Received October 23, 2016, accepted November 4, 2016, date of publication November 11, 2016,
date of current version November 28, 2016.

Digital Object Identifier 10.1109/ACCESS.2016.2628048

Posture Recognition to Prevent Bedsores for Multiple Patients Using Leaking Coaxial Cable

SYED AZIZ SHAH[1], NAN ZHAO[2], AIFENG REN[2], ZHIYA ZHANG[2], XIAODONG YANG[2], JIE YANG[2], AND WEI ZHAO[3]

[1]School of Life Science and Technology and the School of International Education, Xidian University, Xi'an 710071, China
[2]School of Electronic Engineering, Xidian University, Xi'an 710071, China
[3]School of Electro-Mechanical Engineering, Xidian University, Xi'an 710071, China

Corresponding author: X. Yang (xdyang@xidian.edu.cn)

This work was supported in part by the National Natural Science Foundation of China under Grant 61671349 and Grant 61601338, in part by the Fundamental Research Funds for the Central Universities, in part by the Project Funded by China Postdoctoral Science Foundation, and in part by the Postdoctoral Research Projects Funded in Shaanxi Province.

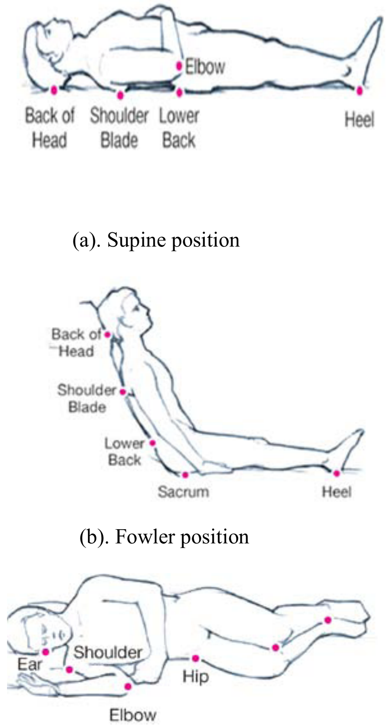
ABSTRACT Leaky coaxial cable (LCX) has long been used to cover blind and semi-blind zones in wireless communication. In this paper, we propose a novel system using a LCX. The key idea is to deploy LCX and use wireless information obtained through PHY layer wireless channel state information (CSI).The core application involves identifying multiple patients' postures in bed in order to reduce the formation of pressure ulcers or bedsores on the skin. The indoor installation and periodic recording of postures help monitor and prevent bedsores. The CSI registrations are collected using 802.11n Intel WLAN NICs. These CSI registration signatures are unique for particular posture. The amplitude variation is used for differentiating and classifying the postures for inference.

INDEX TERMS Channel state information (CSI), access point (AP), received signal strength indicator (RSSI).

I. INTRODUCTION

Bedsores or pressure ulcers are caused by prolonged pressure on the skin that limits blood circulation in neighboring tissues. Pressure ulcers are common clinical problems encountered in hospitals or nursing homes. Limited mobility and lack of repositioning on the bed makes the patient predisposed to bedsores. Chronic suffering that results in critical illness, frail elderly patients; spinal or cerebral patients are at high risk of developing bedsores. Some of the reasons for such lack of susceptibility are: 1) Constant pressure: When the layers of the epidermis, dermis and subcutaneous tissues are compressed due to long periods of lying on the bed. The functioning of small capillaries that circulate blood providing nutrients and oxygen are limited. With lack of oxygen and nutrients, the skin tissues are unable to thermo-regulate and perform metabolic functions. This kind of pressure is typically felt at the elbows, shoulder blades, spine, hips and spine causing deeper infections. 2) Friction: The patient's skin is fragile, with movements on the bed resulting in injuries. The frictional action enhances the chances of pressure ulcers. 3) Shear Force: When the bed is raised at the head, an inadvertent motion results in sliding. This can cause movement of bone a shear or a tensile strain in the subcutaneous layer [1]. Subcutaneous tissue is a rich layer beneath the skin connecting the dermis and epidermis. Its functional roles include acting as an insulator to conserve internal body heat and protect deeper tissue and organs. It also acts like a reserve to store energy and bodily fluids [1]

As a measure to save rapid damage to the skin and to reduce the risk of developing bedsores, it is necessary to relieve the skin pressure by changing the patient's postures every two hours [2]. Hence posture recognition on the bed is vital since timely intervention can reduce the risk of developing bedsore. For example, in persuasive hospital, a nurse can use a mobile activity monitor to provide immediate care for patients in need of assistance or in risky situations [3]. At homes elderly care requires assistance because of frail mental and physical abilities. The length of hospital stays, as well as hospital costs, for treating bedsores has increased, whereas there has been rise in shortage of nurses [4]. In some cases patients are often unable to make the desired body movements and repositioning that is critical for blood circulation and relieving of prolonged pressure on the body [5] as illustrated in figure 1. In order to prevent the



(a). Supine position

(b). Fowler position

(c). Lateral position

FIGURE 1. Pressure sores prone areas affected by body position on bed. (a). Supine position. (b). Fowler position. (c). Lateral position.

aforementioned effects, continuous patient's body postures and reporting of the status is necessary.

