

Review of wireless Polysomnography System

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Abstract

In last years , the number of people suffering from sleep disturbance has increased. Traditional polysomnography (PSG) in hospitals or sleep centres records many physiological signals while a patient is sleeping in order to diagnose sleep disturbances. But the enormous number of connected wires needed for conventional PSG is typically one of the main problems that result in sleep disruptions. Traditional PSG devices are not suitable for sleep monitoring at home due to their high cost and big body size. In this review paper, it cover the wireless techniques which used to recorded physiological signal during sleep. Wireless PSG developed systems can be used at home or in the hospital. These techniques could make a PSG test less challenging in particular situations, eliminate the requirement for hospital or healthcare overnight stays, and make self-setup and internet-based diagnostics easier.

Keywords: polysomnography, obstructive sleep apnea and sleep stages .

1.Introduction

Many studies have shown that the causes of death is related to insufficient sleep, where excessive sleepiness leading to risks of motor vehicle crashes and effects causes increased danger of obesity and insulin resistance [1][2]. According to a research, Jane E et al. [3], a large percentage of the world's population suffer from sleep disorder, about 30% of adults suffering from wakefulness ,also, spread of obstructive sleep apnea is 9 to 21 % , which increases in male from 24 to 31%. Therefore , it has become necessary to have techniques to monitor state of sleep. Different techniques are employed by PSG to concurrently and continuously record physiological parameters while a person is sleeping. PSG gives information about the relationship between the physiological changes that occurring in different organ, and sleep stages and wakefulness. Additionally, PSG techniques allow for the quantitative and qualitative documentation of sleep disturbance, the change from sleep to awake, and the functions of sleep-affected organs. A lot of these do not appear during wakefulness, such as sleep apnea. The use of PSG is crucial for diagnosing a range of sleep disorders, including those that affect breathing during sleep (including obstructive sleep apnea), behavior, and repetitive sleep movements. All-night PSG recordings, involving electroencephalograph (EEG), electrocardiograph (ECG), electrooculography (EOG), and electromyography (EMG), are typically obtained from patients for sleep diagnosis, and the recordings are assessed by a qualified professional by the Rechtschaffen and Kales (R&K) guidelines published in 1968 [4]. According to the number of parameters being assessed, the American Academy of Sleep Medicine (AASM) has

divided PSG procedures into four categories, ranging from sophisticated (class I) to simple (class IV) [5]:

- 1) level-I and level-II are distinguished by EEG measurements with more than seven physiological signals, such as EOG, EMG, respiratory flow. Sleep parameters are evaluated in essentially the same manner in which they are in Level-I (conventional PSG) and level-II, with the exception that there is no monitor screen and

no trained staff to confirm constant capture performance in level-II. Because so many sensors, wires, and pieces of equipment are attached to various parts of the body, these procedures have an impact on patient comfort and sleep quality. PSG class I requires a technician to be on-call all the time and an overnight stay at a sleep facility. These problems impact sleep itself. Long waiting lists are caused by the fact that these PSG procedures require expensive examinations that are typically out of the reach of the majority of people, even in wealthy nations [6]. This prolonged waiting period raises the possibility of unanticipated dangers for the development of sleep comorbidities and job loss. Moreover, the first-night effect for the individual could be brought on by sleeping in a strange setting, like a hospital [7].

- 2) _Cardiorespiratory parameters can be evaluated using Level-III unsupervised recording devices. They don't capture EEG, EOG, or chin EMG, making it impossible to determine alertness and sleep stages directly from their data. The class III PSG could identify sleep apnea.
- 3) Measures at least one parameter, typically oxygen saturation, to record a single or dual continuous bio-signal at Level IV. The PSG accuracy is unable to identify the majority of sleep disorders because it only has one or two sensors [8] .

1.1 Sleep stages

The laborious process of determining the sleep stages captured by the PSG is referred to as "scoring" or "staging" sleep stages. Three bio-signals must be recorded by the PSG in order to determine the stages of sleep: EOG, chin EMG, and EEG. Conventionally, the continuously recorded EEG is analyzed in epochs of 30 seconds [9]. The EEG signal is the most dependable non-invasive method for staging sleep [10], sponsoring more and more projects [11][12][13][14]. "non rapid eye movement (NREM) and rapid eye movement (REM) are two common categories for human sleep " . The three stages of

NREM sleep are as follows: The shortest stage of sleep is N1, the true beginning of sleep occurs when stage N2 appears, Stage N2 is characterized by high EMG signal amplitude, then a decrease in body movements. and The longest sleep stage is condition N3 ("referred to as slow-wave sleep or SWS") [15]. Approximately each ninety minutes, REM and NREM sleep alternate. Usually, there are 4-6 cycles of REM and NREM sleep during overnight sleep recordings (such as 6–8 hours) [16]. Based on recording the electro-potential difference between the cornea and the retina, EOG detects eyeball movements. EOG should be recorded for two different purposes. The first is the recording of REM, and the second is the evaluation of sleep beginning, which is characterized by slow rolling eye motions. EMG measures the chin's muscular tone. It is a necessary recording parameter for REM sleep staging and is crucial to identifying the start of REM sleep [17]. Studying sleep-dependent memory consolidation and overnight epilepsy recording can be done using the EEG, EOG, and EMG. [18][19].

