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IoT-based Wireless Polysomnography Intelligent System for Sleep Monitoring

Chin-Teng Lin[1], *Fellow, IEEE*, Mukesh Prasad[1], Chia-Hsin Chung[2], Deepak Puthal[3], Hesham El-Sayed[4], Sharmi Sankar[5], Yu-Kai Wang[1], Jagendra Singh[6] and Arun Kumar Sangaiah[7]

[1]Centre for Artificial Intelligence, School of Software, FEIT, University of Technology Sydney, Australia
[2]Institute of Computer Science and Engineering, National Chiao Tung University, Hsinchu, Taiwan
[3]School of Electrical and Data Engineering, FEIT, University of Technology Sydney, Australia
[4]College of Information Technology, UAE University, Al Ain, United Arab Emirates
[5]Department of Information Technology, Ibri College of Applied Sciences (MoHE), Sultanate of Oman
[6]Department of Computer Science, Indraprastha Engineering College, Ghaziabad, India
[7]School of Computing Science and Engineering, VIT University, Tamil Nadu, India

Email: [1, 3]{chin-teng.lin, mukesh.prasad, deepak.puthal, yukai.wang}@uts.edu.au, [2]verachung.cs96g@nctu.edu.tw, [4]helsayed@uaeu.ac.ae, [5]sharmi.ibr@cas.edu.om, [6]jagendrasngh@gmail.com, [7]sarunkumar@vit.ac.in

***Abstract*—Polysomnography (PSG) is considered the gold standard in the diagnosis of obstructive sleep apnea (OSA). The diagnosis of OSA requires an overnight sleep experiment in a laboratory. However, due to limitations in relation to the number of labs and beds available, patients often need to wait a long time before being diagnosed and eventually treated. In addition, the unfamiliar environment and restricted mobility when a patient is being tested with a polysomnogram (PSG) may disturb their sleep, resulting in an incomplete or corrupted test. Therefore, it is posed that a PSG conducted in the patient's home would be more reliable and convenient. The Internet of Things (IoT) plays a vital role in the e-Health system. In this paper, we implement an IoT-based wireless polysomnography system for sleep monitoring, which utilizes a battery-powered, miniature, wireless, portable, and multipurpose recorder. A Java-based PSG recording program in the personal computer is designed to save several bio-signals and transfer them into the European Data Format. These PSG records can be used to determine a patient's sleep stages and diagnose OSA. This system is portable, lightweight, and has low power-consumption. To demonstrate the feasibility of the proposed PSG system, a comparison was made between the standard PSG-Alice 5® Diagnostic Sleep System and the proposed system. Several healthy volunteer patients participated in the PSG experiment and were monitored by both the standard PSG-Alice 5® Diagnostic Sleep System and the proposed system simultaneously, under the supervision of specialists at the Sleep Laboratory in Taipei Veteran General Hospital. A comparison of the results of the time-domain waveform and sleep stage of the two systems shows that the proposed system is reliable and can be applied in practice. The proposed system can facilitate the long-term tracing and research of personal sleep monitoring at home.**

Keywords: Polysomnography (PSG), JAVA, Internet of Things, wireless, sleep monitoring

I. INTRODUCTION

The Internet of Things (IoT) is a promising technology for smart applications, such as health monitoring and online data processing [48-50]. However, the major concern about IoT deployment is data security [51] and energy efficiency [52]. To address this issue, we focus on developing an IoT framework-based sleep monitoring system. Sleep is a natural state of bodily rest observed in humans and other animals. A sleep disorder is a medical disorder of the sleep patterns of a person or animal. Obstructive sleep apnea (OSA) is the most common type of sleep-disordered breathing. The term "sleep disordered breathing" is commonly used in the US to describe the full range of breathing problems during sleep in which not enough air reaches the lungs (hypopnea and apnea). Sleep disordered breathing is associated with an increased risk of cardiovascular disease, stroke, high blood pressure, arrhythmias, diabetes, and accidents [1-4].

Some sleep disorders are serious enough to interfere with normal physical, mental and emotional functioning. People who complain of daytime fatigue or sleepiness may be suffering from interrupted sleep, which results in daytime sleepiness and an inability to concentrate, which may lead to accidents [5], hence it has a direct impact on the patient's quality of life. In recent years, in Europe, America, and Japan, sleep disorders have become one of the main focuses of public safety.

Obstructive sleep apnea syndrome (OSAS) [44] as evaluated from PSG data was scored by clinical experts using standard procedures and criteria [6]. Sleep disorders are a major public health problem, affecting up to 5% of the world's population [6], with levels reaching as high as 4% for men, 2% for women, and 3% for children [7]. The American Association of Sleep Medicine [AASM] published initial practice parameters regarding the use of Portable Monitor (PM) devices in the assessment of OSA in 1994 [8]. Many studies have been carried out for OSAS screening in an attempt to reduce PSG cost and complexity. Different techniques have been proposed, oximetry-based screening being one of the most widely suggested for both the adult and pediatric population. Although these methods have high sensitivity, they tend to have very low specificity [9]. The ASSM sleep apnea evaluation studies based on the number of channels or signals that the monitor employed, from level I to level IV. A minimum of 6 hours of recording time was recommended when using any of the configurations.

A sleep lab may be in a hospital, a free-standing medical office, or in a hotel. A sleep technician should always be in attendance and is responsible for attaching the electrodes to the patient and monitoring the patient during the study. After the test is completed, a 'scorer' analyzes the data by reviewing the study in 30 second 'epochs' [11].

