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A system for monitoring human postures, seizures, and falls from bed using radio and surface electromyography signals

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ABSTRACT

In this work, a system for monitoring human postures, seizures, and falls from bed using received signal strength indicator (RSSI) and surface electromyography (sEMG) signals is studied through experiments. In this proposed system, a person who is located inside a wireless link is monitored by considering the change in measured RSSI signals as the 2.4 GHz IEEE 802.15.4 signals received at a receiver. Human motions in bed that affect RSSI levels can be captured. Thus, with this technique, it does not raise a privacy concern compared with vision-based technology. Additionally, sEMG signals associated with muscle movements from human postures are recorded from the human body's abdominal muscles. Eight different activities, including normal and critical events, are tested and evaluated. Experimental results indicate that the proposed system could automatically monitor different human postures in real-time. RSSI and sEMG signals correlated to each posture have their own patterns. Furthermore, the relationship between human behaviors and RSSI and sEMG levels is summarized.

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1. INTRODUCTION

Sleep postures, seizures, and falls from bed among the elderly, patients after surgery, and patients with associated serious medical conditions such as sleep apnea, cardiac arrest, tonic seizures, asthma, Parkinson's disease, and so on [1]-[5], are important health issues that should be monitored. To appropriately monitor and quickly detect such critical events, caregivers or medical personnel can aid patients on time and provide the best treatment to reduce the level of injury or danger [5], [6]. Additionally, historical data on sleep postures, seizures, and falls can be utilized as feedback to assist patients in adapting their actions [7]-[9].

Sleep monitoring has been attracting increased interest from the research and healthcare communities due to the importance of the study issue. As a result, several research studies attempted to design an adequate method for monitoring human activities and sleep postures in order to support patients and related people. With the progress of sensing and processing technologies, artificial intelligence (AI), and the internet of things (IoT), monitoring systems associated with this issue can be developed. The following is a review of related works, where Table 1 also summarizes the difference between related works and this work.

Video cameras and image-based technologies can be used to monitor human postures, as reported in [10]-[18], where cameras [10]-[16], near-infrared 3D time-of-flight (ToF) sensors combined with an impulse radar ultra-wideband sensor [17], and thermopile array sensors [18] could be applied. Although such technologies were a great choice for this monitoring since they produced high-resolution data, they had various disadvantages, including expensive deployment costs, specialist experimental installation, and inefficiency in dark and smoky environments. Also, serious user privacy concerns, particularly when employed in a bedroom, should also be concerned.

Human behaviors on bed can also be monitored using sensors mounted to a mat or bedsheet, bed, and pillow [19]-[24]. For example, to detect human postures, a thick pressure-sensitive bedsheet was utilized, as in [20]. The work in [24] used piezoelectric and pressure sensors put under the mattress, while the authors in [23] described a smart mat system for sleep position monitoring based on a dense flexible sensor array and printed electrodes. Although the works in [19]-[24] offered useful systems, expert installation, cost, sufficient surroundings, and effective processing solutions are also required.

Sensors attached to the human body are one of the human monitoring solutions since they do not depend on the surroundings. Although this method is a less comfortable option when applied during sleep, with small and low-cost sensors and microcontrollers (such as a wrist band), this method is popular for use. As in Jeng *et al*. [25], a wrist-sensing sleep posture monitoring device using accelerometers was applied. Nuksawn *et al*. [26], a real-time accelerometer-based and camera-based system for human sleep postures was introduced, where seven activities, including sitting, lying, backward, laying on the left, laying forward, laying on the right, standing, and walking, were investigated. A sleep monitoring system for screening for sleep apnea using a force sensor and an accelerometer sensor was presented in [27], where the sensor device was inserted into a belt that was wrapped around a person's chest or abdomen. Hwang *et al*. [28] uses electromyography (EMG) for sleep/wake estimation. Lee and Ko [29] also investigated the effect of sleep posture on neck muscle activity using EMG. Sleep apnea and changes in sleep postures associated with EMG were investigated in [30], while in [31], seizures were detected using the EMG measurement.