1.2 Obstructive Sleep apnea

The obstructive sleep apnea (OSA) is quite common around the world. Health and quality of life are negatively impacted by the OSA problem, and it also has detrimental effects on the body's systems, including cardiovascular disease, cognitive dysfunction, and respiratory failure [20]. OSAS affects 1.2% to 7.5% of the general population and is a very common disorder [21][22][23][24].

According to reports, there are more than 936 million OSA patients globally, with 176 million of them living in China [25][26][27]. Other kinds include sleepwalking, narcolepsy, insomnia, and restless legs syndrome. Obstructive sleep apnea is a syndrome that causes the collapsible portion of the upper airway to repeatedly become completely blocked (apnea) or partially blocked (hypopnea) when a person is sleeping; the condition is linked to excessive daytime sleepiness or chronic exhaustion [28]. Numerous studies have shown that OSA is associated with a higher risk of accidents, cognitive decline, and cardiovascular conditions [29]. In contrast to individuals who do not have OSA, it may be argued that OSA patients who are excessively sleepy throughout the day have a reduced attention span and may be more likely to be involved in accidents. The detection of nasal airflow and chest and abdominal motion is crucial for sleep apnea [30]. In research, accelerometers are widely used to measure body posture or patient movements [31], where body position when sleeping affects the frequency of apnea and snoring [32][33].

The type III portable monitor (PM) and traditional PSG are the primary diagnostic tools for OSA.

1.2.1 Conventional PSG

Contrary to other illnesses like cancer, obstructive sleep apnea cannot be identified with a tissue biopsy. Thus, it is challenging to calibrate any test for OSA diagnosis because there is no standard by which to establish the genuine illness status. As a reference standard for the diagnosis of OSA, PSG in a monitored setting (sleep

laboratory) has historically been utilized. This necessitates keeping an eye on patients while they sleep [34][35]. A patient spends the night in the sleep lab under a technician's close supervision. Pulse oximetry, EEG, EOG, EMG, ECG, respiratory effort or movement, nasal or oral airflow, and limb movement electromyography are all components of PSG.

PSG therefore keeps track of heart rate, breathing exertion, oxygen saturation, body position, and limb movements. The apnea-hypopnea index (AHI), also known as the respiratory disruption index (RDI), is determined using these data. Apnea is defined as the lack of airflow for less than 10 seconds, while hypopnea is defined as a drop in respiratory effort with less than 4% oxygen desaturation. The AHI is the total of all apneas and hypopneas throughout a sleep cycle. Apneas, hypopneas, and aberrant respiratory episodes added together for each sleep hour make up the RDI.

1.2.2 Portable OSA recording techniques

The "gold standard" for identifying OSA and determining its riskiness is PSG. There are only three signals for respiratory airflow, chest and abdominal movement, and blood oxygen in a type III portable device, which is dependent on the PSG and streamlines the monitoring channels. Patients with comorbidities but moderate to severe OSA may be diagnosed using portable PSG [30]. Wearable sleep and respiratory monitoring is becoming popular thanks to the continued development of monitoring technology [36]. Manoni et al. created a device that must be worn on the bridge of the nose and is therefore likely to be uncomfortable by combining photoplethysmography, accelerometer, microcontroller, and Bluetooth transmission. The device was tested in a lab setting with a small sample size, and it has not been determined whether screening for OSA in the general population is feasible or accurate [37]. The first mobile applications, HealthGear [38], analyzes blood oxygen levels to detect sleep apnea. The OSA detection algorithms in the application correctly recognized all three cases of known OSA with 100% accuracy when it was tested on 20 participants. An oximeter and an accelerometer were also employed by Cao et al. [39] in their study to identify sleep apnea and other respiratory disorders. According to their research, body position can offer further data for analyzing respiratory action. The technique was applied in an experiment to recognize apnea and hypopnea in real time. An automatic count of AHI was performed after the apnea and hypopnea were identified.

A smart phone-based tool to screen for OSA was created by Behar and Al-Mardini. Despite being an inexpensive screening tool, the gadget needs wearing arm bands, microphones, and pulse oximeters [40][41].

An paper on the viability of employing cellphones and their integrated sensors to detect sleep apnea was published by Alqassim [42]. A non-invasive, wearable neck-cuff system for monitoring sleep in real time and visualizing physiological information was created by Rofouei et al. [43]. In their study, Only one subject's

diagnosis the one that was put up against the gold standard was accurate.

