposed a multimedia-based monitoring system. They utilized motion and video sensors to detect the unusual activities of a sleepwalker. The system records a video of the movements and activities of the sleepwalker. A confusion matrix has been complied for both motion detection and face recognition. However, motion detection equipment installation can be more suitable for the home security than sleepwalking detection.

Dobkin [10] presented as part of mobile health, mHealth. Dobkin explains the benefit of using wearable, wireless motion sensor data to monitor the mobility-related activities. This helps to improve healthcare services via mobile communication devices. One of the examples presented in his research is commercial sensor devices as fitness, exercise, and wellness gadgets (placed in a pocket or on a wristband) in which episodic and cyclical body movements are collected and then calculated as activity or steps counted or converted into calorie counts. Examples of these devices are Fitbit [11], BodyMedia, and FuelBand. In addition, he reviewed the research devices such as wireless gait laboratory systems. Those integrate two to seven accelerometers and gyroscopes worn on the wrists, ankles, and chest to detect posture imbalance, and may help preventing or detecting falls. Therefore, wireless remote sensing offers good potential for patient care and clinical trials.

Zhu et al. [12] proposed a framework to detect motion anomalies using wearable sensor devices. The framework detects different types of anomaly events in daily activity, such as falling to the ground, working overtime or sleepwalking. The framework can update and adapt according to living patterns of a patient.

Wongsirichot et al. [13] proposed a mobile application for detecting and monitoring sleepwalking using mobile devices. This application was designed to detect movement using the accelerometer of the mobile device which is placed in a patient’s trouser pocket for identifying unusual activities. If the patient stands up, the application determines the patient’s behaviour and sends an alerting message to the mobile device of the caretaker. However, the limitation of this work is the inconvenient usage of the application as a patient needs to put the mobile phone into his or her pocket while they are sleeping. In addition, the accelerometer of the mobile device detects only the patient’s orientation using gravity. It cannot determine complex behavior including walking and running.

2.2 Remote Sensor SDK

In this work, Samsung Gear Fit smartwatches were utilized as patients’ devices. The Remote Sensor SDK of Samsung API [14] was also exploited for the smartphones and the smartwatch connection. The SDK supports Samsung wearable devices such as the Gear Series and Gear Fit. The SDK allows a user application to access the user activity sensor, pedometer sensor (step counter), and wearing state data from the wearable device. The proposed monitoring application is a background process running on a patient host device. It analyzes states of the remote sensor values stored on a server which will be transmitted from the wearable devices of children.

2.2.1 The user activity data

When a user of the wearable device starts running or walking, the application on the host device of the caretaker can be notified about the relevant events. The application will receive event notification on its first occurrence after being delayed about four to five seconds, corresponding to four to eight walking steps, for noise prevention.

2.2.2 The pedometer data

The application on the host device can get a user step count. The time interval for accessing the step count is fixed at every five minutes. However, there is a way to receive a batch of the step counts within less than five minutes by overriding default implementation parameters of the SDK.

2.2.3 The wearing state data

The application on the host device determines whether the user is wearing the wearable device or not. The application enters the wearing state when the user has already worn the device for at least one second.

The accessing architecture of the Remote Sensor SDK is depicted in Figure 1. The architecture is composed of layers which allow our application to access the Remote Sensor. The Remote Sensor Protocol is primarily responsible for accessing wearable device sensor data. The Remote Sensor Service is for handling channel mixing and data cache for the application running on the host device which depends on the type of the wearable device. Together the enhanced Samsung Accessory Protocol (eSAP) and the Wearable Communication Protocol provide the Bluetooth communication. The Wearable Sensor Service handles the Bluetooth connectivity and channel management.

3. ANALYSIS AND DESIGN

Our test case is an in-home scenario. There are usually rooms for children and their parents seperated in the house. The proposed system prototype is a client-server architectural design which can support multiple patients. The system consists of two modules: monitor and detection (patient section), and notification (caretaker). These are shown in Figure 2.

The patients wear a wearable device connecting with a smart device which itself is connected to the Internet. The User Activities Sensor (UAS) in the wearable device periodically determines User Activity Data (UAD) and sends it to a server via the patient smart device. Core algorithms of sleepwalker detection are also run on the patient's smart device.