Finally, radio-based systems using received signal strength indicator (RSSI) were proposed to monitor and classify human postures in bed, as reported in [4], [8], [32]. The idea of this contactless technology is that the RSSI level at the receiver changes during human presence and movement inside a wireless range. This change can refer to human presence, motion, position, and other behaviors. As shown in the literature, Barsocchi [8] proposed a position recognition system using 2.4 GHz for bedsores prevention, where sleep postures could be detected using RSSI measured from fixed radio devices deployed around the bed. A system for sleep posture detection using Wi-Fi signals was also presented in [32], where the 2.4 GHz Wi-Fi devices were placed on the left and right sides of the bed. Finally, monitoring and classification of human behaviors in bed using RSSI signals was presented by [4], where 2.4 GHz wireless devices were employed and a K-nearest neighbor classifier was applied. In this work, a system for monitoring human postures in bed is presented. The novelty and contributions are as follows:

- First, a system for monitoring human postures, seizures, and falls from bed utilizing both RSSI radio signals and surface electromyography (sEMG) data is proposed. Human postures in bed that affect 2.4 GHz RSSI levels are monitored using Z1 IEEE 802.15.4 low-power wireless devices, and abdominal muscular movements related to human postures are measured using a sEMG muscle sensor module.
- Second, human postures, including normal and critical events, including; i) sleeping on his back, ii) seizures, iii) falling from bed, iv) sitting, v) sitting to sleeping on his back, vi) sleeping on his back to sleeping on his side, vii) sleeping on his side to sitting, and viii) sitting to waking out of bed, are considered.
- Third, experimental results demonstrated that the proposed system can monitor human postures in real-time, where RSSI and sEMG signals are collected for analysis. The link between human postures and RSSI and sEMG signal levels is also summarized.
- Finally, our suggested system can therefore be used to support patients, physicians, and medical staff in monitoring and planning treatment.

The structure of this paper is organized as follows: section 2 describes methods, including the proposed system and test scenarios. Section 3 provides experimental results and discussion, and open research issues are also summarized. Finally, the paper is concluded in section 4.

Table 1. A comparison of related works and this work

Ref.	Video/ image	Sensors attached to a mat or bedsheet, bed, and pillow	Sensor attached to human body	Radio-based
[10], [11], [13]-[18]	✓			
[12]	✓	✓		
[19]-[24]		✓		
[25], [27]-[31]			✓	
[26]	✓		✓	
[4], [8], [32]				✓
This work			✓ *sEMG	✓ *RSSI, 2.4 GHz IEEE802.15.4

2. METHOD

2.1. Proposed system

Figure 1 illustrates a proposed system including RSSI and sEMG measurement functions. For RSSI measurement, one transmitter node and one receiver node are employed for wireless communications. They are placed near the bed on the opposite side. The transmitter continuously sends a packet to the receiver wirelessly while a man, a patient, and an elderly person. Are on the bed within wireless range. The idea of how to monitor human postures is that without a person in a wireless link, RSSI signal levels measured at the receiver are more stable, and they fluctuate around some mean value. However, when the person is in the link that affects the radio signal, the RSSI significantly fluctuates, and its value decreases lower than if the person is not in the link. Also, different human postures, like sitting or sleeping, RSSI signal patterns are also different [4], [8], [32].

