SleepGaze: A Wireless System for Monitoring and Detection of Sleep Disorders

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Abstract - *Sleep disorders are exponentially growing with current statistics as approximately 1 in 6 or 40 million people in USA. This alarming state has to be controlled in its early stage, to achieve physical and mental wellbeing of human beings, contributing to the peace and welfare of whole world. Current sleep monitoring facilities uses dedicated sleep labs at the hospital. However these tests results are error prone since the patient sleep gets disturbed due to the numerous wired sensors attached to their body, new ambience, reduced privacy, and long waiting duration due to the non availability of sleep labs. This research aims to develop a pervasive monitoring system that overcomes these drawbacks and provides the capability to monitor and detect sleep disorders in any place comfortable to the patient such as patients home, hospitals etc thereby collecting the best signals. The real-time data received from the system will be analyzed to detect sleep disorders remotely and issue the alerts to the clinicians. In the first phase of this research, we have designed and implemented the complete system using EMG sensor alone. The initial results are incorporated in this paper.*

Keywords: Sleep Monitoring, Polysomnography, Wireless Sensor Networks, Real-time monitoring

1 Introduction

Sleep is a naturally recurring state characterized by reduced or lacking consciousness, relatively suspended sensory activity, and inactivity of nearly all voluntary muscles" [1]. Sleep is important for the restoration and renewal of the body. Inadequate sleep can lead to many disorders like irritability, poor concentration, memory loss, impaired moral judgment, risk of type2 diabetes, decreased reaction time, increase heart rate variability and risk of heart diseases. Sleep disorders actually disturb the sleep cycle and the quality of sleep. According to the statistics of National Heart, Lung, and Blood Institute (NHLBI), 1 out of 6 American are having sleep disorders [2]. Even though a clear statistics about the amount of sleep disorders prevalent in India is unknown, we estimate to have a similar figure equal to that in US. One of the major problems faced in India is the improper treatment & diagnosis available for sleep disorders. This is mainly because of the lack of facilities and the exorbitant cost for the diagnosis and treatment [3]. The proposed system targets to solve this issue and is aimed at Indian Population.

According to the statistics by World Health Organization [4], it is estimated that 5-10% of the population at any given time is suffering from identifiable depression needing medical attention. By analyzing the sleep pattern, it is possible to detect depression. This can be found by analyzing the time it takes to sleep after going to bed, actual sleep duration, quantitatively measuring whether having deep or shallow sleep, number of awakening during sleep. The proposed system actually can calculate all these parameters to detect depression. Untreated sleep disorders will lead to poor concentration and Excessive daytime sleepiness (EDS). About 22% of the road accidents [5] are caused due to EDS in drivers. Obstructive sleep apnea is also a cause for EDS. Sleep apnea and other sleep disorders can be detected with the proposed system.

The system can be also used for disaster management applications, to monitor the sleep pattern of panic struck population and to provide proper medication to overcome them from the state of trauma.

Polysomnography is used to diagnose sleep disorders like sleep apnea, periodic limb movement disorder (PLMD), Rapid Eye Movement (REM) behavior disorder and narcolepsy. Polysomnography is performed in dedicated sleep labs with all the measuring electrodes positioned on the patient body. With the placement of the electrodes the patient discomfort increases, which in turn affect the sleep leading to the failure of the test. The discomfort is mainly due to the change in the environment and also due to limited mobility since large number of electrodes fixed to the patient body. The proposed system actually takes care to reduce the patient discomfort, since it's a wireless system it overcomes the mobility and environment problems listed above. The system also supports remote monitoring so that the patients can take-up the test from the comfort of their home. The proposed system also helps in data collection from patients to capture the important biomedical signatures before and after an epileptic attack, which can be used for clinical research people to study epileptic attacks in detail.

The remaining portion of the paper is organized as follows, Section II describes the related work. Section III explains the architecture and design of the proposed wireless remote sleep monitoring system. Section IV outlines the implementation details and Section V concludes the paper and provides the future work.