Body posture detection is obtained through the PHY layer feature. The Channel State Information (CSI) feature of the leaky coaxial cable (LCX) provides accurate report per channel. In [5], the author considers Received Signal Strength Indicator (RSSI) to estimate typical body postures in bed to support bedsore prevention using generic wireless devices. The RSSI characterizes either path loss power or radio fingerprint. The performance of RSSI dramatically degrades in complex situations due to temporal dynamics and multipath fading. In comparison with conventional RSSI, CSI is efficient for small-scale multipath fading and thus acts as a fine-grained descriptor of the wireless channel [6]. The signal strength and phase information for the subcarriers improve the signal-to-noise ratio (SNR) between the transmitter-receiver pair. The beam formation pattern is more directional and offsets noise due to co-channel interference.

The usage of LCX subcarriers is mainly to identify unique patterns for body postures in bed. This is verified for single and multiple patients in accordance to the 802.11 wireless range. The experiment was performed on eight different subjects at two different locations. The testing was carried out in the presence of another person and close frequency range of signals.

II. RELATED WORKS

Many approaches have been used to determine the patient's body postures in bed. Some of them have used pressure sensors. Hsia *et al.* [2] introduced a mattress pad that monitors changes in patient's body pressure using a force-sensing resistor (FSR). Huang *et al.* [7] presented a multimodal position identification system. This uses video images and a sensing resistor map with sixty-force sensors. Yousefi *et al.* [8] introduced a pressure mapping pad that included 2048 sensors for posture classification. The system complexity involves a large number of sensors and lengthy evaluation time to improve performance. In [9], Ni. *et al.* used ultra-wideband (UWB) tags with a Flexiforce sensor (FFS) where location was determined by ultra-wideband sensors. Six UWB wearable tags were used on the patient's clothing. Thirty-two pressure sensors equivalent to two-array FFS matrices were embedded in the bed. A higher accuracy was achieved in order to determine the patient's sleep posture but there were two limitations: 1) Integration of the two systems 2). The wearable UWB-tags in the clothing were mandatory for carrying out the monitoring process.

Another approach for determining a patient's posture is based on the accelerometer. In [10], Chang developed a sleep activity monitoring system using a tri-axis accelerometer. Although, it is only considered for posture detection, it posed difficulty in terms of accuracy. Reason being that the accelerometer was embedded in a solid crate on the subject's chest belt. Artifacts that hamper accuracy due to chest motion were a possibility. Secondly, the sensor position could get displaced during sleep. Yang *et al.* [11] proposed a wearable system that measures electrocardiography (ECG). The key limitation of this system is that the patient must wear the shirt embedded with eight textile sensors and a control box. The control box comprises two-lead ECG amplifier, microcontroller, filter and a wireless transmitter. The shirt that consists of hardware could cause level of distress to the wearer. Renganathan *et al.* [12] proposed a wearable device that include a 9 axis MEMS Inertial Measurement Unit (IMU) which consists of a 3 axis accelerometer, a 3 axis gyroscope and a 3 axis magnetometer in a single package. The main limitation to this system is that the wearable device should be attached to the chest.

Thus, we propose a novel idea in terms of system deployment and analysis of the acquired data. We determine a typical patient's body postures through wireless sensing. A fine-grained PHY layer CSI based on the leaky coaxial cable provides the signal for the analysis. In this case the patient's body is presented as an obstacle for radio signals that in turn generate a unique signature. The channel state information is measured using new CSI 802.11n WLAN NICs.

III. RADIATION PATTERN OF LCX

The LCX design and slot pattern is a commercial off-the shelf (COTS) cable with radiation that is highly directive.

The periodicity and adjacency in the slots make it very efficient in signal collection. The orientation of the slots results in constructive and destructive interferences of the RF feed. The radiation of the signal is characterized by the mode of the LCX.

The Orthogonal frequency division multiplexing (OFDM) splits the signal into 30 subcarriers. The frequency spacing of the subcarriers is orthogonal and hence reduces interference. It also improves the spectral efficiency for reconstruction and reduces hardware cost for realization. With the OFDM-PHY layer, currently 802.11a/g/n/ac standards, we can extract the Channel Frequency Response (CFR) in the format of Channel State Information (CSI) from off-the-shelf commercial hardware [13].The usage of standardized 802.11 bands makes the application low cost, which and seemingly integrates into the existing infrastructure.

IV. LCX VS ANTENNA

In a leaky coaxial cable or continuous antenna, each slot radiate energy with the propagation angles that make it highly directional. The directivity is also dependent on the relative permittivity of the material, periodicity of the slots and RF signal wavelength.