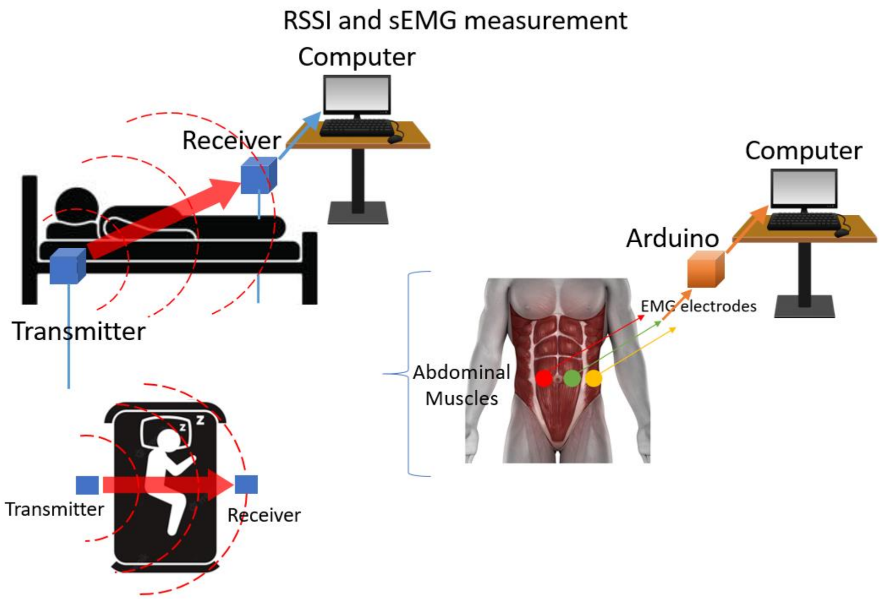
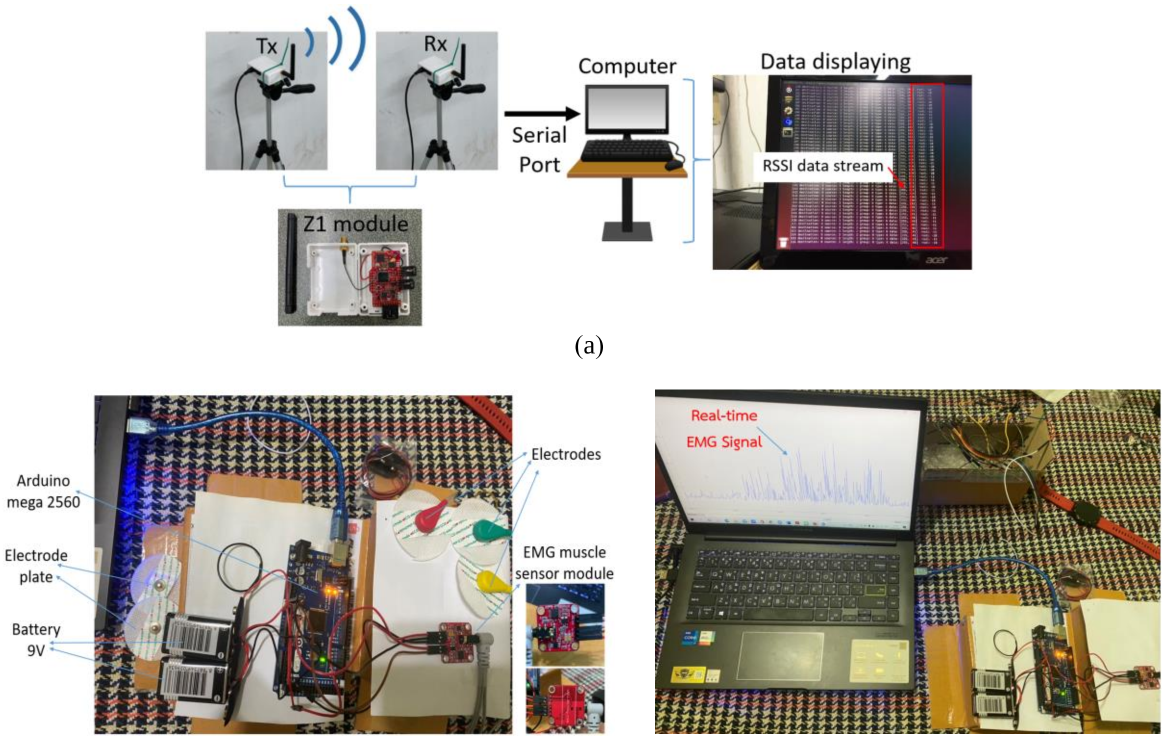


