

Monitoring of atopic dermatitis using leaky coaxial cable

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In our daily life, inadvertent scratching may increase the severity of skin diseases (such as atopic dermatitis etc.). However, people rarely pay attention to this matter, so the known measurement behaviour of the movement is also very little. Nevertheless, the behaviour and frequency of scratching represent the degree of itching, and the analysis of scratching frequency is helpful to the doctor's clinical dosage. In this Letter, a novel system is proposed to monitor the scratching motion of a sleeping human body at night. The core device of the system is just a leaky coaxial cable (LCX) and a router. Commonly, LCX is used in the blind field or semi-blindfield in wireless communication. The new idea is that the leaky cable is placed on the bed, and then the state information of physical layer of wireless communication channels is acquired to identify the scratching motion and other small body movements in the human sleep process. The results show that it can be used to detect the movement and its duration. Channel state information (CSI) packet is collected by card installed in the computer based on the 802.11n protocol. The characterisation of the scratch motion in the collected CSI is unique, so it can be distinguished from the wireless channel amplitude variation trend.

1. Introduction: TST of patients with skin diseases is a diagnostic index in clinical diagnosis, which is the ratio of the total scratching time to the total recorded time during sleep. The longer the patient's scratching, means the itchier his skin is, the more serious its pathological state is, the greater the value of TST. For example, the itchier the patients' skin with atopic dermatitis is [1, 2], the greater its TST value. Although scratch motion can reduce the degree of itching in a short time, this may still cause inflammation, which may affect the quality of sleep, and may lead to more serious problems [3, 4].

As people wake up, they will be conscious to control the scratching motion, so only at night when the body falls asleep, can the value of TST be accurately measured. Measurement method in traditional clinical medicine is using infrared cameras to measure the scratching motion frequency [3] and patterns. However, it is not conducive for the protection of human privacy, and some occlusion positions cannot be accurately measured. There are also non-invasive bio-sensing systems measuring the scratching motion, such as pressure-sensing beds and accelerometers integrated into the bed [5, 6]. Such bio-sensing systems need to supply power to the sensory devices, or install access amplifiers, filters and so on, which make the system complicated. There are other methods such as measuring the angular velocity of the accelerometer placed on the wrist, measuring the current activity of the forearm muscle using a motorised current gage, measuring the back pressure change, or compression or inflation of the fingers with other devices and so on [7–10]. However, in these methods, the sensing devices must be directly attached to the arm or other body parts, thus causing discomfort. Additionally, attaching these sensing devices directly to the arm or other body parts makes it a bit complicated. We propose a wireless non-contact way of measuring through the wireless channel state information (CSI) in the physical layer, which can monitor small human body motions during sleep, such as scratching motion.

LCX is often referred to as a leaky cable. As shown in Fig. 2, its structure is basically the same as a common coaxial cable, which is composed of the inner conductor, insulating medium and outer conductor opening the periodic slot. Electromagnetic wave in the cable

while the vertical transmission go on the outside radiation through the slot [11], and the energy of the electromagnetic radiation are as follows:

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

Z_n in the formula is a periodic function with Z as a variable. $R(\eta_n, r, \varphi)$ is related to the distance r , the angle φ and the radiation constant η . When n is a multiple of 2π

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

there is no n th harmonic, the electromagnetic emission intensity is also higher than other modes. External electromagnetic fields can also be induced through the slot to the inside of the cable and transmitted to the receiving end. At present, the frequency band of LCX covers 450 MHz to 2 GHz or more, and is adapted to the existing variety of wireless communication systems and its applications include subway of limited wireless transmission, railway tunnels and highway tunnels. The LCX is also used for indoor coverage abroad. Compared with the traditional antenna, the LCX has the following advantages:

- (i) In conventional wireless communication systems, the transmitter and the receiver typically use a single conventional antenna, which is also known as a single-input and single-output system. The system performs reliable communication in a noisy channel with an upper rate. No matter what kind of modulation scheme and channel coding method is used by telecom workers, only a little bit close to it, but no more than it, and the rate has become a major bottleneck in the development of modern wireless communications. One of the most important ways to improve the spectrum efficiency is to use diversity. Single-input multiple-output systems use

best-in-class receive diversity techniques to improve the signal-to-noise ratio of the receiver, improving channel capacity and spectrum efficiency. Nevertheless, the cost of installing a large number of traditional antenna is expensive, and the received signal is also more complex. As shown in Fig. 1, the shaded part on left side on the figure cannot receive the signals, so inevitably, it loses a lot of data. LCX is easily installed and covered, even for narrow tunnel space, no blind spots [11, 12], and it can achieve a complete reception of data seen on the right side of the figure.