1. Wireless Polysomnographic techniques

In 2005 and 2007, a variety of research came to light that revealed that in highly chosen populations, the results of using continuous positive air-way pressure (CPAP) devices were at least similar when compared to portable PSG [44].

Several studies have found that two different strategies reduce patient suffering :-

I. sensor methods

The adoption of innovative sensor techniques, such as the non-invasive physiological Radar Monitoring system (PRMS), presented by Mehran Baboli [45], wireless Sleep Apnea Detection using quadrature microwave Doppler radar, eliminates the need to apply sensors to the body. An algorithm was created to detect sleep apnea and actigraphy in real-time. A modules to generated microwave signal in frequencies 2.4GHz and a 24GHz are used in the PRMS monitoring system as shown in Fig. 1 to accomplish great resolution and sensitivity.

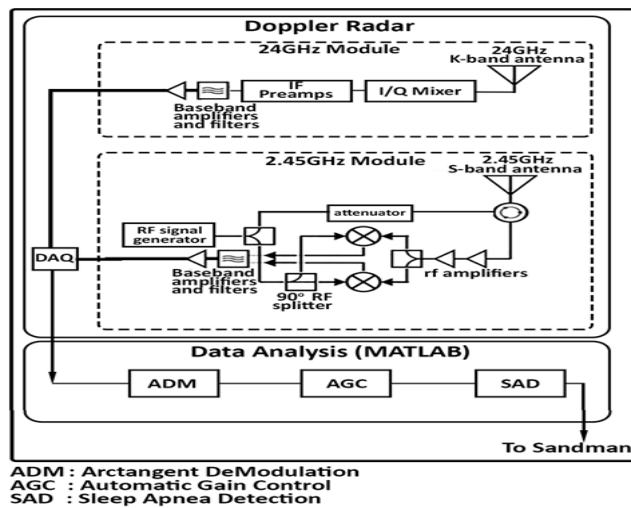


Fig.1 Diagram of the PRMS [45]

Fig.2 shows the entire setup of the experiment. The subject was the only person in the room when the test was being conducted. An observation room was used to remotely monitor the subject.

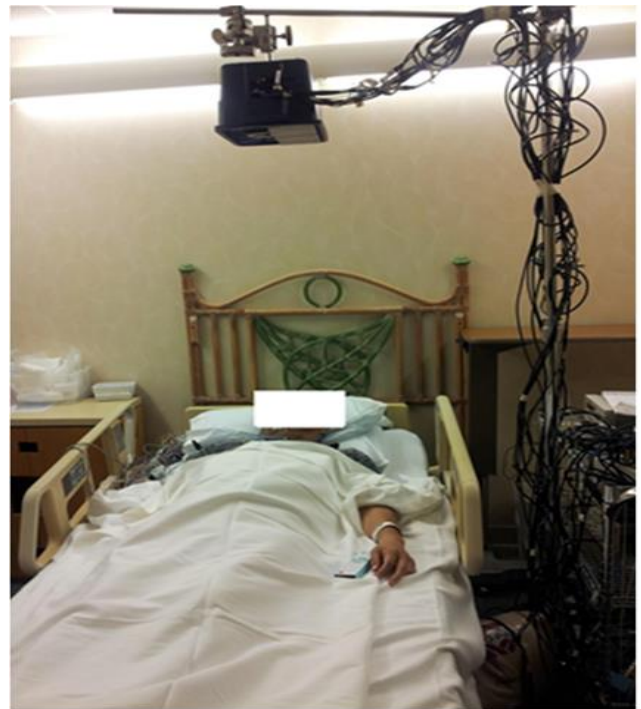


Fig.2 Monitoring of an experiment for sleep disorders [45].

An inexpensive sleep monitoring system for patients utilizing conventional PSG has been developed by Lokavee et al.[46], and it will be helpful for patients to communicate with medical personnel and/or family members. They also put up a straightforward motion model to describe how the distribution of pressure on the head and body can alter. Additionally, they could record respiration rate as it related to other physiological aspects while in various stages of alertness and sleep.

Figure 3 shows the schematic for the automatic care system for recording body movement (BM) and respiration rate (RR) when a person is sleeping. The system is made up of the following three main parts: (1) Force sensing resistors (FSR) based on polymer thick film (PTF) technology integrated on the bed sheet and cushion as input devices; (2) wireless devices based on affordable ZigBee technology for acquiring and wirelessly transmitting data of the FSR arrays to PC or monitoring device; and (3) software to analyse and classify posture movements and respiration rate. Fig. 3 illustrates the design of this sleep monitoring system.

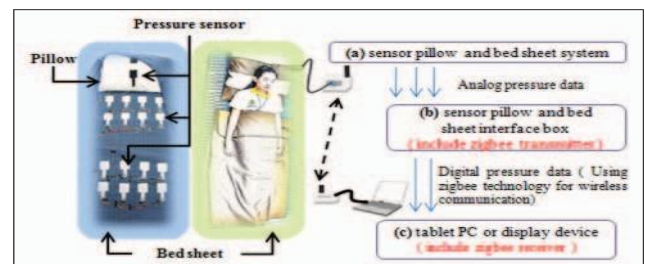


Fig.3 ZigBee technology was used in the conceptual drawing to portray the cushion and bed sheet as a wireless network monitoring system for breathing rate and sleep body movement (BM)[46].