For the caretaker, a smartphone is the main device which performs as an alarm device to notify the caretaker when the patient is in a sleepwalking state. The application on the smartphone has a receiver function that will be triggered by signals sent from the smartwatch.

The sequence diagram of interactions among relevant modules for the proposed architecture is shown in Figure 3. The caretaker starts the application, and then the host application (at the monitor and detection module) checks patient state from the server periodically. When the host application detects that the patient's state involves sleepwalking using the proposed detection algorithms, the caretaker will be notified. The patient application requests the Bluetooth connection for establishing communication between the wearable device and smartphone. After the patient application is successfully connected, the UAS of the wearable device automatically sends the UAD to the patient smartphone. Then, the UAD determines the sleepwalking state of the patient, which is sent in a status message for updating the database on the server.

Table 1: *The states of UAD and their descriptions*

Value	Activity	Sleepwalking State
0	No movement	False
1	Walk	True
2	Run	True

3.1 Monitor and Detection Module

This module performs the communication between a wearable device and a smart device (such as a smartwatch and a smartphone), connecting and then exchanging data via the Bluetooth connection, as shown in Figure 2. The smartphone connects to the database using a HTTP connection. The UAS of the smartwatch is utilized to acquire UAD. Its current positions are monitored by the UAS.

3.1.1 Monitor Section

In the case of position change of the smartwatch, the UAD will be sent to the smartphone. The UAD state will be determined and sent to update the patient state in the database. In sleepwalking, the system will trigger a notification to a caretaker as shown in Figure 4. The caretaker's application provides an GUI and requires interactions for stopping alarms, and for starting the detection once again.

Possible states of the UAD sent by the patient's smartphone to the server are described in Table 1. The value zero means no patient movement or the patient has not moved in the last four seconds, so the patient is considered as not being in the sleepwalking state. The value one means that the patient has moved slowly for four consecutive seconds (or is walking) and the value two means the patient has moved quickly for four consecutive seconds (or is running).

3.1.2 Detection Section

The proposed detection algorithm for sleepwalking using the Remote Sensor is shown in Figure 5. First, a session variable for storing the zero values of UAD is initialized. The received UAD periodically detects the sleepwalking state. When the state is not sleepwalking, the algorithm always repeats this step. Meanwhile, when the UAD indicates sleepwalking, the session variable will be checked. If the session variable is more than four, the state will be updated on the server. In case when the session variable is less than four, the current value of the session variable will be increased by one. Then, a timer is started for 29 seconds. UAD detection is periodically performed every four seconds. There are three seconds of delay for the smartphone to acknowledge the detected UAD.

Since the timer has started, the algorithm repeats these steps to get the UAD from the wearable de-

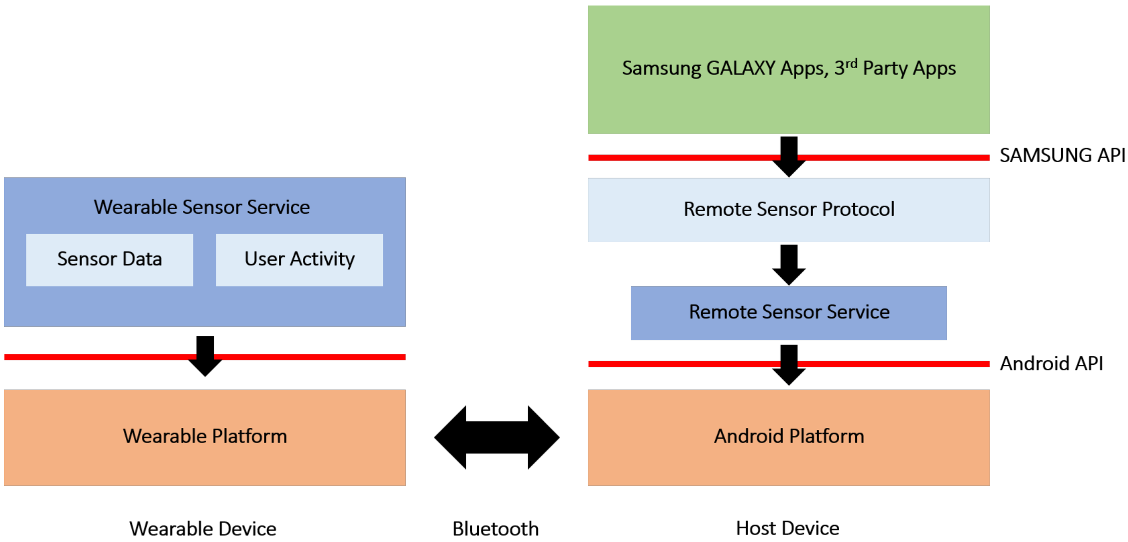


Fig.1: *Accessing architecture of the Remote Sensor, a wearable device, and a host device using the Bluetooth connection [14]*