Figure 1. The proposed system

As in Figures 2(a) and (b), Z1 nodes as low-power wireless modules [33] are employed. It has a CC2420 RF transceiver [34] based on the ZigBee standard, 2.4 GHz IEEE 802.15.4, and an MSP430F2617 microcontroller. Z1 is fixed to the tripod and placed at the same level as the man's bed. In our system, data packets are continually sent from the transmitter node to the receiver. When each packet is received, the receiver node can check the RSSI level of the packet using information provided by the CC2420 radio circuit. The receiver node then forwards the RSSI data to the computer through a serial port for processing and monitoring. Figure 3 depicts the sequence of communications between the transmitter, receiver, and computer, where the start packet, request packet, reply packet, acknowledgement packet, and data packet are utilized. We point out that in our study, wireless node communications between Z1 nodes are conducted on channel 16 using the carrier sense multiple access/collision avoidance (CSMA/CA) protocol. Here, we verify that there are no Wi-Fi interferences since the Wi-Fi analyzer software is used to verify all accessible Wi-Fi channels before the experiment.

For sEMG measurement, an EMG muscle sensor module with a small size of 25.4×25.4 mm and a 9 VDC power supply is used to measure surface EMG signals, as shown in Figures 2 and 4. This sensor has an AD8221 signal amplifier chip, and the output signal is rectified and smoothed. It communicates with the Arduino Mega with a standard I2C communication protocol. The sEMG sensor is placed on the abdominal muscle of the human body, where two electrodes are used for sEMG measurement and one electrode is used as the reference electrode. Any actions in the bed that affect this muscle, including sitting, sleeping with different postures, seizure sleeping, and falling, as we studied, can be captured. We note that, before the test, the subject's skin beyond the considered muscles is cleaned with alcohol, and the electrodes positions are marked to ensure the same measurement area for other tests. Also, the sEMG sensor is connected to the Arduino for processing, and the sEMG data at the Arduino are then forwarded to the computer for monitoring.



(a)

(b)

Figure 2. RSSI and sEMG measurement: (a) RSSI measurement using 2.4 GHz Z1 nodes and (b) sEMG measurement using an EMG muscle sensor module