However, the expensiveness and limited monitoring capabilities of the new sensor technologies, together with their low accuracy, make them unsuitable for use in home healthcare. This makes the environment for diagnosis less suited.

II. modular PSG solution

A spread PSG system that is more suited and has the ability for use at home was proposed and implemented by Da-Wei Chang et al. [47]. The creation and use of a more practical, distributed, and modular PSG system with potential for home recording. To lessen sleep disruption caused by recording wires, it is made up of numerous, compact, inexpensive, and wirelessly coordinating signal collection nodes. every node collects particular bio-signals in a restricted anatomic location. Fig. 4 shows the location of detectors and data collection models. The model is composed of three data collection nodes that are directly attached to the patient's head (H-node), currently attached to the subject's waist (w-node), and carried on the patient's wrist (W-node).

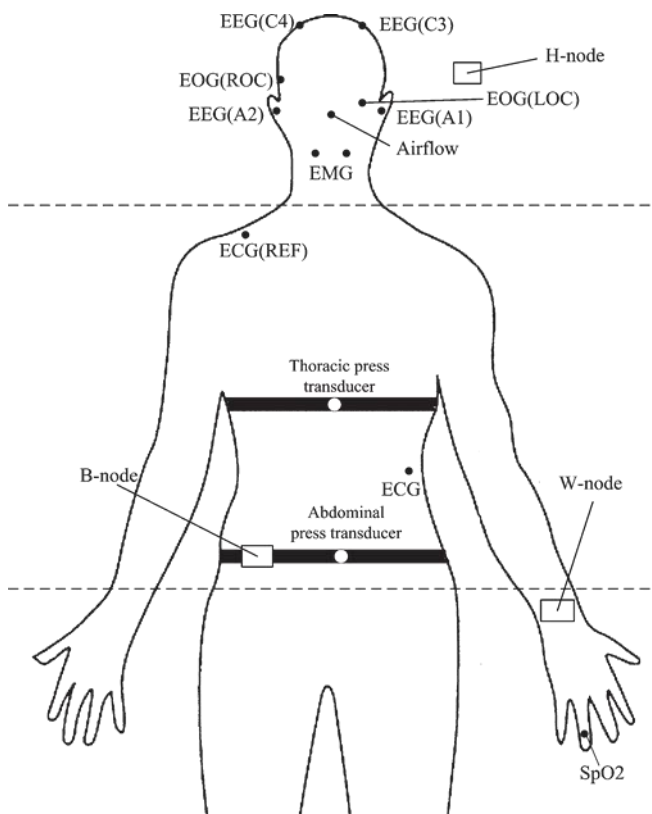


Fig.4 three data collection nodes' and detectors positions [47].

Three nodes were used in the system to collect EEG, ECG, EOG, and SPO2 signals. Each node had a microcontroller board for data sampling, a storage board, and circuitry for signal amplification and filtering. The block diagram of the suggested PSG is shown in Fig. 5.

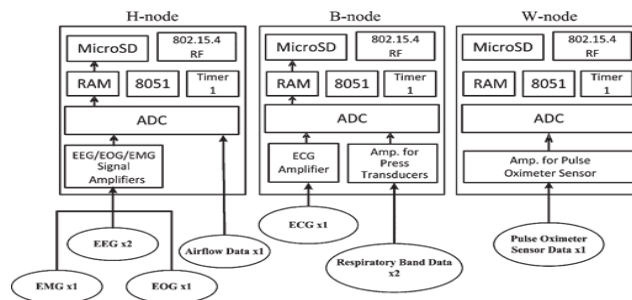


Fig.5 Block diagrams of the nodes that collect data [47].

The lack of specialist boards in the system raises system volume and patient suffering. Furthermore, this design doesn't keep records of environmental variables.

An Internet of things based wireless PSG system for sleep recording is implemented by Chin et al. [48]. This system makes use of a battery-operated, tiny, wireless, portable, and multipurpose recorder. The personal computer is equipped with a Java-based PSG recording tool that can record several bio-signals and export them in European data format. The patient's sleep stages can be determined from these PSG records, and OSA can be identified. A comparison between the traditional "PSG-Alice 5 Diagnostic Sleep System" and the presented system by Chin and his colleagues was conducted to show the viability of their PSG system. Under the guidance of experts at the Sleep Laboratory in Taipei Veteran General Hospital, a number of healthy volunteers took part in the PSG experiment and were simultaneously monitored by the conventional "PSG-Alice 5 Diagnostic Sleep System" and Chin's system. Their system is trustworthy and practical when compared to the results of the time-domain waveform and sleep stage of the two system.