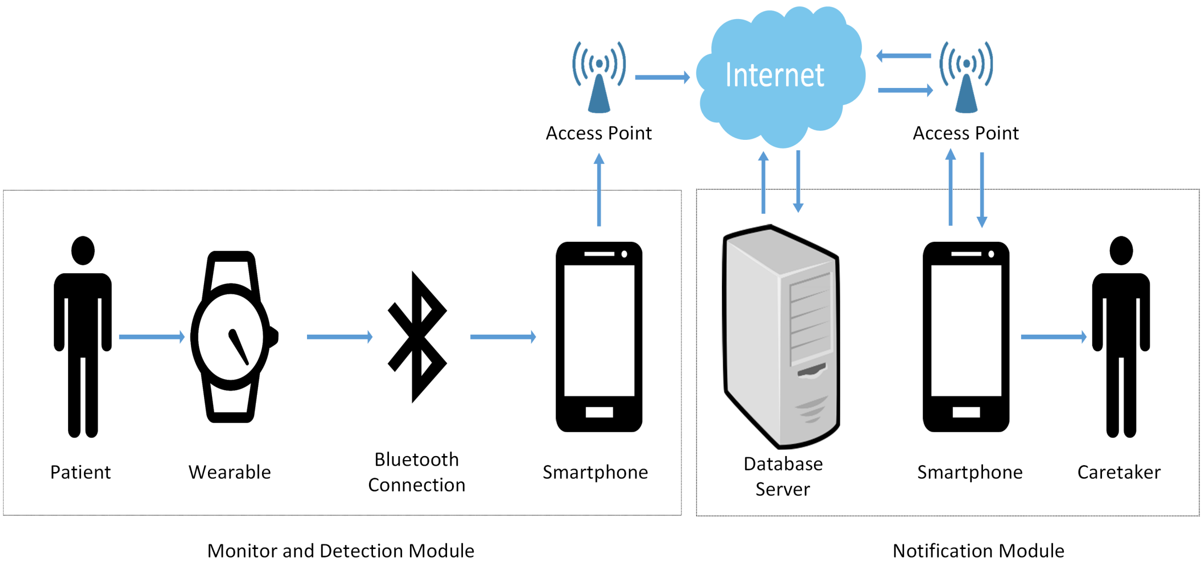


Fig.2: *The proposed architecture for sleepwalking detection and alarm system*

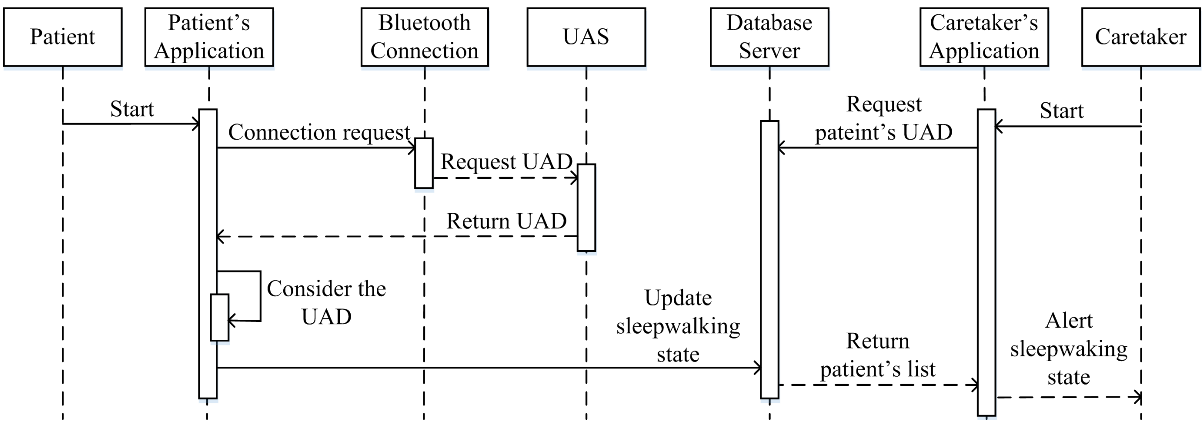


Fig.3: *Sequence diagram of overview interactions among relevant modules*

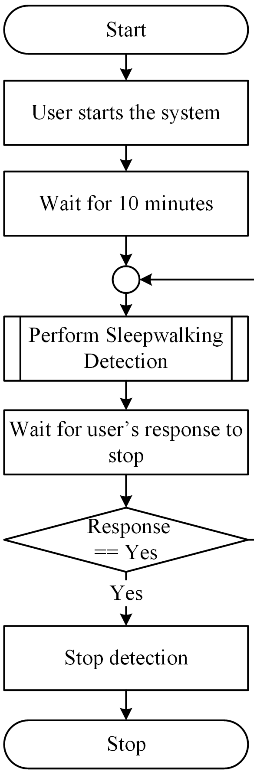


Fig.4: *The proposed algorithm for sleepwalking state detection*

vice and processes them. When the wearable device is sending the sleepwalking state while the timer is counting down for 29 seconds, the system updates the state on the server. Otherwise, the timer will be stopped and the system will start another session timer for 30 seconds, then it will start over at the UAD fetching step from the wearable device again. When the session timer has finished counting down, the session will be cleared and repeated again starting at the first step.

3.2 Notification Module

The proposed sleepwalking algorithm to notify the caretaker is shown in Figure 6. This module consists of a host application on smartphone connected to the database using an Internet connection. The UAD is checked every five seconds. The application in this side triggers to start and stop the system. Three main functions will be performed including sleepwalking detection, Bluetooth connection monitoring, and patient device availability monitoring.