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The objective of the meta-analysis in [12] is to compare the accuracy of home sleep studies with laboratory polysomnography in the diagnosis of OSA. Home sleep studies provide similar diagnostic information to laboratory polysomnography in the evaluation of sleep-disordered breathing but may underestimate the severity of sleep apnea. The lower cost of home sleep studies makes it a viable screening tool for patients with suspected OSA; however, these lower costs are partially offset by the higher rate of inadequate examinations.

The primary end point examined is the ability of PM devices to confirm or rule out disease. The AASM guidelines [15] allow for the use of PM devices under certain conditions. These include the lack of available polysomnography for patients with severe clinical symptoms consistent with OSA, the inability of the patient to be studied in a laboratory, or to evaluate the response of a patient who has already undergone traditional in-laboratory polysomnography to therapy. A number of limited-channel, in-home devices for the diagnosis of OSA have been described in [10, 13, 14, 16-22, 45]; however, as a group they have not been recommended in the published practice parameters for in-home unattended studies [15, 23]. The primary reason given is the lack of acceptable validation studies. However, when a scheme classifying sleep apnea diagnostic systems into levels of complexity is used to simplify comparisons [23], it has the effect of obscuring the validity of individual devices with acceptable validation studies.

However, there are several limitations of PM devices that must be considered as well. These include the inherent lack of an attendant during the study, which may potentially affect data quality. In addition, the most widely used applications of PM technology do not have electroencephalogram (EEG) channels and are unable to assess the sleep architecture of staging. This inability does not allow for the computation of the apnea-hypopnea index (AHI) because total sleep time cannot be calculated.

While clinicians have increasingly turned their attention to this syndrome, and referrals to sleep clinics for diagnostic evaluations have increased dramatically, the infrastructure to support them has not [24]. The report stated that simpler and less expensive diagnostic tests as well as simpler prescreening tests prior to full-channel PSG are needed [25].

Time is of the essence: as many as 82% of men and 93% of women with moderate-to-severe sleep apnea have not received a diagnosis, as estimated by data from the Wisconsin Sleep Cohort study [26]. Patients may have sleep apnea for up to 7 years before coming to medical attention and they may wait up to an additional 8 months before seeing a sleep specialist [27].

The recently recognized adverse consequences of sleep apnea, along with ongoing therapeutic advances, have heightened the urgency for expeditious diagnosis and treatment. The high prevalence of sleep-related breathing disorders has highlighted the limitations in patient accessibility to diagnostic and therapeutic services. In addition, as the need for studies has increased, less costly but comparable efficacious alternatives to laboratory-based polysomnography are being sought in response to current economic imperatives. Finally, home studies may provide a more realistic appraisal of nighttime pathology than can be obtained in the laboratory setting.

Because of these and other considerations, portable systems to assess sleep apnea have been developed for use in settings outside the sleep laboratory. Utilizing a conventional wireless ambulatory recorder, we have developed a portable multipurpose recorder which can store several biosignals simultaneously. In this study, the EEG, EOG (electrocardiogram), EMG (electromyography), EKG (electrocardiography) and airflow are recorded during sleep using monitoring/recording software designed by Java. Data are written in a binary file following the standard European Data Format (EDF), a standard file format designed for the exchange and storage of medical time series [28]. The exchange format can be imported to other software to analyse sleep disorder and the sleep stages can be scored by a specialist.

The rest of the paper is organized as follows: Section II describes the basic studies, Sections III and IV elaborate the hardware framework of portable bio-signal acquisition systems and the software framework of portable bio-signal acquisition systems, respectively. Section V presents the experimental results and finally, the conclusion is drawn in Section VI.

II. BASIC STUDIES

The purpose of this research is to develop a portable wireless polysomnography system for sleep monitoring. In order to do this, a system to acquire and monitor/record the bio-signals in EDF format is needed, where the exchange format can be imported by other analysis software to score the sleep stage; so, it was divided into two parts: one is how to get the data for signal processing in the experimental environment and the other is to determine what this bio-signal means in scoring the sleep stage. The diagrammatic overview of the system is shown in Fig. 1.

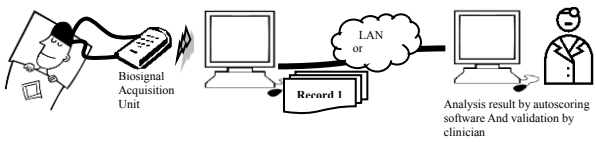

Fig. 1: Diagram of wireless polysomnography system

A. Bio-signals

A polysomnogram will typically record a minimum of eleven channels requiring a minimum of 22 wire attachments to the patient. Two channels are for the EEG [30, 46], one or two measure airflow, one is for chin movements, one or more for leg movements, two for eye movements (EOG), one for heart rate and rhythm, one for oxygen saturation and one each for the belts which measure chest wall movement and upper abdominal wall movement [47].

Wires for each channel of recorded data lead from the patient and converge into a central box, which in turn is connected to a computer system for recording, storing and displaying the data. During sleep, the computer monitor can display multiple channels continuously. In addition, most labs have a small video camera in the room so the technician can observe the patient visually from an adjacent room.

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Table 1: Medical and physiological parameters [29]

Parameter	Principal Measurement Range of Parameter
EEG	20uV-200uV
EMG	10uV-5000uV
EOG	50uV-3500uV
EKG	0.5mV-4mV
Airflow	0uV-2000uV

The different types of electrical potentials are listed in Table 1 [29]. We describe the different biosignals of the electrode position and recorded signal, for example: this patient is wired up for an overnight sleep study (polysomnogram) [43].

