

Chapter 2

Vision of the Wireless Monitoring Techniques in Sleep Apnoea

2.1 Introduction

In the preceding Chap. 1 Introduction, the significance of wireless sleep monitoring and the outline of the book have been presented. There are many varieties of sleep monitoring devices available in the market. Usually, sleep labs have been equipped with these wired sensor devices and their computer peripherals in the laboratories for decades. However, the current method of collecting data in the sleeping laboratory might not provide the accurate physiological data from the actual sleeping patterns of a patient. This is only possible when she/he sleep in an unconstraint condition on own bed at home. This most appropriate solution is the wireless sleep monitoring sensors attached to the sleeping gown or similar sort of configuration.

The next biggest challenge is to collect data from the paediatric patients when they are collected with many wires. Children tangled with many wires have a severe fear factor, and they become unrest and scared with the current sleep devices. Therefore, one of the prime objectives of the project is to develop wireless sleep monitoring transducers so that these fear factors from the paediatric patients can be removed. Our motivation has been derived from the industry demand to develop the wireless sleep apnoea sensor and the wireless monitoring system from scratch to focus mainly on the paediatric patient. In this chapter, the motivation and the configuration of the proposed wireless monitoring system are presented.

As stated before, sleeping data contains multiple parameters including ECG, EEG, respiratory, physical activity and temperature. Normally, the main difficulty faced with patient monitoring for physiological data and vital signals has been that the patient is hard-wired with a large number of electrode connections and then confined to the immediate proximity of the patient's monitoring device that collects the data. This method has come at great expense to hospitals and clinicians. The current sleep monitoring system needs (i) dedicated area for patient monitoring, and hence an expensive infrastructure and installation; (ii) expensive electrodes and (iii) expensive computing peripherals to collect and interpret the data deducible for

clinicians. Due to the artificially created environment for the patient monitoring system in the sleep labs, the integrity of the patient data is a question. Therefore, the data often does not truly represent the analytical details due to the discomfort of the patient. As proposed in the developed system, wireless connectivity between the on-body wireless electrodes and the remote base station monitoring device immediately removes these predicaments and offers a revolutionary new approach. Some researchers and developers [1–11] have since attempted to provide the wireless patient monitoring by introducing an element of portability through incorporating a battery and data acquisition memory card to store patient details (see Fig. 2.1a). However, these systems rely on battery time to determine the amount of patient information acquired, and also must be strapped onto the patient in some manner for the patient’s mobility; this device is usually quite heavy and uncomfortable for the patient. This issue of discomfort also remains as a result of all electrodes and sensors being connected in a similar manner and thus potentially effecting the integrity of the patient’s data. Current wireless medical telemetry technology involves strapping an active transmitter the size of a Palm Pilot plus a case to the patient and running wires to all the sensors from head to toe as shown in Fig. 2.1a. Companies competing in this market include Medtronics [12], Grass [13], Hewlett Packard [14], SensorMedics [15], Compumedics [16] and Jaeger [17]. The investigators are unaware of a comparative development of the proposed wireless passive RF monitoring system.

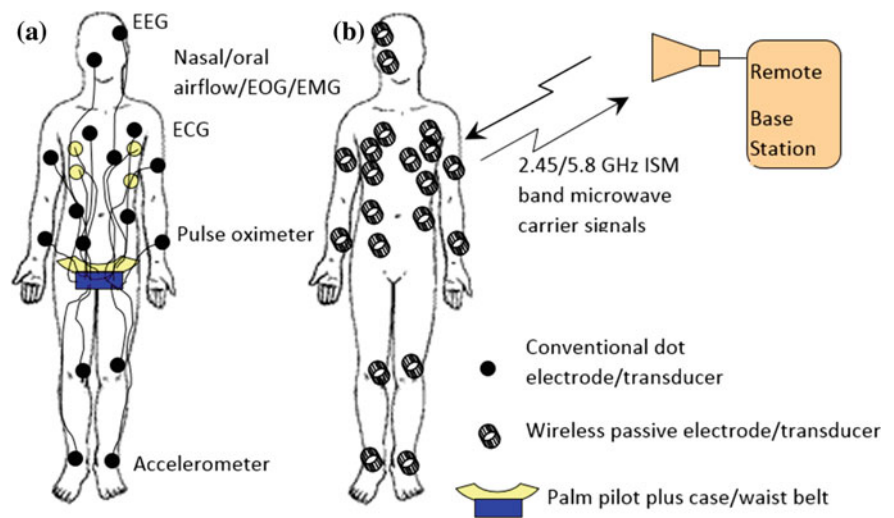


Fig. 2.1 Typical eBio polysomnography transducer arrangement: **a** Current wired monitoring system, **b** Proposed wireless monitoring system

2.2 Traditional Sleep Monitoring Systems

The sleep monitoring systems can be classified broadly into two groups: cable-based systems and wireless systems, according to the signal transmission methods. These systems have different features and implementation scenarios, which are discussed in the following sections.