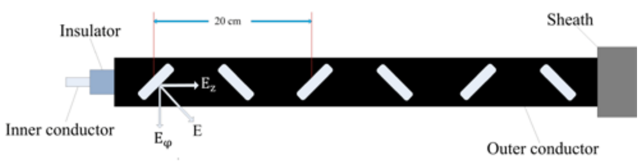


FIGURE 2. The leaky coaxial cable used in the proposed system has zig zag slots.

The LCX cable as shown in figure 2 has a spacing and orientation that alternates. The RF signal is radiated and received from these slots located on the cable.

The field generated around LCX is given as in [14].

$$E_\varphi (r, \varphi, z) = \sum_{n=-\infty}^{\infty} Z_n \left(1 - e^{jn\pi}\right) R(\eta_n, r, \varphi)\, e^{-j\beta_{zn}^{z}} \quad (1)$$

Here Z_n is the periodic function in z direction, $R(\eta_n, r, \varphi)$ relates to the distance r, and radial transmission constant η is in the direction φ. When n = multiple of 2π

$$E_\varphi (r, \varphi, z) = \sum_{n=-\infty}^{\infty} Z_n * 0 * R(\eta_n, r, \varphi)\, e^{-j\beta_{zn}^{z}} \quad (2)$$

Resulting in the suppression of the nth harmonic. Radiating field strength is higher for odd order modes.

When compared to an antenna setup, wireless access systems with LCX are robust. Installation of the access point unit and overloads of the handover mechanism within one cable segment is minimal [15].

Signal measurement with one antenna as the transmitter and another as the receiver is called a single input single output (SISO) system. A single input multiple output (SIMO) can reduce the error rates, and increase the SNR and reliability. Yet the deployment of receiving antennas that are Omni-directional over a large area is expensive. It also results in complex receiving and computational setups. Figure 3 compares the signal acquisition with an antenna in an occluded structure.

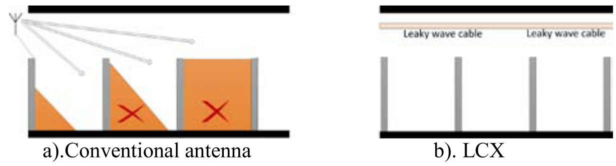


FIGURE 3. Conventional antenna creates shadow zones while LCX cable covers wider area. a). Conventional antenna. b). LCX.

The conventional antenna with structural obstruction will have shadow zones and chances of missing data are inevitable. LCX deployment is considerably easy and hence blind zones are overcome and seamless data reception is possible.

Protecting the cable from dust, a dielectric outer sheath is used to cover the slots. In the radiating mode, energy is radial and slots behave like an array antenna of length L. In case of a leaky electromagnetic signal, reception and transmission is all along the cable. This overcomes the disadvantage of the existence of blind zone in traditional communication [14], [16].

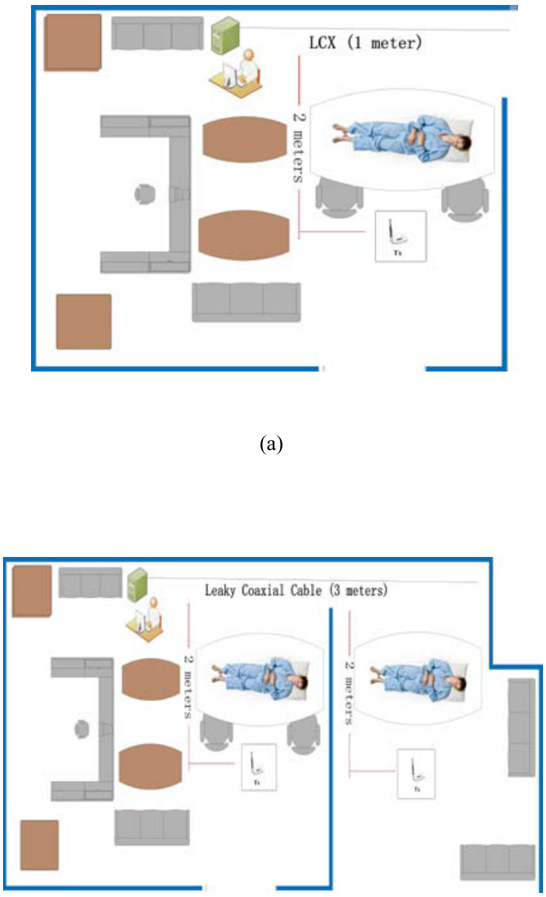
V. PROPOSED METHOD

Obstacles in the wireless range cause signals to be out-of-phase at the receiver. The signal strength is reduced due to multiple reflections and diffractions [6]. A simple description of monitoring sleep postures is shown in figure 4. LCX of one meter in length is wired around the area and signals are watched periodically.