On the course of a nighttime sleep cycle, the volunteer is wearing a proposed system that is designed to continuously collect different signals. This wearable, battery-operated module is a mobile acquisition system. The consumers would find it comfortable and simple to set up. First, the module continuously measures a variety of bio-signals. The filters in module filter out all noise outside from the frequency band of the multiple signals after amplification of the tiny multiple bio-signals. Then, the analog-to-digital converter digitizes the filtered multiple bio-signals, which are then transmitted over Bluetooth to the computer. The computer based software was created using "Java" and is designed to take digitalized raw data from portable capture module, decode raw data, show raw data in real-time, and store raw data in a standard format. The network can be used to send the recorded records to a hospital where they can be examined by autoscoring software and verified by a doctor. The PSG test is made simpler through an examination of the autoscoring software and the clinician's validation, and patients' sleep monitoring can now be done at home. portable PSG system facilitates more accustomed and regular sleep patterns while being simpler and more comfortable for the patient. The voltage and frequency ranges of some common signals are illustrated in Fig. 6, which is a representation of the portable acquisition device for different types of detectors.

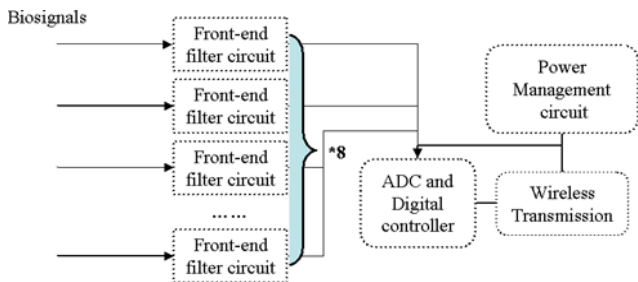


Fig.6 Illustration of a portable bio-signal acquisition system [48].

The hardware of the portable PSG device is shown in Fig. 7. The portable EEG device has 12 leads, 6 ECG inputs, 2 airflow inputs, 3 references, and 1 ground

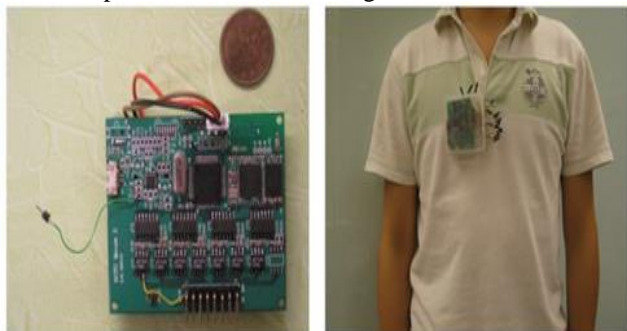


Fig.7 The portable PSG system [48].

To study the classification of sleep stage, Sung et al.[49], developed a wireless PSG system . Its less energy consumption and can be worn on the head, the direct sleep-stage classification is carried out using an algorithm. As shown in Fig.8, the recommended wireless PSG has two processing methods for analysis and monitoring of signals in a double process control structure for sleep study. First off, by using a sensor module to detect a variety of signals, including EEG, EMG, and EOG. Then the signal processing pathway is classified into the display mode and the analysis mode, based on the user's objectives.

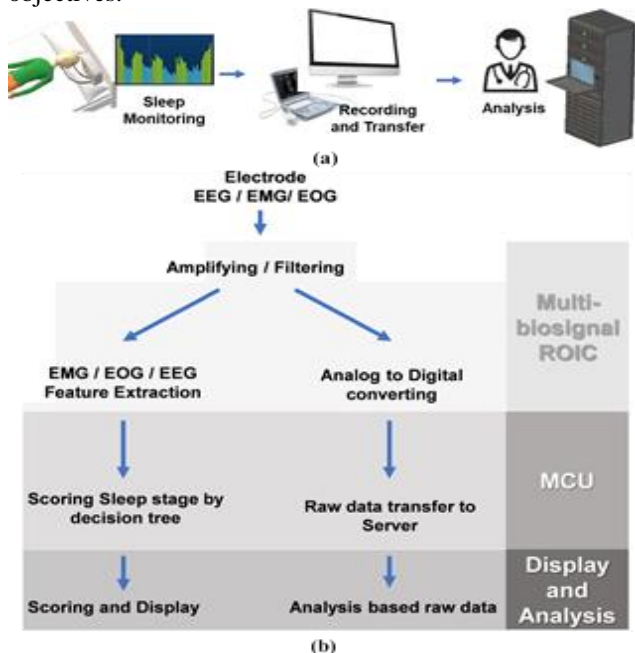


Fig.8 Proposed embedding of the sleep analysis process (a) traditional post-processing technique and (b) simple approach for classifying sleep stages [49].