B. *Sleep Stage*

According to the AASM Manual for Sleep Scoring [11], considered the world-wide standard in the medical community, sleep staging relies on three fundamental biopotentials: the brain wave activity measured by an EEG, the eye movement recorded via an EOG and the muscular tone measured by an EMG. The sleep structure is represented in a dedicated graph, called a hypnogram, which represents the course of the sleep stages of the patient overnight (see Fig. 2), and provides the clinician with relevant information for the diagnosis of sleep disorders.

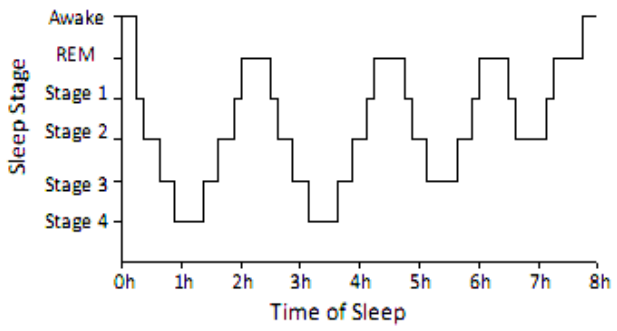

Fig. 2: Sleep stage patterns [41]

Sleep proceeds in cycles of REM and NREM, the order normally being N1 → N2 → N3 → N2 → REM. There is a greater amount of deep sleep (stage N3) early in the night, while the proportion of REM sleep increases later in the night and just before natural awakening.

The stages of sleep were first described in 1937 by Alfred Lee Loomis and coworkers, who separated the different EEG features of sleep into five levels (A to E), which represent the spectrum of wakefulness to deep sleep[31,33]. In 1953, REM sleep was found to be a distinct stage, whereupon William Dement and Nathaniel Kleitman reclassified sleep into four NREM stages and REM [34]. The staging criteria were standardized in 1968 by Allan Rechtschaffen and Anthony Kales in the R&K Sleep Scoring Manual [35]. In the R&K standard, NREM sleep was divided into four stages, with slow-wave sleep comprising stages 3 and 4. In stage 3, delta waves made up less than 50% of the total wave patterns, while they made up more than 50% in stage 4. Furthermore, REM sleep was sometimes referred to as stage 5.

In 2004, the AASM commissioned the AASM Visual Scoring Task Force to review the R&K scoring system, which culminated in several changes, the most significant being the combination of stages 3 and 4 into Stage N3. This was published in 2007 as the AASM Manual for the Scoring of Sleep and Associated Events [11, 32]. Arousals and respiratory, cardiac, and movement events were also added [36, 37].

Sleep stages were scored in 30s sequential epochs commencing from the beginning of the study and a stage was assigned to each epoch. If two of more stages coexist during a single epoch, the stage comprising the largest portion of the epoch [11] was assigned to Sl.

C. *Scoring apneas*

The amplitude criteria for scoring an apnea are at least a 90% drop or more in the thermal sensor excursion, lasting for at least 10s. It is labeled obstructive if the efforts (respiratory and abdominal continue) are seen; it is called central if none of these excursions are seen, and mixed, if this effort is resumed toward the end of the period of apnea.

D. *Scoring Hypopnea*

The duration of hypopnea should be at least 10s. The drop in the amplitude of the nasal transducer is > 30%, with a 4% drop in saturation of > 50 %, with a 3% drop in saturation.

E. *European Data format*

The European Data Format (EDF) [28] is a simple and flexible format for the exchange and storage of multichannel biological and physical signals. It was developed by several European medical engineers who first met at the 1987 international Sleep Congress in Copenhagen. A data file consists of a header record followed by data records. The variable-length header record identifies the patient and specifies the technical characteristics of the recorded signals. The data records contain consecutive fixed-duration epochs of the polygraphic recording.

There is a detailed digital format of the header record (upper block, ASCII's only) and of each subsequent data record (lower block integers only). Note that each one of the ns signals is characterized separately in the header. Following the header record, each of the subsequent data records contains 'duration' seconds of 'ns' signals, with each signal being represented by the specified (in the header) number of samples. In order to reduce data size and adapt to commonly used software for the acquisition, processing and graphical display of polygraphic signals, each sample value is represented as a 2-byte integer in 2's complement format.

III. HARDWARE FRAMEWORK OF THE PORTABLE BIO-SIGNAL ACQUISITION SYSTEM

In our experimental environment, the user wears a portable acquisition system developed to continually obtain multiple bio-signals during the period of overnight sleep. This portable acquisition system is a battery-powered and wearable module. It is easy to set up and is comfortable for the users. First, multiple bio-signals are continually measured by our portable acquisition module. After amplifying tiny multiple bio-signals, all noise except the frequency band of multiple bio-signals is

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removed by the filters in our portable acquisition module. Then, filtered multiple bio-signals are digitized by the analog-to-digital converter, and are transited to the PC via Bluetooth. The PC-based software is development by JAVA to receive digitalized raw data from our portable acquisition module to decode raw data, to display raw data in real-time and to save raw data in standard format. The saved records can be transmitted to a hospital via the network, and can be analyzed by autoscoring software and validated by the clinician. An analysis of the autoscoring software and the validation of the clinician simplify the polysomnography test, and allow the sleep monitoring of patients to be conducted in their homes. Our portable PSG system is easier and more comfortable for the patient and enables more familiar and normal sleep habits.