In figure 4(b) the cable length is increased to accommodate multiple patients, to improve the accuracy and reduce false positives.

In wireless range, people around an obstacle cause multipath propagation phenomena. While such effects are often averaged out, when looking at a single average RSS measurement, the individual subcarrier measurements are more likely to change when small movements have altered the multipath environment [17].

The proposed system leverages directional and multipath propagation of wireless signals to determine body posture in bed. An activity is characterized as a series of movements recorded over a certain period of time, where the distribution of CSI amplitudes per channel is acquired and analyzed. Considering the received signal as y=Hx+n, x is the transmitted signal and n is the random noise. H is the Channel Impulse Response or Channel State Information (CSI), a matrix of complex numbers that indicate the channel frequency response (CFR) for spatial data per subcarrier [18]. The captured amplitude can be evaluated both in time and frequency domains [17].



(a)

(b)

FIGURE 4. Experimental setup for sleep posture detection for: a). Single person. b). Two persons.

Ideally, a radio signal would propagate in a straight path from the transmitter to the receiver, known as line-of-sight (LOS) propagation. However Non-line-of-sight (NLOS) radio transmission occurs, when a physical object stands in the radio signal's path resulting in diffraction, reflection and scattering. The received signals will have different CFR (i.e. CSI values).

Figure 5 illustrates the difference in LOS and NLOS signals as received by the LCX. The signals acquired by LCX are processed to detect the relative position of the body posture over time.

For example as seen in Figure 5, change in body posture affect the shift between LOS and NLOS as a result the signal packets received by LCX through LOS and NLOS paths are distinctive. Recording the CFR signals over time helps in deducing the postures for individual patient's in hospital room or across multiple rooms. The key advantage is only one LCX is used instead of installing a dedicated receiving antenna by each bed side.

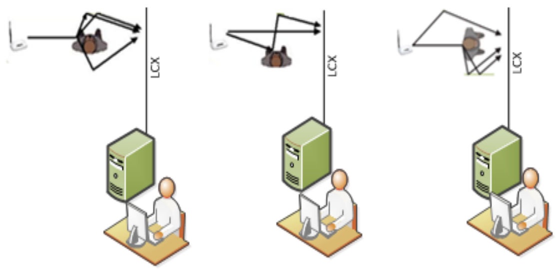


FIGURE 5. Rationale of using CSI for body posture detection – Change of body posture causes change in communication paths between LOS and NLOS.

VI. EXPERIMENTAL SETUP

The experimental setup is low-cost COTS WiFi device compatible with existing standards. NETGEAR R8500 WiFi routers used as the access point (AP) that operates around 2.4 GHz frequency. The WiFi device connected to the AP is an HP desktop computer embedded with Intel 5300 WiFi card. The transmitter and receiver are placed at a distance of 2 meters apart.

The methodology has two components. First, we selected a conference room in Xidian University to detect single patient body posture as shown in figure 4. The subject data is as shown in table-1.

TABLE 1. Subject data used for first scenario signal measurement.

Subject -ID	Subject weight (in Kg)	Subject height (in cm)
1	85	175
2	79	172
3	72	168

Second experiment, one conference room and an adjacent sitting room were used to detect body positions on bed for two different persons simultaneously, to emulate hospital scenario.

In this scenario, we have used two WiFi routers operating at different channels i.e. 2.41 GHz and 2.45 GHz respectively. The key idea of selecting different frequency channels is to avoid interference.

To collect CSI measurements, the client pings the AP at 20 packets per second. A modified driver is used to collect client side data [13]. WiFi link observes the static multipath depending on its location of endpoints [19]. This results in data collection that is different at different locations. Hence the two different scenarios show the variance in recordings when spread over two different rooms.

VII. ANALYTICAL TECHNIQUE

This portion deals with the intuitive way about the experiment and data reading using wireless devices. We first elaborate the first part of the experiment i.e. person's body posture detection through CSI using LCX.

A. SCENARIO-1:

Here the WiFi transmitter sends 20 packets per second. We receive the CSI reading and formulate the data according to matrix H representation. It is a 30x 1 matrix known as the channel frequency response (CFR). Each row indicates one sub-carrier frequency while the column of the CFR matrix refers to the receiving antenna (i.e. LCX).

Let the CFR (k) matrix represent the k^{th} packet received.

$$\mathrm{CFR}\,(k) = [h_1\,(k)\,, h_2\,(k)\,, h_3\,(k)\,, \ldots h_{30}\,(k)] \qquad (3)$$

Note that $h_i(k)$ is the CFR of the i^{th} sub-carrier at time instant k. $h_i(k)$ is a complex number denoted as amplitude or $|h_i(k)|$.

To analyze the change of CFR(k) with time, we put CFR(k) received at different times together, denoted as CFR [20]:

$$\mathrm{CFR} = [\mathrm{CFR}(1), \mathrm{CFR}(2), \ldots, \mathrm{CFR}(m)] \qquad (4)$$

Note that CFR is a 30x m matrix, where m is the number of packets received. Each row of CFR represents the temporal change of the CSI information over one subcarrier [20].