The system's electrode placement, which is based on the global 10-20 system ((standard electrode positions are at 10% and 20% intervals of the distance between the nasion (root of the nose) and the inion (occipital protuberance) on a line in a sagittal plane over the vertex, and on a line connecting the left with the right preauricular point in a coronal plane)) is shown in 9(a). A sensor module prototype with a low energy consumption " MCU (STM32L4)", a Bluetooth module("HC-06"), and "ROIC" sensor is shown in figure 9(b). Wireless connections to the desktop computer and smartphone are supported through its BT-based monitoring interface. A prototype headband called the "Smart Headband" is shown in 9(c).

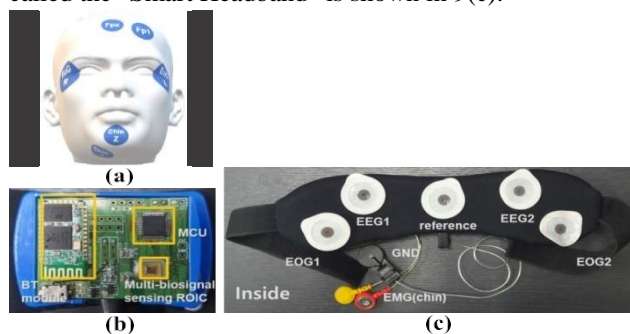


Fig.9 Sleep monitoring multi-bio-signal interface developed: (a) arrangement of electrodes, (b) sensor unit, and (c) intelligent headband [49].

In their alternative class III polysomnography method, Felipe et al. [50] collected environmental factors in addition to patient biological data including ECG, ECG-derived respiration (EDR), and EOG. The boards are capable of receiving a variety of signals from the patient and the surrounding area. As a result, a skilled physician can identify and differentiate between the sleep stages. On the patient's body, just the EOG board (size 82×60 mm) should be placed ; all other modules should lie by the night table. This approach is necessary since the system is tasked with collecting environmental parameters.

The ECG board (size 81×40 mm) collects the ECG signal and measures trunk posture in addition to having the capacity to collect and store data from two external accelerometers and a commercial SpO₂ module. The ACC module (size 54×28 mm) is attached to the patient's right ankle and uses a triaxial accelerometer to capture and record the patient's limb position and motion. There are just two limitations that apply when using the boards in this proposed PSG , the first restriction is that the boards must be battery-powered. Given that the boards' 750 mAh batteries can power at least 16 continuous hours of sleep tracking, the first constraint need not be an issue. The synchronization of all the boards is required before data collecting can begin, which is the second restriction. By interfacing the three boards, and depressing a button on the EOG board for two seconds, the synchronization is accomplished. Figure 10 illustrates this method of wiring procedure.

The functionality of the other modules won't be harmed by the removal of any module from the system. If a system of this kind is required, this crucial characteristic enables a less obtrusive sleep monitoring system. It is also conceivable, but with limitations, to monitor patient signals such as EMG and EEG using boards like those described in this work.

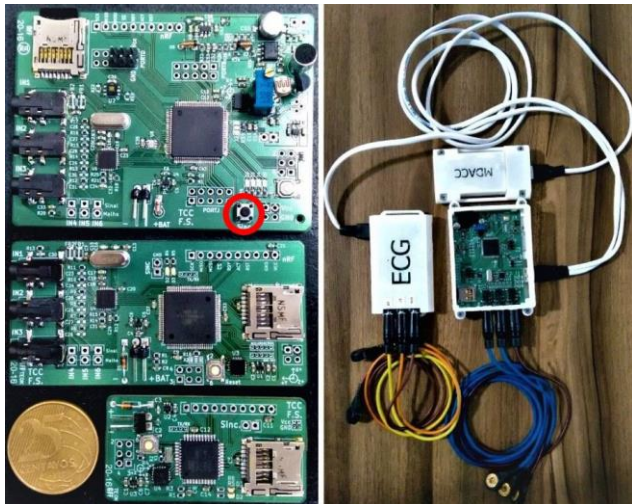


Fig.10 Completed modules are displayed in the following order from top to bottom: EOG, ECG, and ACC boards. The coin is 25 mm in diameter. The synchronization button is highlighted in red by the circle. On the right, The data acquisition must begin simultaneously with the prototype encapsulation and any wire connections [50].

Lun et al. 2020, [51] designed and implemented a multifunctional wearable device to monitor sleep physiological signals. A wearable device constructed on an "Adafruit Circuit Playground Express (CPE) board" and equipped with a "photoplethysmographic (PPG)" optical sensor for heart rate monitoring, as well as numerous embedded sensors for medical applications, particularly the monitoring of physiological signals during sleep. Due to its low cost and ease of use for detecting changes in blood volume in micro vascular tissue beds, PPG, an optical technique, is frequently employed for heartbeat detection [52]. Figure 11 shows a diagram of the hardware for the portable bio-signal acquisition unit as well as the physiological sleep signal monitoring system. Motion, ambient light, noise, and temperature were all detected by the gadget using sound, light, triple-axis acceleration, and temperature sensors that were all built into a Circuit Playground Express (CPE) board. The CPE board is 50 mm in diameter and 1.6 mm thick. The CPE's 2-MB flash storage, which can hold data from all the sensors needed for data analysis for up to 12 months, was used to store the collected data. To detect heartbeats, a PPG optical sensor (green light, 570 nm) was also utilized.