Three timer tasks for performing different tasks at the beginning of the alert algorithms are initialized. The first is a one-second timer, to allow an on-focusing task to be performed every one second. This timer task checks patient states at the database. Updated state will be fetched and examined. If the state is sleepwalking, the task will notify a caretaker and waits for an action from the caretaker consequentially.

The second timer is a 30-second timer task as

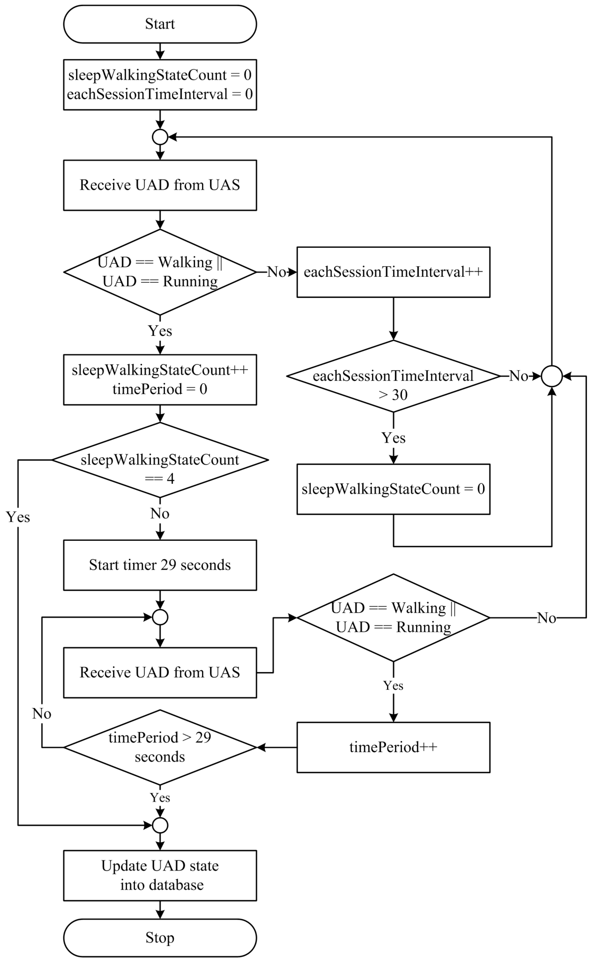


Fig.5: *Our proposed sleepwalking detection algorithm using the Remote Sensor*

shown in Figure 7. This timer task is for checking availability of the Bluetooth connection between the wearable device and the smartphone of the patient. The connection state will be fetched every 30 seconds. In the case that a lost connection has been found, the task will alert the caretaker. In addition, whenever the Bluetooth connection is lost during a sleepwalk of the patient, for example if the patient walks far enough away from his smartphone inducing an out of range problem for the connection, then the caretaker will also be notified as shown in Figure 8.