- (ii) LCX is essentially a broadband system, and some types of LCX can be used for CDMA800, GSM900, GSM1800, WCDMA, WLAN and other systems.
- (iii) High physical foam and closed micro-bubble structure used by LCX insulation are more uniform and stable than traditional air insulation structure in the characteristic impedance, standing wave coefficient, attenuation and other transmission parameters. It can also withstand moisture intrusion for cable in the humid environment. Moreover, declining or losing the transmission performance can be avoided by eliminating the inflation maintenance troubles to greatly improve the product's life, stability and reliability.
- (iv) It has a wide frequency, field strength with uniform radiation stability, high compressive strength and high tensile strength (Fig. 2).

In this Letter, therefore, we present a simple sensory approach using an LCX, without a power supply, but monitoring the scratching motion of the cheek during sleep.

2. Materials and methods

2.1. Basics of wireless sensing: CSI used for wireless communications in the LCX has a comparable multipath resolution that can detect weak fluctuations in the line-of-sight (LOS) or non-line-of-sight (NLOS) paths, thereby increasing perceptual sensitivity, expanding perceptual areas and enhancing the sensitivity and reliability. Ideally, a radio signal is transmitted directly from the transmitter to the receiver over a straight channel, which makes the LOS to occur. NLOS occurs when a physical object that makes the wireless signal diffract, reflect and scatter is placed in the wireless channel. The received signal will have a different channel frequency response (CFR), and Fig. 3a explains the difference between the LOS and NLOS signals. In some conditions (including the scenario shown in Fig. 4b), scratching motion can hardly keep generating such shifting between LOS and NLOS. From the transmitter to the receiver,

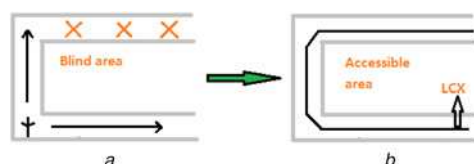


Fig. 1 Antenna coverage area
a Conventional antenna with shadow zones
b LCX without shadow zones

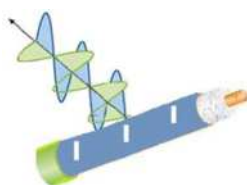


Fig. 2 Leaky coaxial cable

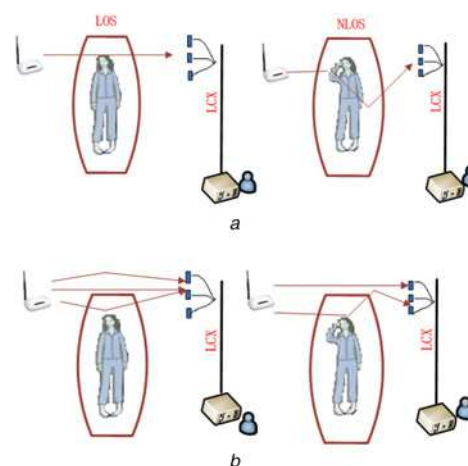


Fig. 3 Difference between the LOS and NLOS signals
a Scratching causes change of communication paths between LOS and NLOS
b Scratching causes change of communication of some NLOS path