2.2.1 Cable Based System

Recognized as the gold standard, polysomnography (PSG) is widely applied in sleep apnoea monitoring and diagnosis. The monitored physiological parameters include electroencephalogram (EEG), electrocardiogram (ECG/EKG), electrooculogram (EOG), electromyogram (EMG), pulse oximeter and nasal airflow sensor. Figure 2.2 shows a paediatric patient being prepared for sleep monitoring [18, 19]. The on-body sensors are connected to the nearby PSG equipment with a number of wires. The installation of such a large number of electrodes and wires on a paediatric patient not only creates inconvenience and discomfort, but may also induce fear in the young patient. PSG is widely applied in sleep disorder analysis by research institutes. The accuracy and functionality of the equipment are the best among all the existing sleep monitoring methods. However, a typical PSG test will take approximately 1–2 h for patient “wire-up”. This undoubtedly leaves the patient feeling uncomfortable and impacts the quality of sleep over the testing period. The fear factor of paediatric patients during the “wire-up” phase is the biggest challenge for the sleep clinicians.

Some of the commercial PSG systems are described as below:

- a. SomnoStar Z4, manufacturer: Viasys Healthcare. The system is classified as a diagnostic sleep system including 40 channels (12 DC, 23 EEG and 9 differential signals). The collection rate is up to 2000 Hz [20].
- b. EMBLA N-7000 recording system offers a high degree of flexibility and impeccable signal quality to meet the demanding needs of clinical work and research. The N-7000 recorder is indispensable in a wide range of settings and represents the integration of advanced digital technology and precision engineering into an ergonomically designed PSG and EEG system. This system is designed for routine and expanded sleep protocols, with up to 60 channels and routine EEG functionality [21].
- c. Alice 6 LDxS manufactured by Philips has a total of 31 channels including 5 for EMG, 6 for EEG, 2 for EOG, 3 for dedicated EMG, 6 for EEG referential, 2 for EOG referential, 2 for actimeter inputs and 8 for auxiliary/DC inputs. The maximum sampling rate and storage rate are 2000–500 Hz, respectively [22].

All the systems mentioned above require a large amount of time for system setting up due to the complex configuration. It turns out to be a difficult way to



Fig. 2.2 A paediatric patient wired up for PSG monitoring. Picture and information obtained from Wikipedia http://en.wikipedia.org/wiki/File:Pediatric_polysomnogram.jpg Source <https://en.wikipedia.org/wiki/Polysomnography>, Accessed on 12 July 2017

generalize these available commercial products because of not only the limitation from the cost, but also the unavoidable discomfort caused by a large number of cables and bulky devices. Therefore, a fully wireless monitoring system with the contactless on-body sensor is believed to be the future healthcare monitoring approach.

2.2.2 *Wireless System*

Wireless monitoring technologies have been widely applied in biomedical applications during the past decade. The telemetry monitoring technologies, such as Wi-Fi, Bluetooth, ZigBee and RF transceivers have been extensively studied using commercial RF communication modules. Among these technologies, 2.4 GHz or lower microwave frequency spectra are the most popular frequency bands. In terms of different wireless technologies, Lam et al. [1] used a Bluetooth module of bulky size with mobile phone assistance [1], Hu et al. [2] utilized a ZigBee transceiver relying on mobile phone/PDA assistance², Drinnan et al. [3] used Wi-Fi technology with a PDA and Wang et al. [4], Yazicioglu et al. [5] and Brown et al. [6] used RF transceiver modules. Zaffaroni et al. [7] used a 5.8 GHz transceiver for only body movement and respiration monitoring due to its contract-free design limitation.