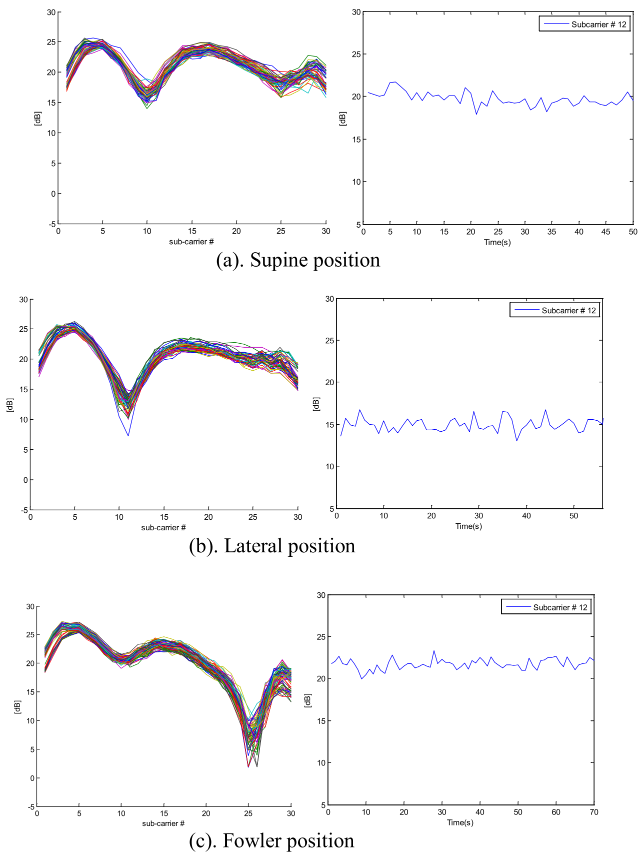


FIGURE 6. The CFR amplitude and time history measured during the experiment. (a). Supine position. (b). Lateral position. (c). Fowler position.

Figure 6 presents raw CFR data as per the CSI packet stream. It is taken over a time period and is typical for body postures of a person in bed.

It shows the variability in amplitude of CFR and time history for a subject's three postures. The CFR amplitudes for the supine and lateral position are almost identical while, for the fowler position, a major change is observed.

In order to see a change in body posture, we select the CFR sequence from the twelfth row of the CFR matrix (the time history of the CSI data varies from the twelfth subcarrier onwards) [20].The choice of this particular subcarrier for analysis is that the highest difference between corresponding subcarriers is observed at this subcarrier and is also observed in the posture changes as shown in Figure 7.

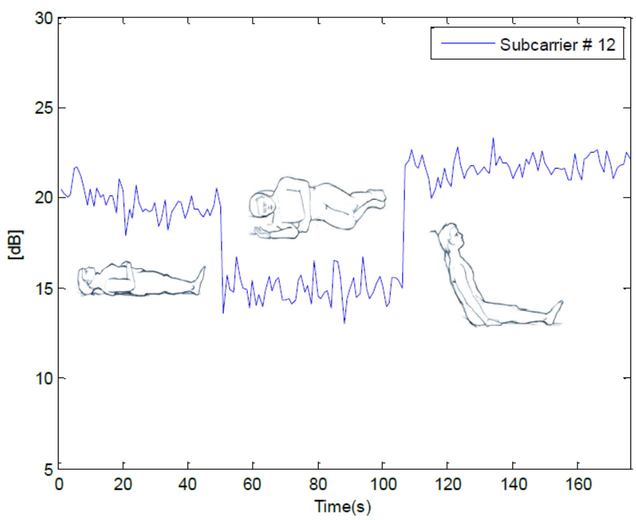


FIGURE 7. The CFR time history of typical body posture on bed.

Figure 7 indicates the CFR registrations of three body postures for an interval of 200 seconds. As per the measurement, the subject was lying in supine position for 50 seconds, lateral position for 60 seconds and then 70 seconds. This major shift in CFR amplitudes coupled with the observation in the sleep position is a fair inference.

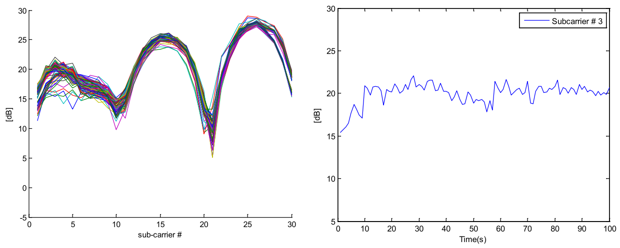
B. SCENARIO-II (For multiple patients:)

In this case we look at the realistic scenario with multiple patients in different rooms or spatially separated. The subject data is as shown in table-2 and the LCX is of a longer length, currently using a 3-meter long cable as shown in Figure 4(b).