The last timer is a five-minute timer task as shown in Figure 9. This timer task is responsible for checking connection availability between the patient host device and the server. If connection loss has been detected, the task will also notify the caretaker.

3.3 States Management

The proposed system allows two roles of users to register: patients and caretakers. The patient application is initialized in the *Pre-Sleeping* state as shown in Figure 10. The user (in the caretaker side) has to trigger the application for going into the *On-Sleeping*

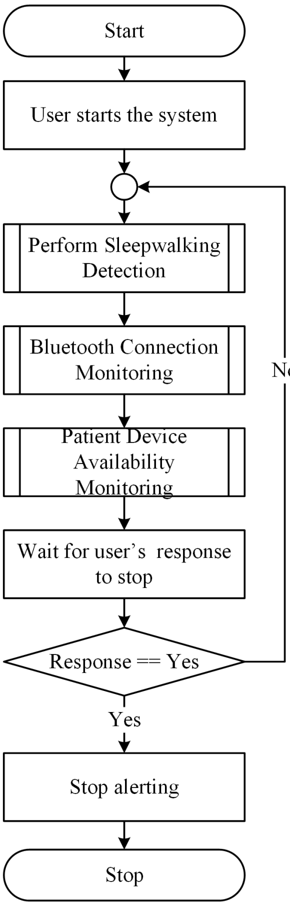


Fig.6: *Algorithm for sleepwalking state detection on the caretaker side*

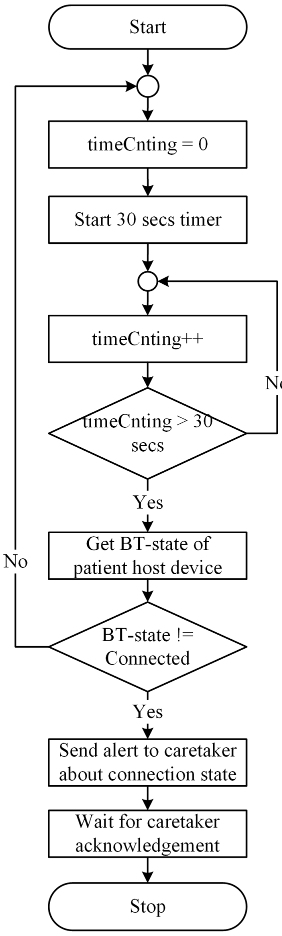


Fig.7: *Timer for the Bluetooth connection monitoring between a patient host device and a wearable device*

state, then a relevant graphical user interface (GUI) will be displayed to report patient states. The GUI will be updated to show current patient states for notifying the user. In case that the patient has already been woken up, the user has to trigger the application for acknowledging this state. Then the application returns to the *Pre-Sleeping* state once again.

The caretaker application is initialized as shown in Figure 11. The application presents the patient list, and their states for the *On-Monitoring*. In case that a sleepwalk or any relevant connection states have been detected, the *On-Alerting* will be invoked so that the application sends an alert message and warning sound to the caretaker. The alerting will be terminated when the caretaker has acknowledged it, then the *Pre-Monitoring* state will be invoked once again.

3.4 Graphical User Interface

Relevant GUIs for both host devices have been designed. The proposed system requires identifications of user roles. The application will notify users about the Internet connection availability and battery level of the device after sign-in has succeeded for both user roles. Figure 12 (a) shows the main page of the prototype GUI of a patient host device. Sleepwalking detection will be executed and monitored when the user has touched the button for triggering the *On-Sleeping* state. The text *"Touch me when you go to sleep"* is presented. In case the system has detected a sleepwalk and the patient has been woken up already, the application returns to the *Pre-Sleeping* state again. The relevant GUI is also shown in Figure 12 (b), with the text *"Touch me when you bring me to bed"*.

The main page of the caretaker application shows a button which can be touched when the user wants to start the system as shown in Figure 13 (a). During the *On-Motoring* state, if the system finds that the patient is sleepwalking, the caretaker application will notify with both a message and an alert sound as shown in Figure 13 (b). The caretaker can access a list of monitored patients and their states as shown in Figure 14 (a). They can also add new patients to the list. Moreover, a monitor log for each patient is supported, as shown in Figure 14 (b).