Fig. 4 Experimental environment design
a Subjects without scratching motions
b Subjects with scratching motions

there is always an LOS path and a number of NLOS paths. As shown in Fig. 3b, the presence of a human body would create a new reflection path while the person's scratching can repeatedly change that path. Due to the change of the wireless communication channel, the obstacle caused by the human body in the channel will lead the phenomenon of multipath propagation. Even small bodily movements can affect the multipath environment and can cause subcarrier channel changes. Obstacles in these wireless communication channels cause phase distortion of the signal of the receiving end, and the intensity of the wireless signal is attenuated by multiple reflections and diffraction. In a system with a receiving end and a transmitting end, x is a transmitted signal and n is a random noise in the received signal, which is defined as $y = Hx + n$. H is the CSI, a matrix that characterises the spatial data channel frequency response of each subcarrier. It describes the attenuation factor of the signal in each transmission path, which is the value of each element in the channel gain matrix H , and indicates information such as signal scattering, environmental degradation, distance attenuation and so on. CSI can make the communication system adapt to the current channel conditions, and provide protection for communication of

high reliability and high rate in the multi-antenna system. The amplitude of the CSI can be evaluated in the time domain and the frequency domain. Since the changes of LOS and NLOS caused by body motion are obvious, the CSI in the wireless communication channel utilising the multipath propagation can recognise the basic scratching motion of the human body and the likes. A simple system for monitoring scratching motion of patients with nocturnal skin diseases is shown in Fig. 4. In a typical house, a 1 m-long LCX was placed on one side of the bed. Subjects lay on the bed and the usual WIFI router is placed on the other side of bed, the signal could be seen cyclically due to obstacles of human motion, a lot of information that shows the subject scratches cheek can be collected at the same time.

2.2. Ratio of total scratching time: After a large number of CSI data packets are obtained by the LCX, it can be seen from the figure drawn by the data that the amplitude of the signal detected by the proposed system is several multiples of the amplitude of the heartbeat period, thereby making it easy to measure scratching motion period. There is a strong correlation between the duration of the scratching motion and the severity of the skin disease, and it is helpful for the physician to determine the amount of prescribed medication (such as systemic antihistamines and glucocorticoids). Specific index are defined by the TST formula as shown below:

$$\text{TST\%} = \frac{T_s}{T_m} \times 100 \quad (3)$$

in the formula, T_s is the time of the scratching motion in the total recording time, and T_m is the total recording time.

2.3. Experiment set-up: The information changes of wireless communication channel state in proposed system can detect small human body movements while sleeping on bed at night, and in order to ensure the feasibility of the proposed system, some experiments were designed for its verification. As shown in Fig. 4, in a typical conference room of Xidian University, the room has two doors, a bookcase, a table, two ordinary seats and a hard board bed. The distance between the router and desktop computers is 1.5 m. We also embedded an INTEL 5300 wireless card on an HP desktop computer in the room, and install a 1 m LCX to which the hotspot launched by a 2.4 GHz band R8500WIFI router is connected. The subjects in this experiment were two healthy male adults, both 24 years old, and have not suffer from any skin disease yet. The detailed information of the subjects is shown in Table 1.

The experiment was carried out after obtaining the consent of each participant. The subjects were lying on the bed between the router and the computer. The starting position was supine, the thighs and arms were straight, as shown in Fig. 4a. In Fig. 4b, subjects were told to raise their arms to scratch their cheeks 20 times, because patients with atopic dermatitis frequently scratch the head area [13]. After 20 times of scratching motions, the subjects returned the arm to the starting position. After 5 s interval, the subjects were again scratching their cheeks 20 times. The computer collects CSI data at 20 packets/s simultaneously, and the data obtained contains a great deal of information about the subjects' movements. The total scratching motion time of 35 sets movements is scratch,

Table 1 Specific information of subjects

Subject ID	Subject weight, kg	Subject height, cm
1	70	180
2	79	172

and TST is calculated by (1) above. The whole process used the system described above.

3. Results and discussion: This part analyses and deals with the experimental data obtained. During the process of experiment, the WIFI Router launches 20 packets/s, and the desktop PC acquires the packet through the LCX. The CSI in the received data packet is represented by an H matrix, which is a 30×1 matrix. Each row of the CFR matrix designates a receiver antenna, while representing a subcarrier frequency. The CFR(K) matrix represents the received K th data packet

$$\text{CFR}(K) = [h_1(k), h_2(k), h_3(k), \dots, h_{30}(k)] \quad (4)$$

$h_i(k)$ is the i th subcarrier of the CFR at time k , which is a complex number that can be represented by the amplitude $|h_i(k)|$. In order to analyse the change of CFR(K) over time, we put together the CFR(K) received at different times, which are expressed as CFR

$$\text{CFR} = [\text{CFR}(1), \text{CFR}(2), \dots, \text{CFR}(m)] \quad (5)$$

Note that the CFR is a $30 \times m$ matrix and m is the sequence number of the received m th packet.