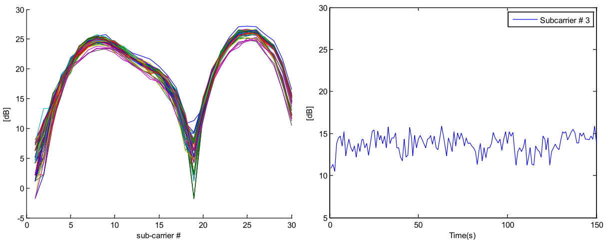
TABLE 2. Subject data used for the second scenario signal measurement.

Subject -ID	Subject weight (in Kgs)	Subject height (in cms)
1	85	175
2	84	170
3	79	172
4	75	173
5	72	168
6	60	158

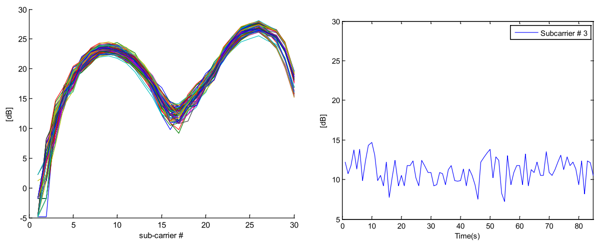
Figure 8 shows the amplitude of CFR and time history for the subject's three postures. The CFR amplitudes for the lateral and supine position are almost identical, while for the fowler position, a major shift in CFR amplitudes can be seen.



a). Fowler position



(b) Lateral position



c). Supine position

FIGURE 8. The CFR amplitude and time history measured during the experiment (conference room). a). Fowler position. (b) Lateral position. c). Supine position.

To correlate the change in body posture, we select the CFR sequence from the third row of CFR matrix (the time history of the CSI data from the third subcarrier) [20]. Again, the choice is empirically done by selecting the particular subcarrier for the analysis, which has the highest difference between observed subcarriers.

Figure 9 indicates the CFR registrations of three body postures for 235 seconds. The reading is as follows: subject was lying in the fowler position for 100 seconds then changed posture to lie laterally until the 250th second and remained in a supine position for 85 seconds until the 325th second.

Note we have considered people who are an obstacle between the transmitter and receiver and causing reflection, refraction and scattering. By accommodating the change in body posture causing a shift in NOS and NLOS, we have the result from the signal received by the receiver as per CFR values [20].

Figure 10 shows the amplitude of CFR and time history for the subject's three postures in a sitting room. This set of measurements includes baseline values to differentiate the sleeping postures verses sitting. Here the CFR amplitudes for the lateral and supine position are almost identical while for the fowler posture, this presents a major shift in amplitudes.

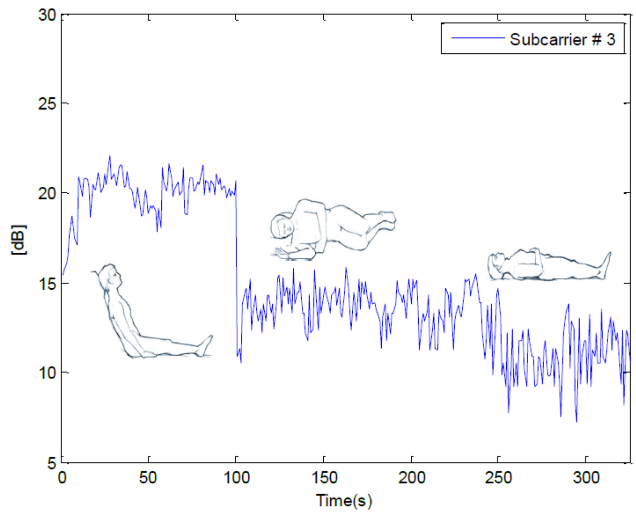
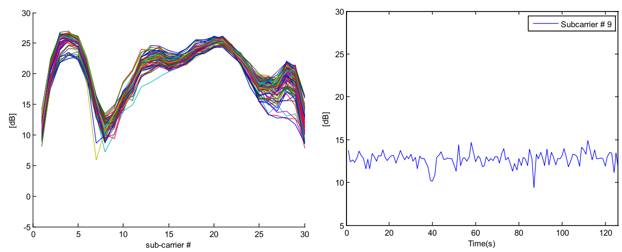
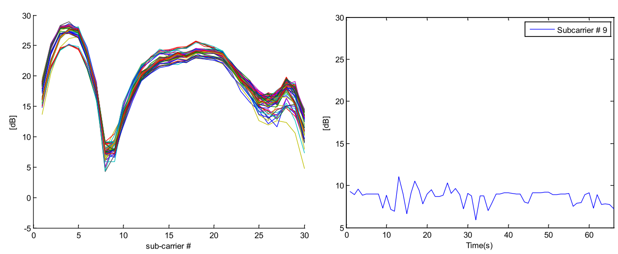