2.2.2.1 Contactable System

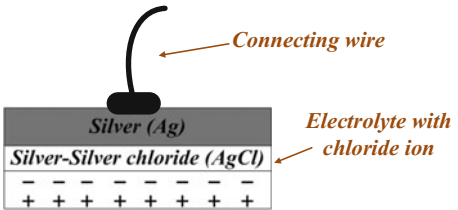
The contactable monitoring system has the sensors nodes which are placed on the human body with contact to the skin of a sleep patient. As introduced in [1–11], the contactable on-body sensors detect the physiological signals through electrode with adhesive firm gels as shown in Fig. 2.3. This approach can easily assist the on-body sensors to collect the weak physiological signals from the surface of the human body, which are normally less than 1 mV [8], [10], [11]. Figure 2.3 shows an illustration of a typical modern biomedical electrode [23]. It has very small offset potential. The AgCl layer is between the silver layer and the electrolyte. The chloride ions move in the body, in the electrolyte and in the AgCl layer, where the current (electron) flows through the Ag plate and the connecting wire.

The electrode as shown in Fig. 2.4 contains conductive Ag/AgCl layers, gel, backing and packaging materials. It is important to consider electrical properties and contact quality when selecting sensors. A high-quality sensor must be durable and stainless. For stud-shaped eyelets, the sensor usually has an Ag/AgCl layer which is placed at the interface to the gel to prevent corrosive effects to maintain its performance and extend its working life. In the market, carbon sensors are also common. As gel quality affects the conductivity of electrical signals, good quality gels can make the on-body sensor durable and sustainable.

2.2.2.2 Contactless System

Non-contact wireless monitoring system normally refers to the physiological signal detection machineries which utilize microwave or radar technologies. One of the successful examples is using Doppler radar for the healthcare monitoring of elderly people, which turns to become a very popular approach due to the contactless implementation method providing a much more comfortable user experience. The challenges in this method are signal processing methods in terms of operating frequencies and distance from the monitored person. Based on this approach, the respiration and heart rate signals can be precisely extracted [24]. Similarly, the method of applying radio frequency spectrum is also proposed in [25], where a low-power frequency-modulated continuous wave (FMCW) radar is used in the remote monitoring of vital signs in patients. The electromagnetic (EM) wave signals reflected from the surface of the patient body or tissue boundaries are measured

Fig. 2.3 A silver–silver chloride ECG electrode with adhesive firm gel in electrolyte layer



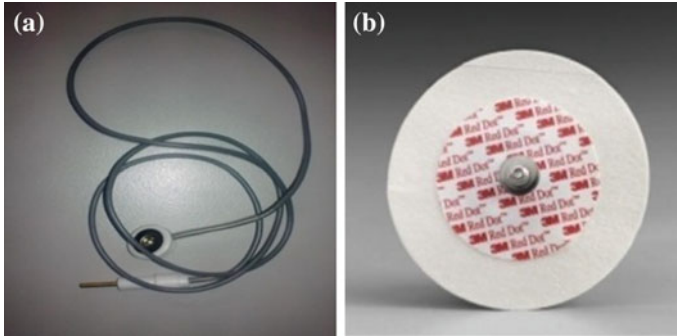


Fig. 2.4 ECG lead and electrode: **a** A single ECG cable with the button side connected to electrode and pin side connected to signal processing circuit, **b** 3 M Red dot with adhesive bottom side

by the gigahertz (GHz) frequency radar. The received signals are processed with time series analysis signal processing method that provides simultaneous information on range, size and reflective properties of the multiple targets in the field of the scope of the radar view. Accordingly, the information of respiration and cardiac rates can be extracted in a real-time scenario. So far we have discussed various sleep monitoring methods available in the open literature and off-the-shelf.

2.3 Challenges and Limitations of Current Monitoring Systems

The primary diagnostic process of potentially serious sleep disorders involves the monitoring of a patient's sleep in a sleep laboratory. Monitoring patients sleep in sleep laboratories has been an area of explosive growth over the last 10 years. However, current sleep monitoring products have the following two major limitations:

- *Patient unfriendliness probes and monitoring system:* Current sleep monitoring products have monitoring wires connected to the patient which convey the signals from the patient to the monitoring computer. These long wires limit movement and create a level of awareness which impedes natural sleep. It is the biggest predicament for clinicians to 'wire-up' a paediatric patient with tens of wires and electrodes due the fear factor and discomfort.
- *The Expense to administer:* Current sleep monitoring equipment requires a hospital/laboratory environment. In the hospital, full-time supervised nocturnal sleep diagnostic monitoring is expensive due to the presence of a full-time nighttime sleep scientist, and space in public or private hospital. Hence, long waiting lists exist. This is a severe problem for paediatric patients.