2 Related Work

In [6], the authors provide a general outline about the measurement of key sleep related biomedical signatures, this can be obtained without wiring or physical contact with the subject. The paper presents a new approach of contact-less measurement of heart rate, physical movement and respiration using Doppler radar mechanism. In the paper the authors illustrate that the Doppler system was able to detect the peaks similar to that of conventional measurements systems. This paper gives a new idea about contact-less sensing of biological signals. The system actually limits the mobility of the patient. The proposed system actually overcomes the mobility limitation.

The paper [7], provides an insight into measuring severity of OSA with the help of a new measure known as the Dynamic Apnea Hypopnea Index time. Normally the severity is measured from the Apnea Hypopenea Index, which is the average of the obstructive sleep events (OAH) during the entire sleep period. According to the authors, the number of OAH events is a random variable with unknown mean and probability distribution. The paper provides details on how to detect apnea from the available data with minimum error. The details regarding what type of physiological signals used to evaluate the algorithm is not specified in the paper. This paper actually helps in the signal analysis part of the proposed system.

In [8], paper describes a system which performs real time monitoring and transmission of physiological data of patients. The data collected from a wireless pulse oximeter is used to detect apnea on a Personal Digital Assistant (PDA) which has a General Packet Radio Service (GPRS)/Universal Mobile Telecommunications System (UMTS) facility. The analysis is based on SpO2 signals (blood oxygen level). A classifier that runs on the PDA is used for the analysis. The main feature of this classifier is that it works on the limited resources of a PDA. The paper provides more details on the signal processing aspects on how to process the available data to detect apnea from the SpO2 Signals. The accuracy and reliability is improved in the proposed system by considering multiple parameters for the analysis. The system is limited only for the detection of apnea, but proposed system can be used for the detection of a variety of sleep disorders.

3 Problem Domain : Sleep Disorders and Detection

“Sleep disorders involve any difficulties related to sleeping, including difficulty falling or staying asleep, falling asleep at inappropriate times, excessive total sleep time, or abnormal behaviors associated with sleep”[9]. According to International Classification of Sleep Disorders (ICSD)[10], Sleep disorders are classified into four, Dyssomnias, Parasomnias, Sleep Disorder associated with Medical/Psychiatric disorders, and proposed sleep disorders.

3.1 Dyssomnias

This disorder is characterized by problems in getting sleep or staying asleep or of excessive sleepiness. The three core sub-classification include, Intrinsic sleep disorders, Extrinsic sleep disorders, and Carcadian rhythm sleep disorders. Main intrinsic sleep disorders include Psycho-physiological insomnia, Idiopathic insomnia, Narcolepsy, Obstructive Sleep Apnea, Periodic Limb Movement Disorder. Key Extrinsic Sleep Disorders include inadequate sleep hygiene, altitude insomnia, insufficient sleep syndrome, Alcohol-dependent sleep disorder and Sleep Onset association disorder. Few Carcadian Rhythm Sleep Disorders include time zone syndrome, shift work sleep syndrome, irregular sleep wake pattern, and non 24-hour sleep-wake disorder.

3.2 Parasomnia

Parasomnias are characterized by undesirable motor, verbal, or experiential phenomenon occurring in association with sleep, specific stages of sleep, or sleep-awake transition phases [11]. Parasomnias are broadly classified into three, Arousal Disorders, Parasomnias associated with REM sleep and other parasomias like Sleep bruxism, Sleep enuresis, Nocturnal paroxysmal dystonia.

3.3 Sleep Disorders associated with Medical/ Psychiatric Disorders

These are classified into Sleep Disorders associated with Mental Disorders, Sleep Disorders associated with Neurological Disorders, and Sleep Disorders associated with other medical disorders like Sleeping sickness, Fibrositis Syndrome.