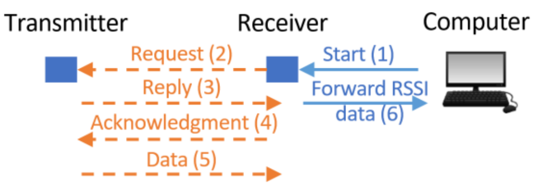


Figure 3. The communication sequence among transmitter, receiver, and computer

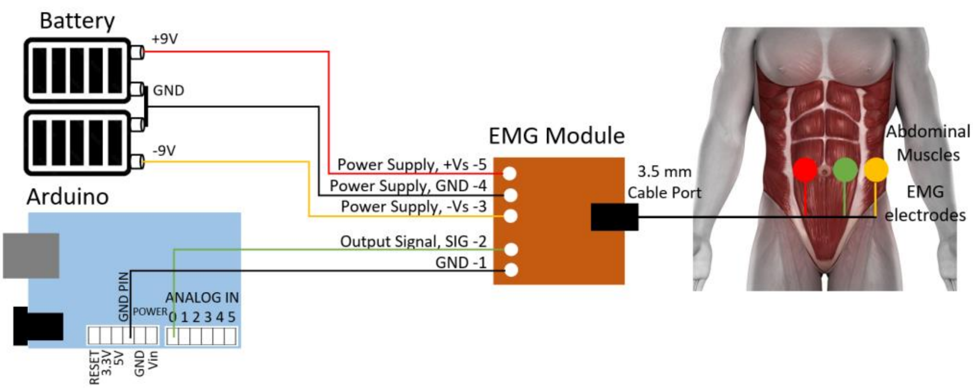


Figure 4. Layout of sEMG connection

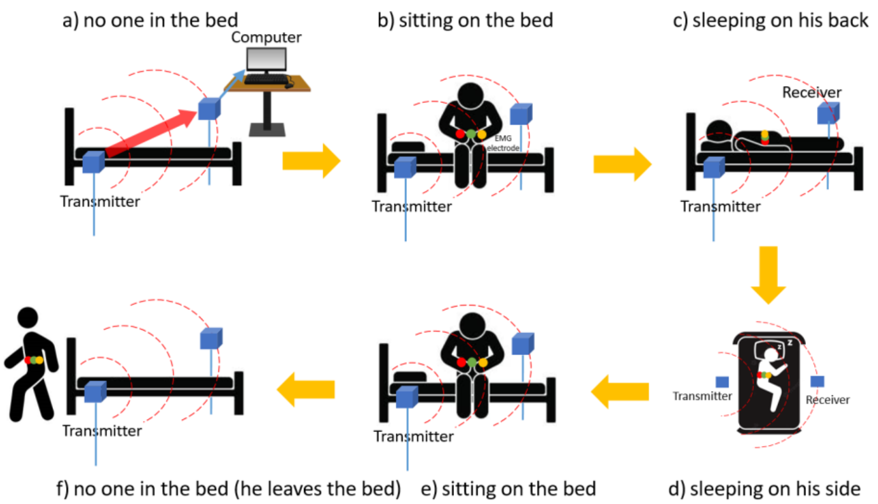
2.2. Test scenarios

Three test situations are investigated, including patterns #1 to #3. Eight postures are checked and assessed based on these patterns, including: i) sleeping on his back; ii) seizures; iii) falls from bed; iv) sitting;

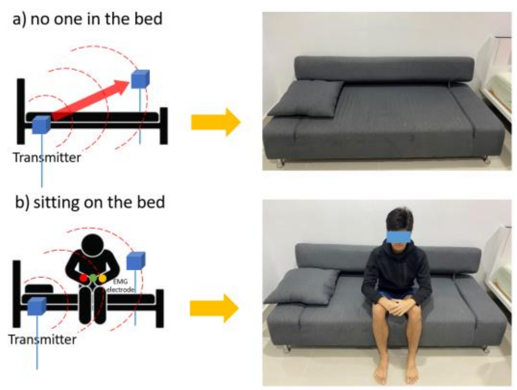
v) sitting to sleeping on his back; vi) sleeping on his back to sleeping on his side; vii) sleeping on his side to sitting; and viii) sitting to awakening out of bed. To begin developing a monitoring system employing radio-based and sEMG-based technologies, at the start of our study phase (before deployment), the proposed system was tested by a healthy subject with no medical concerns. We note that we also protect any subject's safety during testing by providing a convenient device, like a thick mattress. The subject can take a rest during each test. In addition, before testing, the subject was described and asked to allow and perform the test, and he also agreed to participate in the research study. Table 2 shows the test patterns in detail. In our experiments, each test pattern is repeated five times for data collection. Figures 5(a) and (b) also illustrate examples of human postures in pattern #3.

Table 2. Test patterns

Test patterns	Activities
Pattern #1	The man is on the bed, lying on his back, and has seizures while sleeping. This process will be repeated three times for each exam. Summary: a) sleeping on his back ➝ b) seizure sleeping
Pattern #2	The man is on the bed, sleeping on his back. He then moves to sleeping on his side. He finally falls to the floor and lies down on the floor. Summary: a) sleeping on his back ➝ b) sleeping on his side ➝ c) falls from the bed.
Pattern #3	Firstly, there is no one on the bed, an empty bed. The man then enters the room and takes a seat on the bed. He begins sleeping on his back and continues to sleep on his side. He then sits down on the bed. Finally, he left the room (no one was on the bed). Summary: a) no one in the bed ➝b) sitting on the bed ➝ c) sleeping on his back ➝ d) sleeping on his side ➝ e) sitting on the bed ➝ f) he leaves the bed.
Summary of actions	i) Sleeping on his back, ii) seizures, iii) falls from bed, iv) sitting, v) sitting to sleeping on his back, vi) sleeping on his back to sleeping on his side, vii) sleeping on his side to sitting, and viii) sitting to awakening out of bed.