Each row of CFR represents a brief CSI information change. Fig. 5a shows a CSI chart of normal sleeping lying in bed

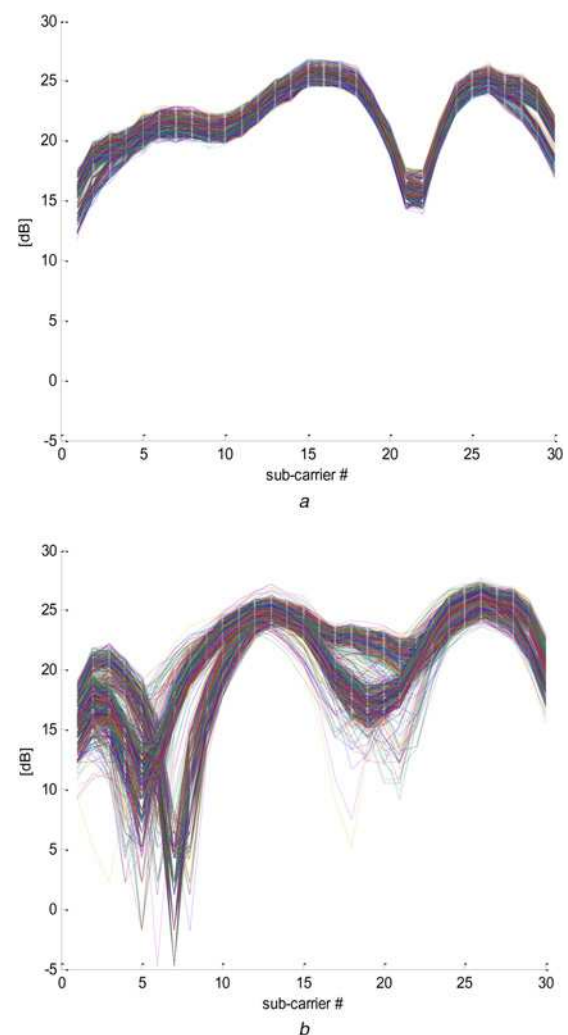


Fig. 5 CSI packets display
a Subjects without scratching motions
b Subjects with scratching motions

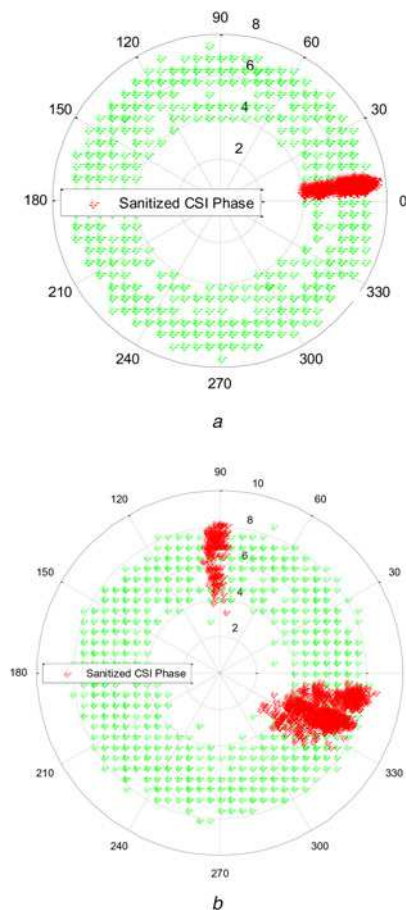


Fig. 6 Phase display
a Subjects without scratching motions
b Subjects with scratching motions

without scratching motion for a period of time. Fig. 5a shows a CSI chart of normal sleeping lying in bed with scratching motion for a period of time. Fig. 6a shows a CSI chart of normal sleeping lying in bed without scratching motion for a period of time. Fig. 6b shows a CSI chart of normal sleeping lying in bed with scratching motion for a period of time. Spare red zone in Fig. 6b represents the CSI phase in scratching time, and the small common red zone in Figs. 6a and b represents the CSI phase in normal sleeping time.