The portable biosignal acquisition unit comprises four parts: (1) front-end filter circuit, (2) analog to digital converter and digital controller, (3) power management circuit and (4) wireless transmission. A diagram of the portable biosignal acquisition unit for various kinds of biosensors as shown in Fig. 3, which indicates the voltage and frequency ranges of some common biopotential signals [38].

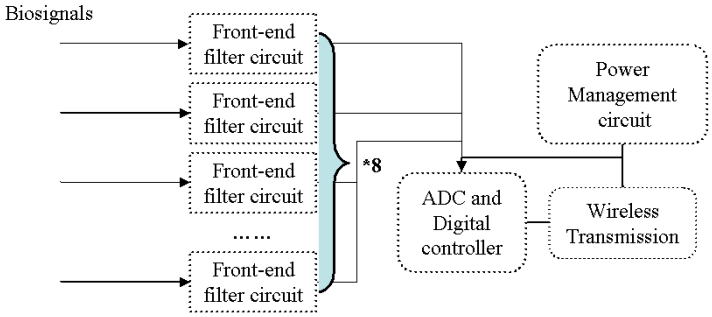

Fig. 3: Diagram of portable biosignal acquisition unit

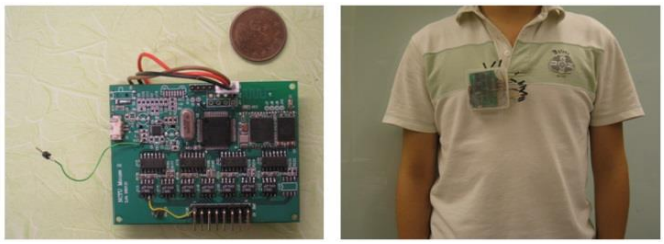

Fig. 4 : The hardware of the portable biosignal acquisition unit

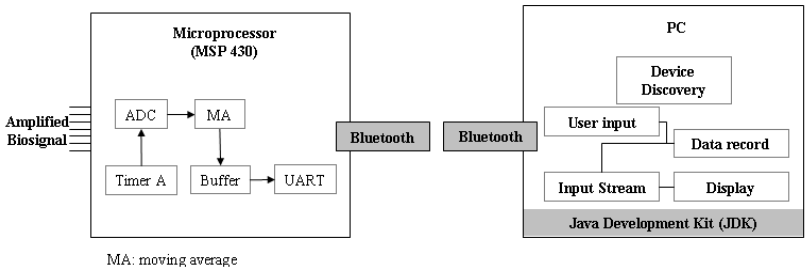

Fig. 5: Diagram of software framework

Table 2: The specifications of the portable biosignal acquisition unit

Type	Portable biosignal acquisition unit
Operating Temperature	-40° to +85°C
Size	65 x 50 x 8 mm^3
Weight	33 g(with battery) 66 g (with battery and box)
Channel Number	8
power	Rechargeable Lithium 3.7V 450mAh
Gain	Depend on difference channel
Bandwidth	Depend on difference channel
Input signal range	Depend on difference channel
ADC Resolution	12bits
Power capacity	16~20hours
Sampling rate	2048Hz up to 200kHz
Communication Interfaces	Bluetooth 2.0

Fig. 4 shows the hardware of the portable biosignal acquisition system. There are twelve leads in our portable EEG system, six ExG inputs, two airflow inputs, three references, and one virtual ground of the front-end analog circuit. The specifications of the portable biosignal acquisition unit are listed in Table 2.

IV. Software Framework of the Portable Bio-signal Acquisition System

In the proposed PSG system, a microprocessor (TI MSP430) was used to perform bio-signal data acquisition in the bio-signal acquisition module and transmit digitized bio-signals wirelessly to the PC via Bluetooth [40]. The software framework of the whole system is shown in Fig.5. It comprises two parts: the firmware in MSP 430 and the software in the PC.

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A. *Software in the Personal Computer*

We developed a Graphics User Interface (GUI) using the Java Development Kit (JDK) 6 to monitor and record the bio-signals as shown in Fig. 14. Where, a function menu is in the upper left corner, a system information board is in middle left side, a real-time display of bio-signal waveform is in right side and a form for user information is in bottom of the window. The software of the proposed PSG system is handled by five modules which are explained in the following sections.

B. *User input module*

According to the EDF file format described in Table 3, in the header of EDF, there are two fields which need input: local subject identification and local recording identification. We use KeyListener to handle and check the user input. The date and time fields are provided by the system. The time field is handled by a thread; it stops when the user pushes the button "start recording" and it continues when the user pushes the button "stop recording".

C. *Device discovery module*

A PC with a Bluetooth USB dongle was used as the local device and our probable bi-signal acquisition module was used as the remote device. When the user pushes the button "Begin receiving biosignal", the local device discovery procedure starts to search the remote device as shown as Fig. 7. The Discovery Listener interface allows an application to receive the device discovery and service discovery events. This interface comprises four methods, two for discovering devices and two for discovering services. The specification of Java TM APIs for Bluetooth is described in JSR 82.