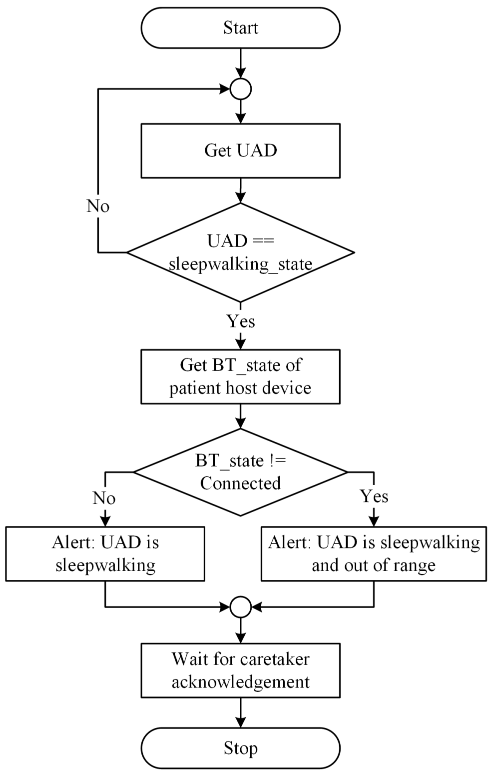


Fig.8: *Algorithm for connection monitoring of a patient host device and a wearable device*

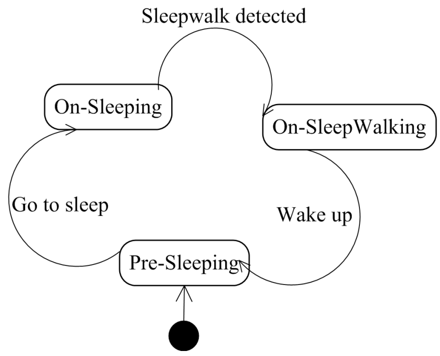


Fig.10: *States of a patent*

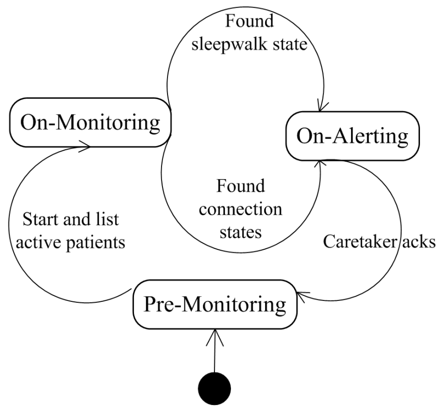


Fig.11: *States of a caretaker*

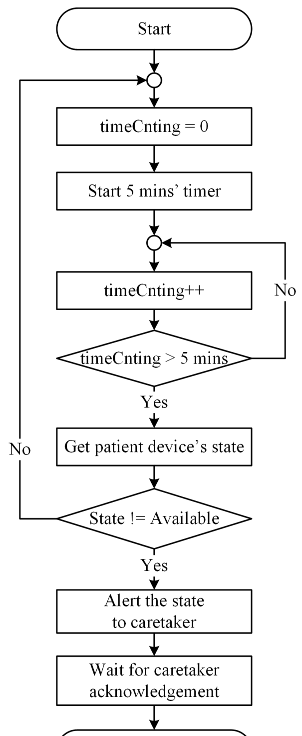
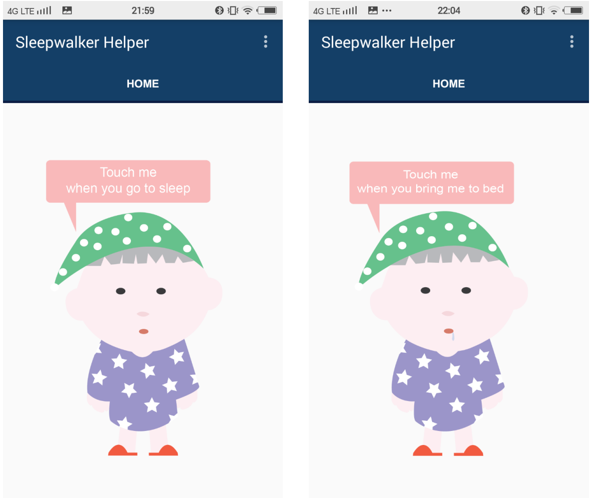