(a)



(b)

Figure 5. Examples of pattern #3: (a) actions of test pattern #3 and (b) real test illustration

3. RESULTS AND DISCUSSION

Figures 6 to 8 show, respectively, the RSSI signals and the sEMG signals obtained from test patterns #1 through #3. The experimental findings indicate that human activities and sleeping postures have an impact on both the measured RSSI and the EMG signals, where the signals change according to the postures. As shown in Figure 6, the man is lying on his back on the bed and has seizures while sleeping. This behavior is repeated three times for each test. The RSSI therefore has two distinct sets of levels: the upper level (about between -17 and -18 dBm) refers to sleeping on his back, while the lower level (roughly between -18 and -21 dBm) corresponds to seizures. This is because when a man has a seizure, his body blocks and influences the radio signal propagated from the transmitter to the receiver more than when he sleeps on his back, as in a static case. In this case, when the subject experiences a seizure that affects his abdominal muscles, the sEMG signals exhibit larger amplitudes.

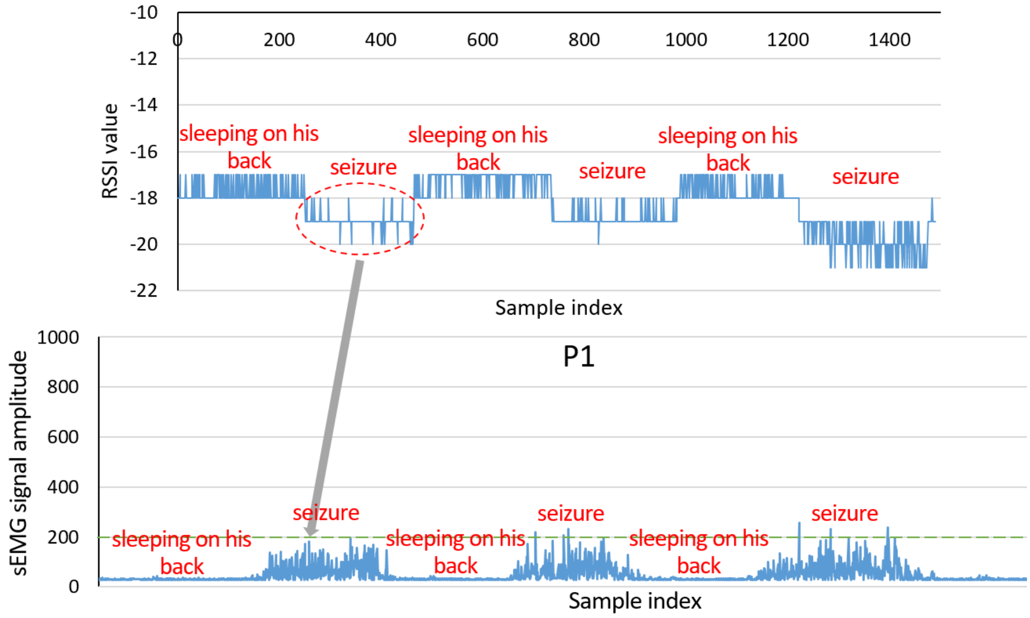


Figure 6. RSSI and sEMG signals measured form test pattern #1

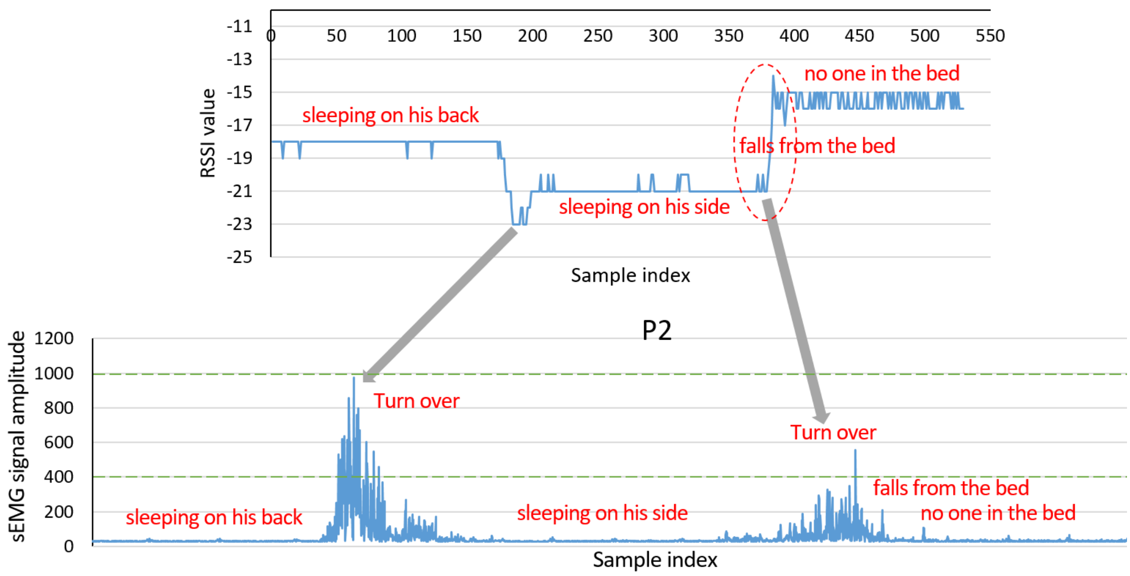


Figure 7. RSSI and sEMG signals measured form test pattern #2

In Figure 7, the RSSI signal changes following pattern #2. As seen in the graph, when the man is on the bed with sleeping on his back, the RSSI is at the level, like in pattern #1. The RSSI is reduced more when the man moves to sleeping on his side, to approximately -21 dBm. Finally, when the man falls from bed to the floor and lies down on the floor, the RSSI changes to the highest level (i.e., around -15 to -16 dBm). This is because there is