D. *Input stream module*

After discovering the remote device, we used the Bluetooth protocol Radio Frequency Communication (RFCOMM) to exchange data between the local and remote devices. The RFCOMM is on top of the L2CAP protocol, providing emulated RS-232 serial ports. We obtained the Uniform Resource Locator (URL) of the remote Bluetooth and opened the connection between the local device and the remote device, and exchanged data based on the RFCOMM protocol. The Java.io package was used to receive data from our portable PSG device. This package has an InputStream and OutputStream. Java InputStream is defined for reading the stream, byte stream and array of the byte stream. Fig. 8 shows that the data format of the software in PC coincides with the firmware in MSP430. The first column of the header is 0xFF and second column is 0x62, the rest is the data of each channel. FF is the identifier for channel data, 62 is representative of the sample rate and the number of channels. After receiving, the data of each channel was rebuilt as follows:

*Channelx = Channelx low byte + Channelx high byte *256*

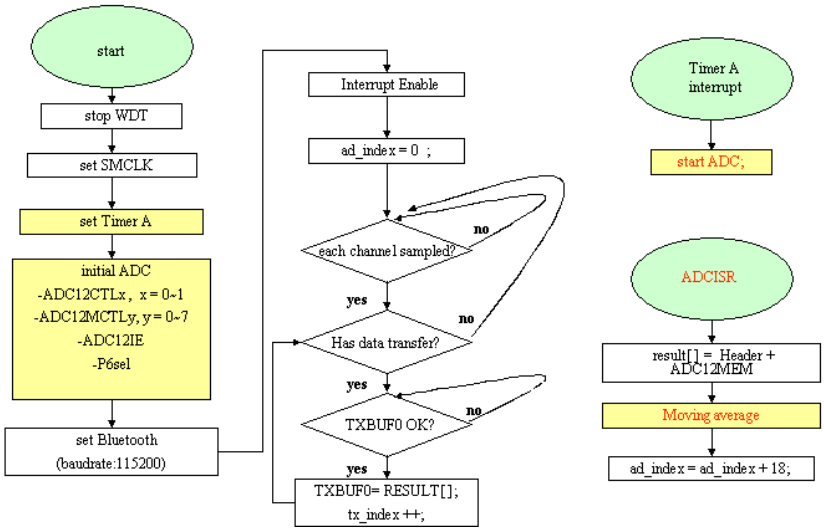

Fig. 6: Flow chart of firmware in MSP430

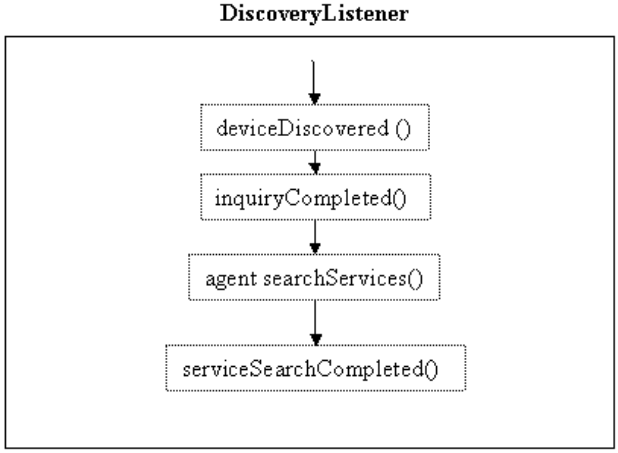

Fig. 7: Procedure of Discovery Listener

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Table 3: The parameters of the EDF header

	Physical minimum	Physical maximum	Digital minimum	Digital maximum
EEG	-333	333	-2048	2047
EOG	-702	701	-2048	2047
EMG	-330	329	-2048	2047
EKG	-13393	13392	-2048	2047
Airflow	-4854	4854	-2048	2047

E. Display module

In bio-signal recording, the scientist and clinician need to know not only the bio-signal waveforms but also their amplitudes. Therefore, we restore the signal and mark the amplitude of bio-signals and the bio-signal waveform is circular, drawn using Graphics 2D on a Java JPanel, the panel shows in right side of the windows in Fig. 14. The sampling rate of the screen display was down-sampled to 128 Hz, and each page shows five-second bio-signals.

F. Data record module

When the user pushes the start recording button, the data is recorded in two formats using the Java.io package. Form 1 is recorded in text form, as shown in Fig. 8.

EEG	CH2	CH3	CH4	CH5	CH6	CH7	Timestamp
C4-M1	O2-M1	EOGL	EOGR	EMG	EKG	Airflow	

Fig. 8: Record data in text format

Form 2 is an EDF file format as shown in Table 3, where there are four fields in the EDF header, and these four extreme values specify the offset and amplification of the signal, the parameter of amplitude and offset is (phy_max - phy_min) / (dig_max - dig_min). In the data records, each sample value is represented as a 2-byte integer in 2's complement and a little endian format. Depending on the feature of the EDF file format, we buffered the incoming data until a second amount of data was collected. Next, we wrote to the EDF file when every second amount of data was collected. When the user pushes the "stop recording" button, the "Number of data records" field of the header will be updated. The flowchart of the program and successfully EDF saved file are shown in Fig. 9 and 11, respectively.

V. RESULTS

To assess the feasibility of our proposed PSG system in this study, we used two settings to verify the system. One is the simulated signal test and the other is preliminary test on healthy volunteer patients under the supervision of specialist at Sleep laboratory of Taipei Veteran General Hospital.

The reference system is a complete polysomnography system designed by Philips Respironics. According to the comparison of the difference between the aforementioned two system in the time domain, our proposed system can perform well and can be applied in practice. A more quantitative comparison is performed by looking at the duration of each sleep stage and the percentage of each sleep stage over the night. Relative errors in stage duration show very good results for sleep (Stage 1), Stage W and the REM stage.