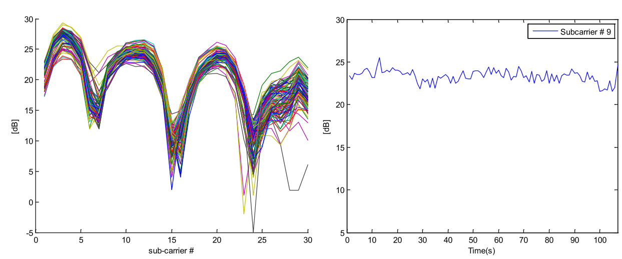
FIGURE 9. The CFR time history of typical body postures in bed (conference room).



(a) Supine position



(b) Lateral position



(c) Fowler position

FIGURE 10. The CFR amplitude and time history measured during the experiment (sitting room). (a) Supine position. (b) Lateral position. (c) Fowler position.

In order to see a change in body posture, we select the CFR sequence from the ninth row of the CFR matrix (the time history of the CSI data from the ninth subcarrier) [20].

Note that the WiFi router (transmitter 2) operates at a central frequency of 2.42 GHz. The reason for selecting different frequency channels for transmitter 1 and transmitter 2 is to avoid co-channel interference.

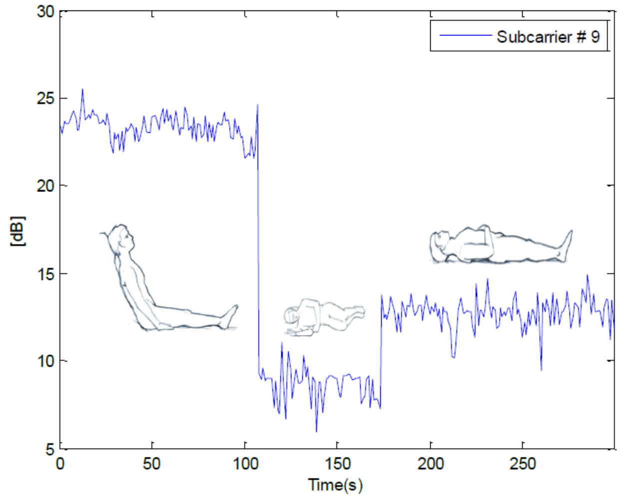


FIGURE 11. The CFR time history of typical body postures in bed (sitting room).

Figure 11 illustrates the CFR registrations of three body postures for 300 seconds. The subject was lying in the fowler position for 120 seconds then changed posture to lie laterally until 190th second and remained in supine position for 110 seconds until the 300th second.

The measurement changes in amplitude variations along with consistency in empirical observations give a fair estimate. The time interval during which there are no changes indicate a routine check on the patient. Long duration of the patient in any aforesaid position will result in constant amplitude. Thus, this indicates a plausible need for assistance.

VIII. CONCLUSION

The automatic patients' body posture detection with fine-grained channel state information is essential to prevent pressure ulcer development: measurements indicated that using the leaky coaxial cable with low-cost wireless devices can classify postures for multiple patients in hospitals. The system works for two or more than two patients when a dedicated WiFi router is deployed for each subject that operates at different frequency channel. The features considered in the proposed system for posture detection are computationally inexpensive, can be easily deployed and obtain high identification accuracy. The improvement in system performance is based on improving the AP and better monitoring applications. The reporting and notification has to be automated and classifiers that are robust will notify based on longer observation time. This can vary from 6–24 hours.

ACKNOWLEDGEMENT

The authors would like to thank Prof. Jie Tian for help and guidance.

REFERENCES

[1] A. C. Ahn and T. J. Kaptchuk, "Spatial anisotropy analyses of subcutaneous tissue layer: Potential insights into its biomechanical characteristics," *J. Anatomy*, vol. 219, no. 4, pp. 515–524, 2011.

[2] C. C. Hsia, K. J. Liou, A. P. W. Aung, V. Foo, W. Huang, and J. Biswas, "Analysis and comparison of sleeping posture classification methods using pressure sensitive bed system," in *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc.*, Minneapolis, MN, USA, Sep. 2009, pp. 6131–6134.

[3] M. Tentori and J. Favela, "Activity-aware computing for healthcare," *IEEE Pervasive Comput.*, vol. 7, no. 2, pp. 51–57, Apr./Jun. 2008.

[4] H. J. Lee, S. H. Hwang, S. M. Lee, Y. G. Lim, and K. S. Park, "Estimation of body postures on bed using unconstrained ECG measurements," *IEEE J. Biomed. Health Informat.*, vol. 17, no. 6, pp. 985–993, Nov. 2013.

[5] P. Barsocchi, "Position recognition to support bedsores prevention," *IEEE J. Biomed. Health Inform.*, vol. 17, no. 1, pp. 53–59, Jan. 2013.