2.4 Motivations for a Novel Microwave Sleep Apnoea System

Wireless technologies have become more and more popular in various industrial applications since the IEEE communication protocols have been established during the past 20 years. However, academic exploration of wireless technologies in complicated medical applications has commenced only in recent years, and the progress has been slow. The main challenge is the integration and coordination between experts of very diverse disciplines and removing the boundaries of traditional domain-based research practices. Our proposed research plan and project goals will focus on these explorations, the monitoring of sleep apnoea for diagnostic purposes. The project was conducted with the collaboration and sponsorship of clinicians, doctors and the industry sponsor. Significant contributions will be made in the following fields:

- Passive circuit development in 2.4–5.8 GHz wireless monitoring systems for sleep apnoea diagnosis with the following unique contributions in technological development:
 - Compact and conformal microstrip patch antenna design that can easily be integrated with existing wearable transducers;
 - Novel high compact and high selectivity microwave narrow bandpass filter design;
 - Monolithic microwave integrated circuit (MMIC) GaAs high-power amplifier (HPA) design;
 - System cost reduction; and finally,
 - Excellent performance of the antenna for microwave signal penetration capability.
- System integration at 2.4 GHz has made the following unique contributions:
 - Integration of printed circuits with front-end sensor circuits; and
 - A reliable wireless sleep apnoea monitoring machine is taking the place of the traditional cable-connected PSG system.
- 5.8 GHz signal propagation trials in a simulated sleep environment contribute to the following achievement:
 - Experimental results are obtained for proving the signal penetration capability at 5.8 GHz.
- Highly compact 5.8 GHz band design of the wireless communication system provides the following unique attributes:
 - 5.8 GHz satisfies the ISM band for free licences; hence, we do not need to pay royalties to existing technologies such as Bluetooth and ZigBee;
 - Compact size of microwave circuits to meet the WSN requirement and offer comfort to patients; and finally,

- Avoidance of interference with other 2.4 GHz equipment (e.g. cordless home phones, data communication between Bluetooth devices, internet browsing using Wi-Fi from laptops).

Wireless sleep monitoring systems have been a popular research topic in recent years. A number of researchers are exploring the existing standard IEEE wireless LAN protocols in Wireless Broadband-Sharing Network (WBSN) and some research results have been published. However, the application of microwave radio technology in WBSN patient monitoring is still lacking. Based on our proposed RF-based wireless patient monitoring system, we have developed an innovative RF-based transducer for physiological parameter acquisition to contribute to knowledge in this research field.

Our aim is to design an innovative complete RF-based wireless patient monitoring system operating at unlicensed industrial, scientific and medical (ISM) bands of 2.45–5.8 GHz in Australia. The main advantages of this system are as follows:

- Compact wireless physiological parameter measuring transducers operating at 2.45–5.8 GHz;
- Low-cost and compact on-body device;
- Low power consumption; and
- Low-weight transducer for patient comfort.

The concept of the proposed system is presented in Fig. 2.1b. The wireless passive electrodes and transducers are arranged in different areas of the patient body corresponding to the series of monitoring physiological parameters. These wireless sensors/transducers form a wireless body sensor network which communicates with the remote base station for a fast and reliable sleep apnoea monitoring.

2.5 Conclusion

This chapter presents a detailed review of existing sleep monitoring technologies. First, it discusses the functionality and limitations of the traditional wire-based and emerging wireless monitoring systems. Next, a classification of these technologies is presented. The main aim of the work is to investigate the existing and novel wired and wireless monitoring systems for sleep apnoea that are available in open literature and resources. The outcomes of the investigation will be the foundation for the higher level applications of the wireless passive RF monitoring systems for sleep apnoea and other medical condition monitoring applications. We aim to fulfil the research gaps with the development of wireless monitoring system that will replace: (i) the cable-based traditional PSG system, (ii) the contactable wireless monitoring system, and (iii) the non-contact wireless monitoring system. The wireless monitoring transducers and system that are presented in this book has a wide range of applications for ubiquitous wireless monitoring of sleep apnoea patients.

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Microwave Sleep Apnoea Monitoring

Karmakar, N.C.; Yang, Y.; Rahim, A.

2018, XV, 305 p. 186 illus., 126 illus. in color.,

Hardcover

ISBN: 978-981-10-6900-0