3.4 Proposed Sleep Disorders

Proposed Sleep Disorders include short sleep, long sleep, subwakefulness syndrome , Sleep hyperhidrosis and Terrifying Hypnogogic Hallucinations. To diagnose and to identify the disorders listed above a detailed multi-parameter sleep study known as Polysomnography (PSG) is carried-out. The test result is known as Polysomnogram which contains a detailed capturing of key biological signals related to brain activity (EEG), Eye Movements (EOG), Muscle Movements (EMG), cardiac rhythm (ECH), respiration and blood oxygen saturation during sleep. PSG is conducted with an overnight stay in dedicated sleep labs. The main factor that affects the test is the amount of quality sleep the patient gets during the sleep study at sleep labs, which is dependent on the discomfort level the patient faces while placing the electrodes for measuring various parameters which in turn tethers the patients to the bed. Also the new environment of the sleep labs can also affect the quality of the sleep. The proposed system overcomes all the drawbacks with the conventional PSG techniques.

4 Architecture and Design of SLEEPGAZE

The top level overall architecture of the proposed system in depicted in Figure 1. The proposed system has three tier architecture. The base level module has the interface to the patient and the top most module has interface to the clinicians. The modular design and the plug n play features allow the system to be scalable and robust. The proposed system performs the real-time acquisition, wireless transmission and signal analysis & characterization of the signals. The major advantage of the system is that it can detect the sensor failure if the electrode comes out from the patient body and can provide alert to the bystander to fix the sensors properly.

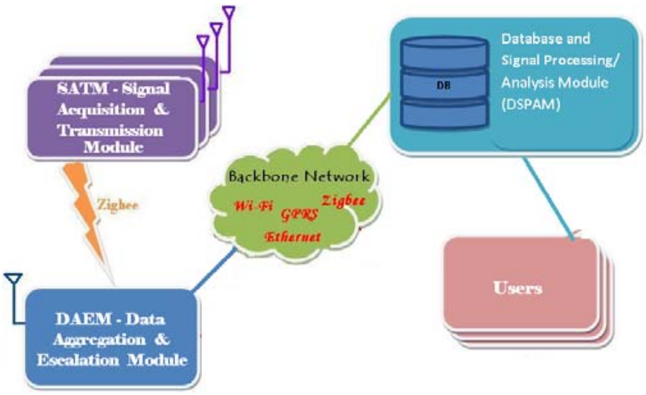

Figure 1. Top Level Architecture

4.1 Signal Acquisition and Transmission Module (SATM)

SATM is the module that has an interface with the patient. This module actually acquires the biomedical signal, performs basic signal conditioning and wirelessly transmits to the base station unit.

The module block diagram is shown in the Figure 2. The electrodes used are Ag/AgCl electrodes. The electrodes pick the bio-potentials and generate a corresponding voltage output. The micro volt level of the electrode output needs to be amplified. The instrumentation amplifier amplifies the electrode output and generates an output that is sufficient for further signal conditioning. The band pass filter performs the required filtering of the signal and processed signal is sampled and wirelessly transmitted using MicaZ motes.

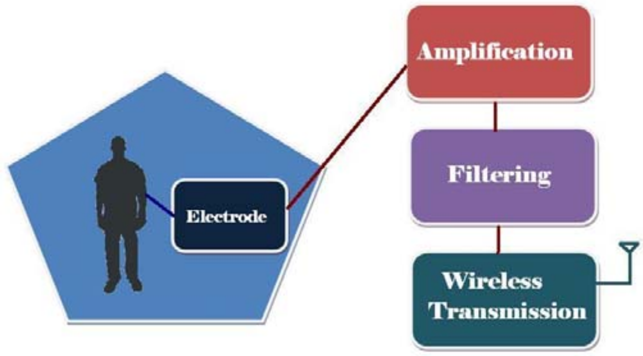

Figure 2. Block Diagram of SATM

The sampling rate of the signal can be changed real-time depending upon the application and the user requirements, if required. The key feature is of this module is the plug n play capability of the module. Different modules can be interface to the system depending on the requirement and the type of parameter that is to be monitored.

4.2 Data Aggregation & Escalation Module (DAEM)

The functionality of DAEM is to receive the continuous real-time signals from the SATM. The received signals will be aggregated, and transmitted to the server through heterogeneous wireless networks. If the congestion experienced in the wireless networks is high, then the signals have to be temporarily stored in DAEM, and later transmitted to the server.