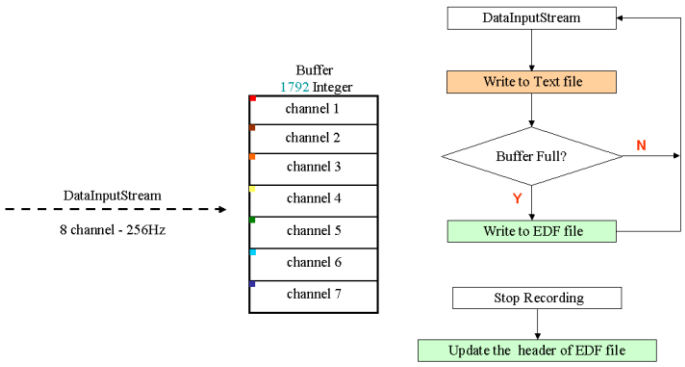

Fig. 9: Recording procedure of the text file and EDF

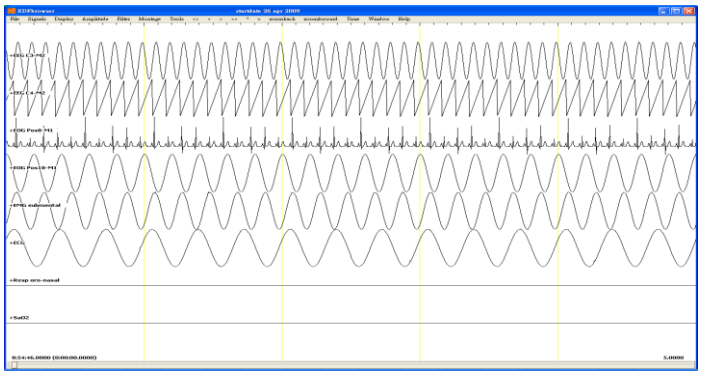

Fig. 10: Simulation data in EDF format and browse by EDF browser [42]

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A. *Verification of Simulation Signals*

The feasibility of the proposed PSG system is discussed in this section. In order to verify the validity and evaluate the performance of our PSG system for various kinds of bio-signals, first sin waves with difference frequency (1Hz、5Hz、15Hz and 20Hz) and 100μV vibration amplitude generated by a function generator were used to simulate the signal test. First, the simulated signal was measured by the proposed PSG system, digitized, and then transmitted to the PC via Bluetooth. A Java program was designed to receive signals transmitted from our PSG system. Fig. 11 shows a comparison of FFT between the simulated signals obtained by our PSG system and the reference signals generated by MATLAB. Here, sin waves generated by MATLAB were used as reference signals. Both simulated signals and reference signals were in 1, 5, 15, and 20 Hz respectively. The results show that the frequency properties of the simulated signals obtained by our PSG system were accurate and matched those of the reference signals.

B. *Comparison between our proposed system and the reference system*

We recorded EEG (O2-M1, C4-M1), EOG, EMG, EKG and airflow at the same time. The Alice 5 Diagnostic Sleep System sampling rate is 200Hz and our proposed system sampling rate is 256Hz. After recording, the records of the two systems were adjusted to the same sampling rate, and restored the original signals. A comparison of the time domain signal and the sleep stage was used to verify the system. Fig. 12 shows a diagram of the bio-signals processing for system verification. Fig. 13 shows the electrodes disposal of the two systems.

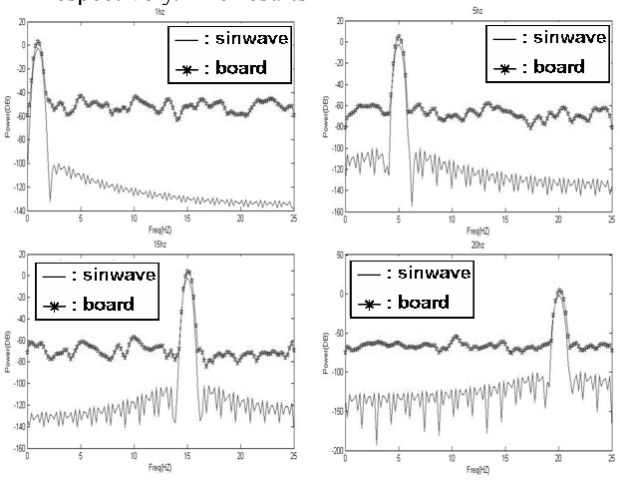

Fig. 11: Comparison of FFT between simulated signals obtained by our PSG system and the reference signals generated by MATLAB for 1, 5, 15, and 20 Hz sin waves.

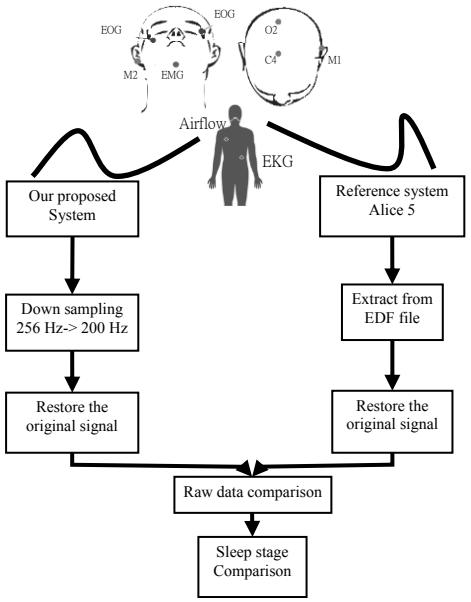

Fig. 12: Diagram of bio-signal processing for system verification

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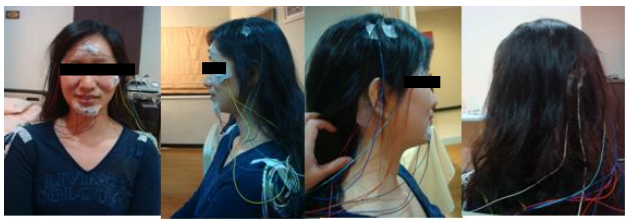