[6] Z. Yang, Z. Zhou, and Y. Liu, "From RSSI to CSI: Indoor localization via channel response," *ACM Comput. Surv.*, vol. 46, no. 2, Nov. 2013, Article no. 25.

[7] W. Huang, A. A. P. Wai, S. F. Foo, J. Biswas, C. C. Hsia, and K. Liou, "Multimodal sleeping posture classification," in *Proc. 20th Int. Conf. Pattern Recognit. (ICPR)*, 2010, pp. 4336–4339.

[8] R. Yousefi *et al.*, "Bed posture classification for pressure ulcer prevention," in *Proc. Annu. Int. Conf. IEEE Eng. Med. Biol. Soc.*, Sep. 2011, pp. 7175–7178.

[9] H. Ni *et al.*, "Multi-modal non-intrusive sleep pattern recognition in elder assistive environment," in *Proc. 10th Int. Conf. Smart Homes Health Telematics*, 2012, pp. 132–139.

[10] K. M. Chang and S. H. Liu, "Wireless portable electrocardiogram and a tri-axis accelerometer implementation and application on sleep activity monitoring," *Telemed. J. E-Health*, vol. 17, no. 3, pp. 177–184, Apr. 2011.

[11] C. M. Yang *et al.*, "Sleeping ECG and body position monitoring system," in *Proc. 31st Int. Conf. IEEE Eng. Med. Biol. Soc.*, Sep. 2009, pp. 1856–1859.

[12] B. S. Renganathan, S. P. Preejith, S. Nagaiyan, J. Joseph, and M. Sivaprakasam, "A novel system to tackle hospital acquired pressure ulcers," in *Proc. 38th Annu. Int. Conf. IEEE Eng. Med. Biol. Soc. (EMBC)*, Orlando, FL, USA, Aug. 2016, pp. 4780–4783.

[13] D. Halperin, W. Hu, A. Sheth, and D. Wetherall, "Tool release: Gathering 802.11n traces with channel state information," *ACM SIGCOMM Comput. Commun. Rev.*, vol. 41, no. 1, p. 53, Jan. 2011.

[14] X. Zhang, X. Yang, L. Guo, W. Li, and W. Zhang, "Research of leaky coaxial cable using for mobile radio communication in the Blind Zone," in *Proc. 1st Workshop Multidisciplinary Res. Human Life Human Support*, Harbin, China, 2004, pp. 166-170.

[15] M. Nakamura, H. Takagi, K. Einaga, T. Nishikawa, N. Moriyama, and K. Wasaki, "Development of a 300 m 2.4 GHz frequency band leaky coaxial cable for wireless network access," in *Proc. IEEE Radio Wireless Symp.*, Orlando, FL, USA, Jan. 2008, pp. 687–690.

[16] M. Heddebaut, "Leaky waveguide for train-to-wayside communication-based train control," *IEEE Trans. Veh. Technol.*, vol. 58, no. 3, pp. 1068–1076, Mar. 2009.

[17] S. Maheshwari and A. K. Tiwari, "Walking parameters estimation through channel state information preliminary results," in *Proc. 9th Int. Conf. Signal Process. Commun. Syst.*, Cairns, QLD, Australia, Dec. 2015, pp. 1–8.

[18] P. W. Q. Lee, W. K. G. Seah, H. P. Tan, and Z. Yao, "Wireless sensing without sensors—An experimental approach," in *Proc. IEEE 20th Int. Symp. Pers., Indoor Mobile Radio Commun.*, Tokyo, Japan, Sep. 2009, pp. 62–66.

[19] Y. Zeng, P. H. Pathak, and P. Mohapatra, "Analyzing shoppers behavior through WiFi signals," in *Proc. ACM Workshop Phys. Anal. (WPA)*, Florence, Italy, May 2015, pp. 13–18.

[20] X. Liu, J. Cao, S. Tang, and J. Wen, "Wi-Sleep: Contactless sleep monitoring via WiFi signals," in *Proc. IEEE Real-Time Syst. Symp. (RTSS)*, Rome, Italy, Dec. 2014, pp. 346–355.

SYED AZIZ SHAH received the B.S. degree in electronics engineering from COMSATS IIT, Pakistan, and the M.S. degree in wireless networks and electronics from Linkoping University, Sweden, in 2010 and 2012, respectively. He is currently pursuing the Ph.D. degree with the School of Communication and Information System, Xidian University, China. His research interests include wireless networks, wireless sensing, antennas and propagation.

NAN ZHAO, photograph and biography not available at the time of publication.

AIFENG REN, photograph and biography not available at the time of publication.

ZHIYA ZHANG, photograph and biography not available at the time of publication.

XIAODONG YANG, photograph and biography not available at the time of publication.

JIE YANG, photograph and biography not available at the time of publication.

WEI ZHAO, photograph and biography not available at the time of publication.