Fig.9: *Timer for the connection monitoring between a patient host device and a server*

4. IMPLEMENTATION

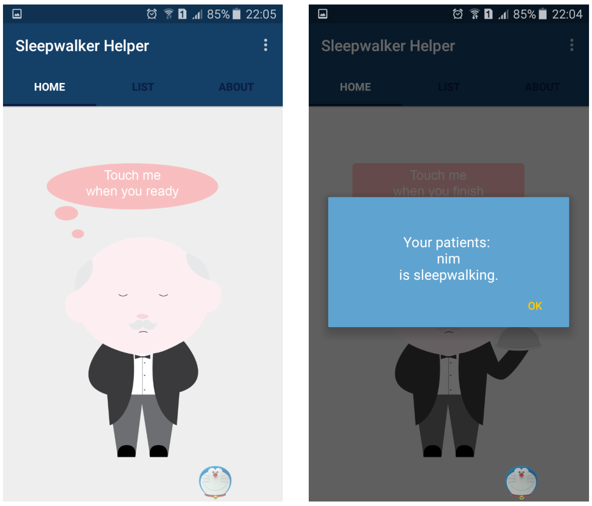
The proposed system has been developed using the Android Studio development environment. Java programming has been done, applying the Remote Sensor SDK. Any Samsung wearable device is supported. These are supported because they are widely used, well-known, and available at reasonable prices. In this work, a *Samsung Gear Fit* was used. The proposed system does not require any installation or modification of any software package on the wearable device. Requesting and receiving of the UAD are done by the host patient device.

However, the Remote Sensor SDK requires prerequisite software configurations. Both host devices (patient and caretaker sides) must be driven by the Android 4.3 (Jelly Bean API level 18) or higher. Installation steps of the prerequisite software packages have to follow an exact order. The host devices must have installed the Gear Fit Manager or Gear Manager application first, followed by the Remote Sensor Service, and finally our application. If the installation steps are not done in the correct order, the Remote Sensor SDK may not work properly. Therefore, the installation steps are restricted and important. Gear Fit Manager version 2.0.15, Remote Sensor Service version 1.0.0, and Sensor SDK version 1.0.0 were used for the software configurations in this work.



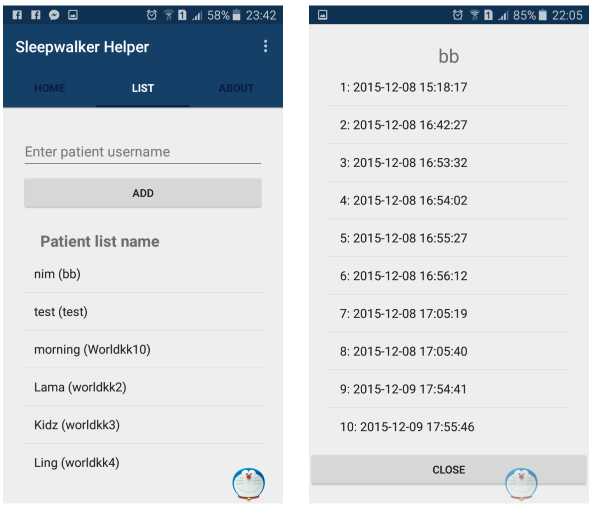
(a) (b)

Fig.12: *GUI of patient host device*



(a) (b)

Fig.13: *GUI of caretaker host device*



(a) (b)

Fig.14: *GUI of caretaker list*

Table 2: *Physical Activities and their detected states*

Physical Activity	Testing Repeated		
	1^{st}	2^{nd}	3^{rd}
Scratch for 20 seconds	F	F	F
Change arm positions in every 1 second 15 times	F	F	F
Rotate body to the right and return to the same position 7 times	F	F	F
Rotate body the left and return to the same position 7 times	F	F	F
Sit on a bed 7 times	F	F	F
Stand on a bed 7 times	F	F	F
Sit and then stand on a bed 7 times	F	F	F
Leave from a bed and then stand 7 times	F	F	F
Walk 5 steps and return to the same position	T	T	T
Walk 5 steps and stop	T	T	T
Run 5 - 7 steps and return to the same position	T	T	T
Run 5 - 7 steps and stop	T	T	T