no one on the bed blocking the radio signals from the transmitter to the receiver. When considering the sEMG signals, the signal can be clearly captured when the man moves or changes his postures, from sleeping on his back to sleeping on his side, and from sleeping on his side to falling from bed. Also, we can observe that, for sleeping on his back to sleeping on his side, the signal has higher aptitudes than the case of sleeping on his side to falling from bed. Additionally, compared with the case of seizures, the sEMG levels are different.

In Figure 8, the results reveal that the RSSI levels from low to high are from the cases of; i) sitting on the bed, ii) sleeping on his side, iii) sleeping on his back, and iv) no one in the bed. This result shows that when more parts of the human body block the radio signal path, like in the case of sitting on the bed, the RSSI greatly decreases. Additionally, using RSSI, the results also indicate that we can separate the case of the man falling from bed from the man leaving the bed. As in Figure 7, when the man falls from bed, the RSSI suddenly changes back to the higher level, while in the case of the man leaving the bed (see Figure 8), since he moves from sitting to walking, the RSSI reduces to -35 dBm before returning to -15 dBm as there is no one on the bed. For the sEMG signal, it is activated when the man changes his postures, such as standing to sitting, sitting to sleeping on his back, sleeping on his back to sleeping on his side, sleeping on his side to sitting, sleeping on his side to falling from bed, and sitting to standing and leaving the bed. The summary of our major findings is also provided in Tables 3(a) and (b), where the relationship between human actions and the levels of RSSI and sEMG signals is summarized.