Fig. 13: Electrodes disposal of the two systems

C. *Experiment output*

A total three subjects wore the two systems (Alice 5 diagnostic sleep system and the proposed system) at the same time, and their physiological signals were simultaneously measured during sleep. After the test, we imported the EDF file to Alice Sleepware and the clinician was asked to score the sleep stage. Fig. 15 shows the variations in the subject's bio-signals during the awake sleep stage. According to the 2007 AASM standards, there are five different stages of sleep, namely Stage W (Wakefulness), Stage N1 (NREM1), Stage N2 (NREM2), Stage N3 (NREM3) and Stage R (REM). After completing the sleep experiment, a 'scorer' analyzes these data by reviewing 30-second epochs to make up a hypnogram for overnight sleep and to summarize sleep structure. The top signals as shown in Fig. 15 are the sleep stage of Alice Sleepware and other 30-second physiological signals are shown in the main window. These physiological signals listed from top to bottom respectively are EOG-left, EOG-right, EEG(C4-M1), EEG(O2-M1), EMG, Airflow and ECG.

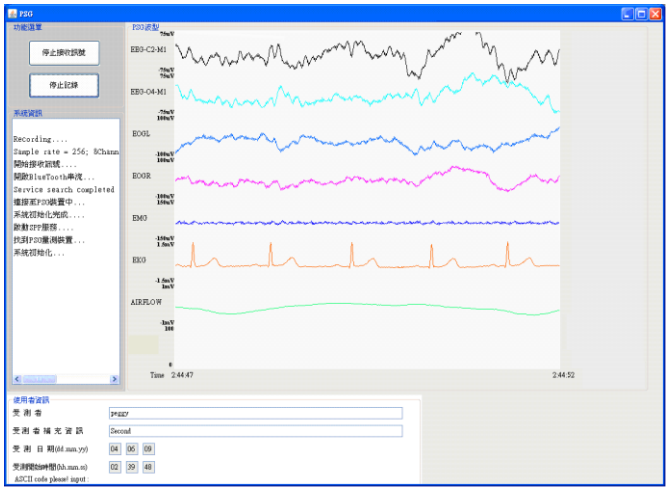

Fig. 14: PC-based recording/monitoring user interface

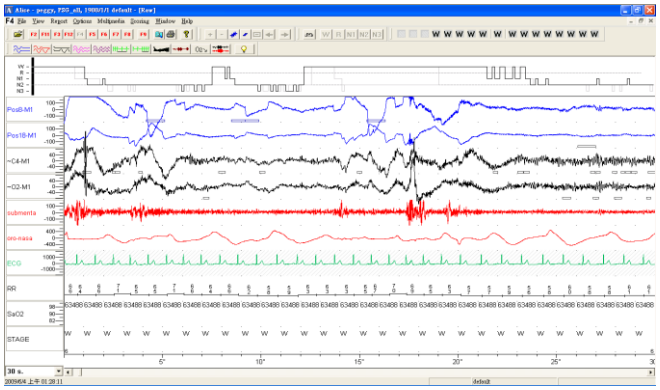

Fig. 15: Stage W: note the eye movements with high chin tone, 30-s epoch

In order to verify the validity of the bio-signals obtained by our PSG system, we randomly select 30-seconds of raw physiological signals obtained by our PSG system and the Alice 5 Diagnostic Sleep system, and compared both. The two sets of physiological signals looked very similar and displayed the same obvious features. Therefore, a more quantitative comparison was then performed by using cross-correlation and the correlation coefficients function in MATLAB to obtain the linear correlation of the two sets of physiological signals. Fig. 16 compares 30-second raw physiological signal data in the time domain and their correlation in every 1 second in EEG-C4M1. From the above results, we found that the physiological signals obtained by our PSG system and the reference system in the time domain were highly similar. Therefore, our PSG system can be seen as having a high level of reliability.

The hypnogram built on the two sets of records is shown in Fig. 17. We found that the night patterns evaluated by the expert clinician for the two sets of data were similar. A comprehensive view of subjects 1 and 3 at the beginning of the recorded time were different, but this did not affect the trend of the whole sleep architecture. The major difference in the interpretation between the reference system and our PSG system occurred in the case of subject 2. This is because the electrode lead fell off at 5 o'clock. In the case of subject 3, the sleep stage interpretation of our PSG system was the most similar to that of the reference system.