To observe the variation of the channel caused by the scratching motion, as shown in Fig. 7, the vertical axis represents the amplitude value and the horizontal axis represents the time. Fig. 7a shows that in a period of time, the figure of the normal sleep without scratching motion has no special changes. While in Fig. 7b, it can be seen that the time axis mapped by the red and green areas each represents a time period of moving the arm and a time period of scratching motion. It can be clearly analysed that the posture of the subjects is the initial posture from 0 to 320 s, the waveform detected by CSI at this time shows the heartbeat state. Between 320 and 325 s, the subjects just moved their hands to the cheek. As the arm movement is large, it leads to the formation of obstacles in the wireless channel, causing the CSI changes. It has the most dramatic ups and downs from the corresponding waveform. The subjects' scratching motions were more regular and amplitude values were four to five times greater than those of the heartbeat period, which was seen from the time of 325–650 s in the image. When subjects move their hands from the cheek to the starting position, the waveform of 650–655 s in the figure has a greater volatility, which is similar to the waveform changes from 320 to 325 s. Between 655 and 1150 s, the subjects were in the starting state, the figure showing the heartbeat waveform, as well as the waveform state between 0 and 320 s.

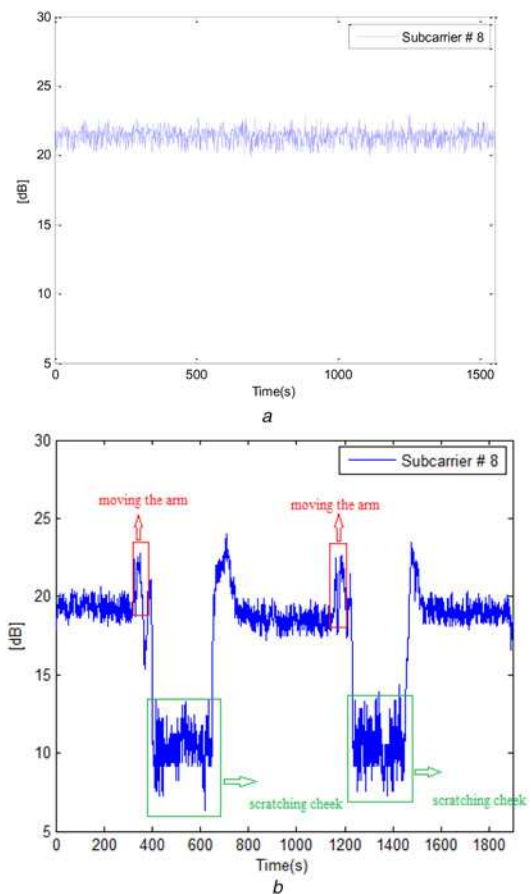


Fig. 7 CSI subcarrier trend
a Subjects without scratching motions
b Subjects with scratching motions

The later trend of the scratching motion wave is the same as before, and the experiment's TST value is 0.34 from the figure.

4. Conclusion: In this Letter, we focus on the severity of pathological itching and propose a wireless non-contact way to measure the scratch motions with CSI during the skin disease patients' sleeping time, and the system consists of a leaky cable and a R8500WIFI router, router and LCX on both sides of the human body. The above experiments proved that this method can detect the scratching motions of patient lying in bed. The TST is an important index used to evaluate scratch motions and can be calculated from sub-channel information monitored by CSI. When the body lying in the bed in the room equipped with the monitoring system, the LCX can receive signals in the daytime and nighttime environment, and can achieve real-time automatic monitoring and reporting in 24 h a day stably. The system is convenient and cheap, easy to install and operate relatively simple, and what need to do to improve the system is to find a better application point and enhance the performance of the router.

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