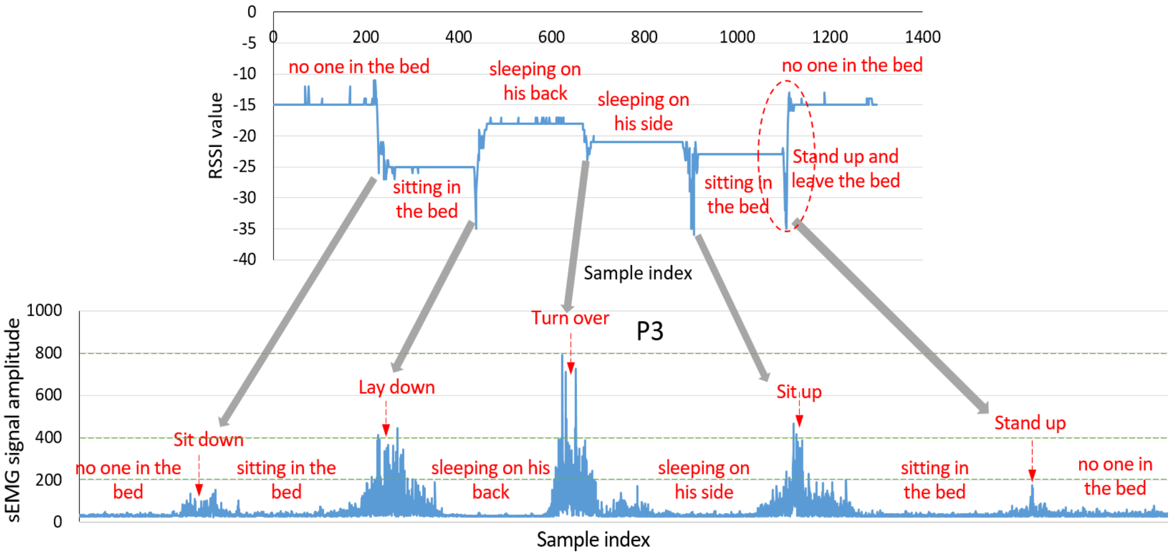


Figure 8. RSSI and sEMG signals measured form test pattern #3

According to our study and findings, open research issues related to this system are outlined as follows:

- First, monitoring and measurement of RSSI and sEMG levels related to other human activities, including normal and critical events such as other sleep postures, sleep apnea, other types of seizures [35], different types of falls, and sleep posture-related medical problems, should be more studied.
- Second, a system that integrates RSSI and sEMG functions and processes data simultaneously should be developed. For system testing, more participants, test scenarios, and test patterns should be included.
- Third, classification processes using RSSI data, sEMG data, and AI methods to properly separate each human posture should be developed. This can be used to assist patients, physicians, and medical professionals in the assessment and planning of care.
- Fourth, a graphical user interface (GUI) should be designed and developed for this system in order to assist users in monitoring, tracking, and notifying.

– Finally, to support healthcare applications, telemedicine technologies that connect patients with caregivers or medical staff should be taken into consideration.

Table 3(a). Summary of findings: human actions vs. RSSI levels at the receiver

Human actions	RSSI levels at the receiver
Sitting on the bed Sleeping on his side Seizures Sleeping on his back No one in the bed (empty bed)	Low ↓ High
Falls from bed (then no one in the bed)	Medium to high
Sitting to standing and leaving the bed (then, no one in the bed)	Low to high with fluctuation

Table 3(b). Summary of findings: human actions vs. sEMG levels measured from abdominal muscles

Human actions	sEMG level
Group 1	Low
– Seizures	
– Standing to sitting	
– Sitting to standing	
Group 2	Medium
– Sitting to sleeping on his back	
– Sleeping on his side to sitting	
– Sleeping on his side to falls from bed	
Group 3	High
– Sleeping on his back to sleeping on his side	

4. CONCLUSION

This work describes a system for monitoring human postures in bed, seizures, and falls utilizing RSSI and sEMG data. Human postures in bed that impact RSSI levels measured from IEEE 802.15.4 wireless modules at 2.4 GHz are recorded. In addition, muscular movements from human postures are measured by an EMG muscle sensor module placed at the abdominal muscle. The experimental results show that the proposed system can automatically monitor human postures such as: i) sleeping on his back, ii) seizures, iii) falling from bed, iv) sitting, v) sitting to sleeping on his back, vi) sleeping on his back to sleeping on his side, vii) sleeping on his side to sitting, and viii) sitting to waking out of bed. RSSI and sEMG signal patterns associated with each human posture were examined. Furthermore, the relationship between human behaviors and RSSI and sEMG signal levels is summarized. Our suggested system and results can therefore be utilized to support patients, physicians, and medical staff in monitoring, evaluating, and planning treatment.

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