The DAEM hardware architecture is designed to achieve the above mentioned functionalities. The architecture of DAEM is shown in the Figure 3.

The Zigbee module will be receiving the data wirelessly from the SAT module. The DAE module will aggregate the received over a time and will be uploading the data to a remote server, using the available wired backbone or internet. This module will perform an initial level of analysis to detect sensor failure and has an alerting mechanism to notify the user. The actual signal processing takes place at the server. The memory facilitates the temporary storage of received data. The keypad and the LCD Display provide the required user interface. The Ethernet/USB interface provides the base station with the Ethernet and USB interface for external connectivity.

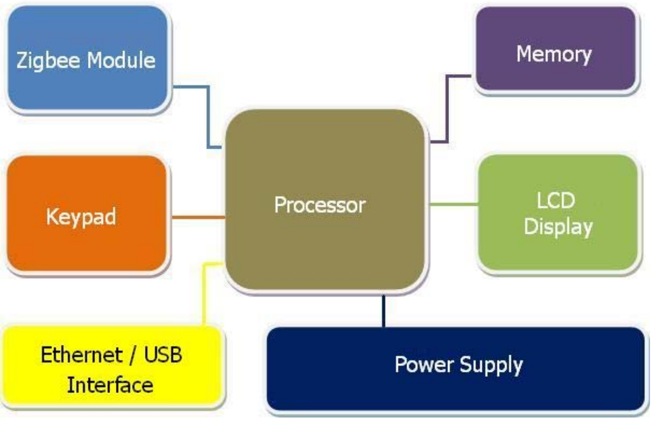

Figure 3. Block Diagram of DAEM

4.3 Database and Signal Processing/Analysis Module(DSPAM)

The functionality of DSPAM module is to store all the transmitted data, perform the essential signal processing and analyze the data.

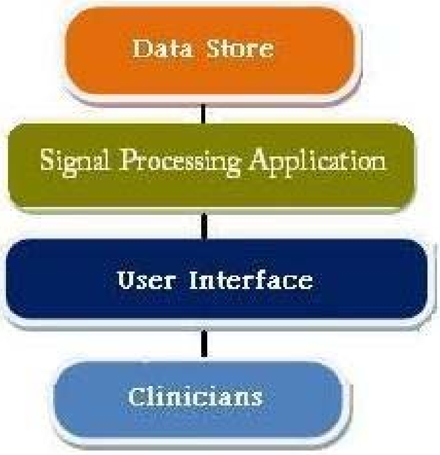

Figure 4. Block Diagram of Server and Signal Processing Application

The analysis results and the raw data will be accessible to the clinicians once they authenticate and login to the application. The signal processing application has access to all the transmitted data and will perform a basic and application specific signal processing depending upon the user requirement. The user interface will display the waveforms. The block diagram is shown in Figure 4. The server can also perform real-time data dissemination depending upon the test scenario and user requirement. i.e.: If the doctor requires an alert to his mobile phone if the measured parameters crosses a predefined threshold, so that he can login and check the real-time data only when there is a necessity.

5 Implementation

As a first phase to the development and implementation of the system, the SAT Module for EMG was developed and tested.

Figure 5. Network Flow Diagram

The acquired signal was wirelessly transmitted to a remote PC using wireless sensor network. The network flow diagram of the test scenario is shown in Figure 5 and the transmitted EMG signal is shown in Figure 6. Since it is an ongoing research activity, the other modules for the entire sleep suite are under development.