5. VERIFICATION OF THE PROPOSED ALGORITHMS

The algorithms to detect the sleepwalking state using a smartwatch were verified by testing the movement in various activities. The verification experiments were run by setting up scenarios that duplicated various physical activities in different movements in different positions. Then, the detection results for identifying if the occurred movement was sleepwalking or not were recorded. The experiments were run repeatedly three times using the same patient in order to certify that the detection results were actual activities from the algorithms and did not happen by a chance. The results of the tested physical activities are shown in Table 2.

The verification shows that the smartwatch sent either state value 1 or 2 to the patient's smartphone when the patient walked five steps and returned to the same position, or walked five steps and stopped. The pattern movements of running behavior has also been evaluated. In contrast, the patient's smartwatch did not send the value of 1 or 2 to the smartphone when the patient just ordinarily moved on the bed.

Furthermore, empirical experiments for the verification of the proposed algorithms using the physical movements of three people revealed the same results as shown in Table 2. Therefore, the algorithms can detect the sleepwalking state correctly.

6. RESULTS AND DISCUSSIONS

The prototype was deployed on two mobile devices, a caretaker's and a patient's mobile device. The sleepwalking detection application on the patient's side starts detecting when a patient wears the smartwatch and touches the button on the smartphone screen. In the meantime, the caretaker taps on the screen in order to start monitoring the patients as shown in Figure 13 (a). The application notifies the caretaker with a message and alerting sound when the system has detected the sleepwalking state, as shown in Figure 13 (b). In addition, the caretaker can access a list of patients' details for patients under their supervision, as shown in Figure 14. They can also add a new patient to the list.

The proposed system detects and monitors sleepwalking of patients using a wearable device and a mobile device. The system detects the incidents based on the proposed algorithm. In addition, the application and devices have been tested in order to verify the accuracy of detecting sleepwalking activities via empirical experiments. The results show that the system correctly indicates the movements of sleepwalking differently from patients changing their positions during sleep. However, due to the restricted access to the remote sensor which functions only with the Java programming language, the application is limited to only work on Android devices. The mobile application has been designed for two groups of users: caretakers and patients.

The limitation of the proposed system is the technical knowledge and support requirements of the end-user. The end-user needs to have technical knowledge for finding and installing prerequisite software components to set up the system in precise order.

The architecture requires both the Bluetooth and Internet connections for interfacing among the devices in the system. The Bluetooth connections are required for the synchronization between the host patient devices and the corresponding wearable device. The architecture also needs the database server for synchronizing between the host patient devices and caretaker devices. Sufficient battery availability is a requirement to support running the system through the night.

In addition, the transmission range limitation of the Bluetooth protocol implemented this work is less than ten meters. In case of connection loss for any cause, the caretaker application will be triggered and then notify the user.

To decrease the technical support requirements for a real deployment, the proposed architecture can be further modified to remove the database server and utilize a tiny database system which can be installed on a mobile device such as SQLite [15], or even a cloud-based database, e.g. Firebase [16].

The issue of access to a smart device has been considered. However the advances in technology these days allow users to be able to purchase a high-end smartwatch with the cheaper price option. The user can use the alternative smartwatch which is bundled with several built-in sensors and utilities in order to monitor their activities. These third party providers also provide state-of-the-art APIs, enabling the cross-platform architecture. The JavaScript-based cross-platform architecture is recommended for supporting multiple OS of the devices, e.g. React Native [17] and Apache Cordova [18] frameworks. Specifications of these enhancements will be topics covered in our future work.

7. CONCLUSIONS

The prototype system was implemented to detect and monitor sleepwalking incidents using wearable and mobile devices. This can be deployed to help prevent the injury of patients when sleepwalking occurs. We proposed algorithms to detect sleepwalking using the data sent from the remote sensor of a wearable device. This system requires at least two user roles: a patient who is sleepwalker, and a caretaker who observes the patient. The prototype system can detect and send alerts when sleepwalking states have been invoked.

The system can be improved and applied to other domains such as monitoring system small children and Alzheimer patients. We have prepared all prerequisite software components. The users can download the application and its corresponding prerequisite software from this URL, `https://goo.gl/sKk4RN`.

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