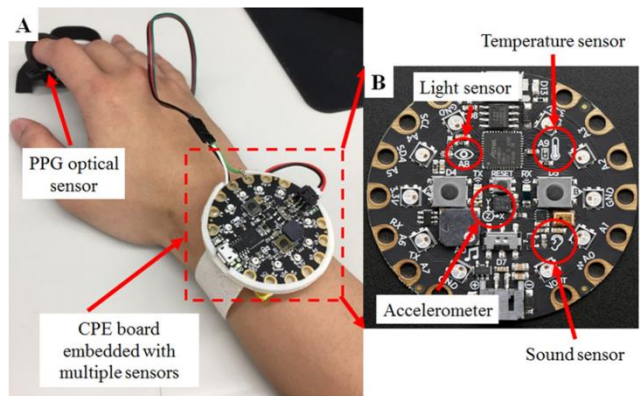


Fig.11 Diagram of the hardware for portable biosignal acquisition unit and sleep signal monitoring system. [51].

A study by Younes et al. [53], examined whether the signals produced by the Prodigy (traditional name) sleep monitor are equivalent to those produced by in vitro PSG. Fifty-nine patients with varied sleep problems were examined, including 25 with moderate to severe sleep apnea. Using common acquisition methods, a full PSG was carried out. Four reusable snap electrodes were used to affix Prodigy to the forehead. The installation of four more electrodes served as a reference and a means of observing ocular and muscle activity (mastoid). A single frontal EEG signal was output in real-time from the monitor and recorded alongside the other PSG signals in the PSG record. PSG was manually analysed for sleep characteristics while a validated automatic system, Michele Sleep Scoring (MSS) (MSS-Prodigy) which just needs one central electrode in addition to ocular and muscular electrodes was used to score monitor records. They pointed out that even in individuals with severe sleep problems, the signal scored using MSS and with only very modest editing, the findings show high agreement with manual scoring of PSG data.

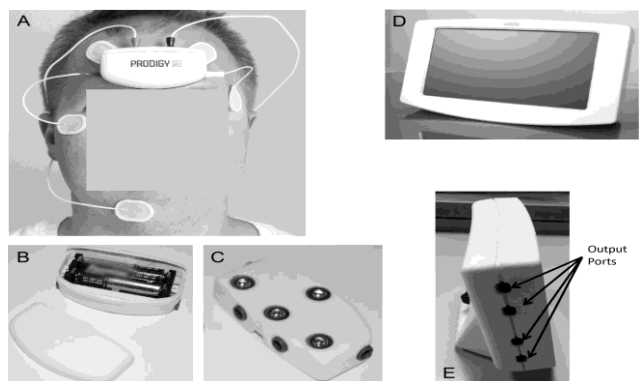


Fig.12 pictures of the device. (A) The numerous electrodes are located on the forehead-mounted head-mounted unit (HMU). (B,C) The battery compartment and the rear snaps are visible on the HMU's front and back. (D,E) Views of the table-top unit's front and sides (TTU)[53].

By contrasting an out-of-laboratory recording method for screening sleep disorders with an in-laboratory system that does full PSG, William et al. [54], demonstrated the

validity of the out-of-laboratory recording system. There were no discernible variations in the measures of sleep efficiency, RDI, periodic leg movement index (PIM), or desaturation index, according to the data.

The validity of a new portable PSG recorder was compared to a laboratory-based PSG device from the same factory by Ivanka J et al.[55], On 20 patients who had been referred for a sleep apnea evaluation, simultaneous, full PSG recordings from the portable device (PSGP) and the laboratory-based system (PSGL) were obtained using different sets of sensors. In the other 10 patients, the signals were reviewed on a laptop computer screen, and the electrode or sensor placement adjustments were made as necessary throughout the studies. Unaware of the source of the data, a techie manually scored recordings. Except a modest decline in respiratory signal quality during PSGP tests, which reduced confidence in respiratory event scoring, the signal quality between the PSGL and PSGP investigations was comparable. The apnea-hypopnea index and sleep factors showed good agreement between PSGP and PSGL.

By contrasting wireless dry headband device for sleep monitoring (named-WS) with concurrent polysomnographic (PSG) recording in healthy young people, Lorenzo T. et al.[56], investigated the validity and reliability of the method. To distinguish between wake, light, deep, and REM sleep, the WS was compared to PSG. They discovered that there was moderate to high agreement between PSG and the WS, with wakefulness detection being a WS limitation.