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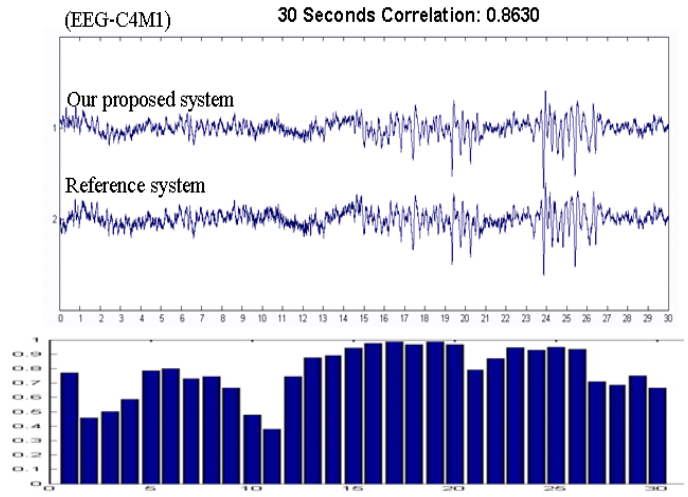

Fig. 16: A comparison of 30-second raw data (EEG C4-M1) and their correlation every 1 second

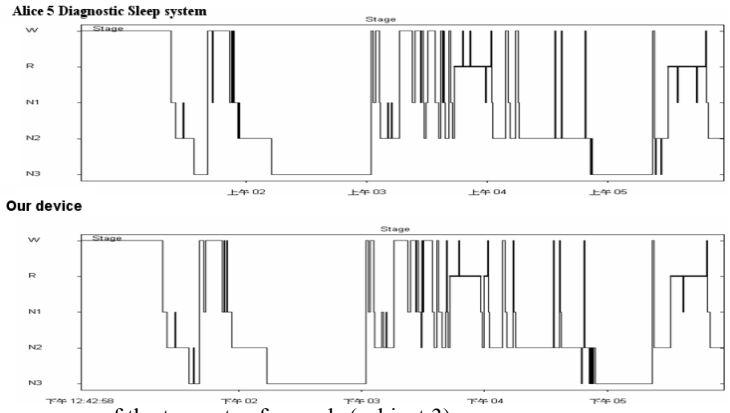

Fig. 17: Hypnograms of the two sets of records (subject 3)

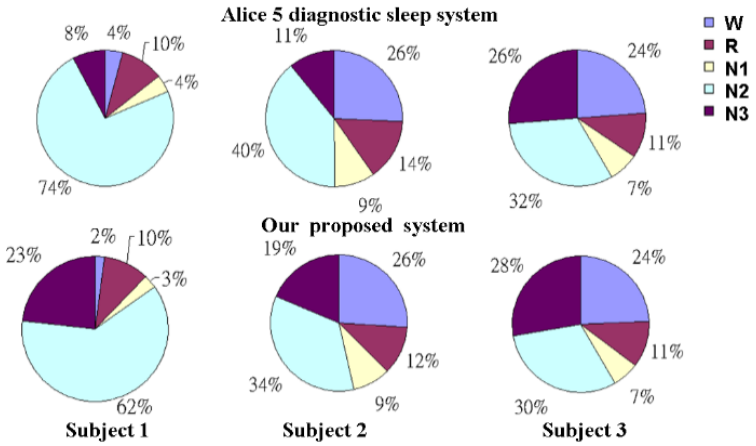

Fig. 18: Percentage of each sleep stage overnight

We rejected the segment of subject 1 and subject 2 records obtained by the reference system, which was prior to the beginning of this experiment for the subject 1, and the subject 2 records obtained by the proposed PSG system, which was after the occurrence of falling off electrode lead. Then, we observed the time duration of each sleep stage which cumulated sleep hours for three subjects as shown in Table 4, and the percentages of each sleep stage overnight in two systems (Fig. 18). In view of the above, we found that the duration of Stage W, Stage N1 and Stage REM in two systems had similar interpretation, but had a gap between Stage N2 and Stage N3. According to the explanation of the clinical expert, the proportion of combining the duration of Stage N2 and Stage N3 to the whole duration of the two systems was the same. Thus, Stage N2 may be interpreted as Stage N3 if some segments of the physiology signals were extremely similar. This caused the difference in the interpretation between the two systems for Stage N2 and Stage N3.

Table 4: Relative errors on time spent in each sleep stage

Sleep stage	Ref.	Our proposed system	Rel. Err.
Awakening	156.5	150.5	3%
REM	90	93.5	3%
Stage N1	52.5	56.5	7%
Stage N2	337.5	372.5	9%
Stage N3	194.5	128	51%

VI. CONCLUSION

This study presented the design and implementation of a battery-powered and ambulatory biopotential acquisition unit and a friendly monitoring / recording interface for sleep monitoring at home. Compared to the standard PSG-Alice 5® Diagnostic Sleep System, our proposed system performed similarly in relation to performance and quality. This experiment is based on the IoT based infrastructure. The PSG recording program in the personal computer was developed in JAVA and can run on any Java virtual machine, regardless of computer architecture. In combination with Bluetooth® wireless technology, our design can be easily used anywhere at home and will not be restricted to a specific activity area. Moreover, compared to other portable PSG systems, our proposed PSG system comprises a two-channel EEG, and therefore can offer more information to fit the requirements of accurate analysis and diagnosis. In our PSG system, the portable biopotential acquisition unit can continually work for about 16 to 20 hours with a 3.7V lithium battery without loss data. Therefore, it capably supports full-night sleep monitoring.

In conclusion, the aim of our proposed PSG system is not to replace the standard 16-channel PSG system, but to collect important physiological information (EEG x 2, EOG x2, EMG x 1, ECG x1, and airflow) for sleep analysis. By using our PSG system, the cost of an attended in-laboratory PSG experiment for OSA diagnosis can be effectively reduced. Furthermore, our system offers the comfort and convenience of sleeping in the patient's own bed, and therefore may record more natural information which more accurately reflects the patient's sleeping behavior.

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