The WS was designed to monitor sleep in the house and other places. Using a dry fabric headband, the system captures a single-channel signal from the forehead and wirelessly transmits it to a base station, where an automated algorithm scores the various stages of sleep in real time, John R et al [57].



Fig.13 Three dry silver-coated cloth sensors are included in the headband, which is roughly the size of a tennis headband [57].

Alexander T et al.[58], their studies found that, " the automated wireless PSG system to monitor sleep bio-signal in healthy adults may provide an easy- to- use and accurate complement to other established technologies for measuring sleep ".

Annika H et al.[59], presented a study to examine the extent to which portable PSG has an effect on objective (measured via actigraphy) and subjective (measured via sleep-log) sleep signals. Thus, it must be evaluated in the reasonableness of portable-PSG in scientific sports field investigations. The results indicated that there were no statistically significant differences between nights with or without the portable-PSG application for all objective and

subjective sleep parameters. Its use seems reasonable without affecting sleep quality significantly.

Validation of portable PSG devices is a difficult task as it compared with PSG. Even though it is regarded as the standard PSG has drawbacks that must be acknowledged. For example, AHI results changed depending on the subject's observational conditions, such as the night of observation or the observer [60], spending more time lying down than usual sleeping [61], and having difficulty sleeping in an unfamiliar environment [62].

Calculating the number of abnormal breathing events during each type of recording provides additional issue when comparing the results of portable PSG with traditional PSG. PSG generally determines the average number of breathing events per hour of sleep by dividing the total number of breathing events by the total amount of sleep time, in hours. The average number of abnormal breathing events in portable PSG, however, are calculated based on the total recording time rather than total sleep time, which could result in an underestimation of the rate of those occurrences when compared to PSG [63][64].

the possibility of data loss increases when a large volume of wireless data was because of interference and collision [65][66], therefore the designer stores PSG signal data in memory and then read it by a personal computer or send it to few distances.

Table2 show the differences between the presented studies about wireless PSG

Authors	Target signal	Communication	Comparison with commercial PSG	Size mm
Da- Chang et al.[47] 2012	ECG,EOG,EMG, airflow , spo2 and abdominal pressure	Instead of sending the sampled data across the wireless channel, each node stores it temporarily .	compared to a commercial PSG equipment, showed a very high consistency (> 93%).	50×50×32(H-node) 35×68×29(B-mode) 45×67×29(W-mode)
CHIN et al.[48] 2017	ECG, EOG,EEG,EMG and airflow	bio-signals are transited to the PC via Bluetooth	In terms of performance and quality, the proposed system performed comparably to the industry-standard PSG-Alice 5 R Diagnostic Sleep System.	65×50×8
Sung et al.[49] 2020	EEG,EOG and EMG	In order to provide wireless connections to both the desktop computer and the smartphone, the Bluetooth module (HC-06) is implemented.	Comparative studies with the findings of post-processing analysis from the OpenBCI module [67][68], whose sleep-stage detection demonstrates a respectable correlation of 74% for four sleep phases, serve as functional validation.	The module box size is 35 × 45 the headband size is 30 × 120
Felipe et al.[50] 2018	Patient signals (ECG, EOG, and body and limb position), ambient factors (temperature, humidity, visible light intensity, and audible noise level)	Every second, each board delivers a packet of data it has collected to its own SD card.		EOG board (82×60 mm), ECG board (81 × 40 mm), And module (54×28 mm) recording and saving the patient's limb position and movement
Lun et al.[51] 2020	Motion detection, photoplethysmographic (PPG) optical signal ,sound, ambient light and temperature	Stored data in memory of the board and then transmitter to personal computer	Compared with ActiWatch2 (Philips North America Corporation) [69] ,The average difference was 1.36%	50 mm in diameter and 1.6 mm in thickness

Conclusion

In the relatively new field of sleep medicine, PSG has emerged as a key technique. The widespread use of PSG in clinical settings and research has been greatly aided by technological advancements. Researchers have produced a low-cost, wireless-based, small, and modularized PSG that outperformed a traditional PSG. The sleep stages identified by recorded EEG, EOG, and EMG signals, the obstructive sleep apnea introduced when recorded the ECG, air flow, and SPO₂ signals. Most authors presented a design for wireless PSG system which had a small size and low cost, these features made the system more comfortable and the possibility to use out sleep laboratory. To avoid data loss, the authors store the pickup bio-signal in memory, then send it to a personal computer by wire interface. There are a lot of problems encountered by the authors, one of them being the synchronization between the bio-signals boards in the PSG system presented by Felipe et al. in 2018. The lifetime of the battery was another issue cause the wireless PSG system should record the signals for long hours of sleep at night. The proposed PCG system composes of EEG, EMG, EOG, SPO₂, and ECG boards and also measures the person's temperature and pressure, system detected sleep stages and sleep apnea at the same time. The proposed system included transmitter and receiver RF boards to send the row data wirelessly to a person computer which is at least one hundred meters away from patient.

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