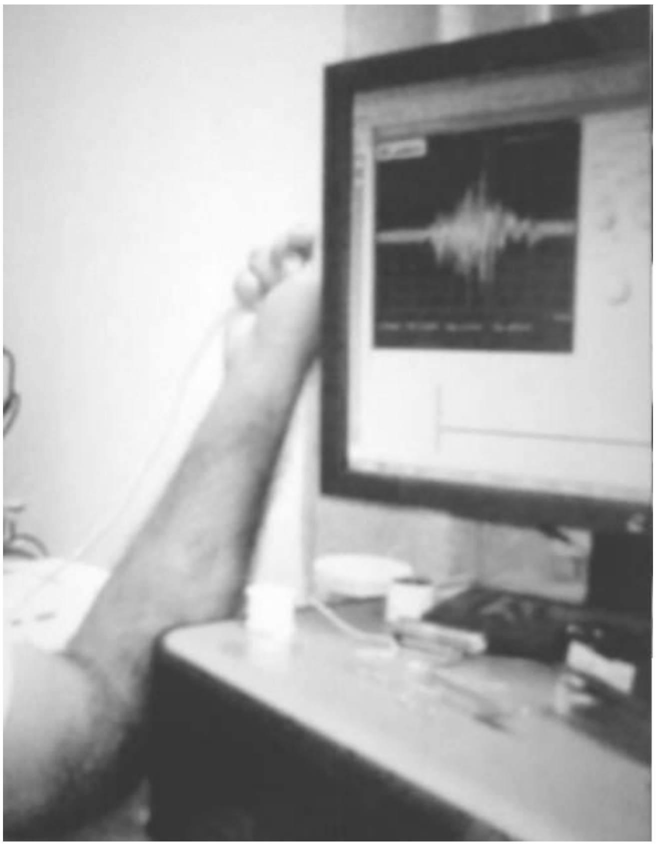

Figure 6. Captured EMG Signal from Electrodes.

The IC used for pre-amplification is INA122 from Texas Instruments. INA122 has a variable gain from 1 to 10000, high CMRR, low noise and low quiescent current which makes it suitable for physiological amplification applications. The filtering is performed in the range of 10 to 500Hz. Active fifth order Butterworth high pass and fifth order Bessel low pass filters were designed, developed and tested. Maximally flat response in both magnitude and phase and nearly linear-phase response in the pass band makes the Bessel filter ideal for this applications. The software tools used for the design and simulation of the above circuits were TinaTI from Texas Instruments, FilterLab from Microchip and LabVIEW & MultiSIM from National Instruments.

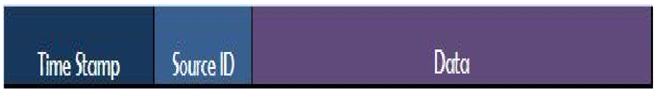

Figure 7: Packet Structure

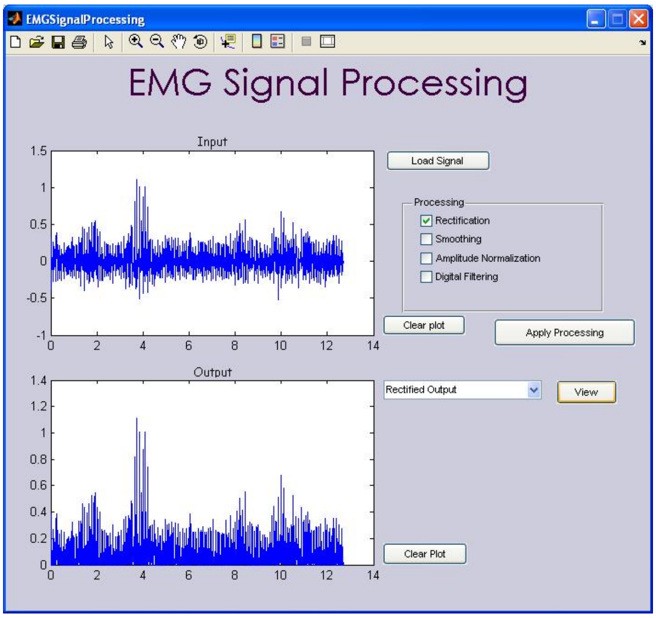

Figure 8 : Signal Processing GUI

The conditioned EMG signals were sampled satisfying the Nyquist criteria and was wirelessly transmitted to a remote location using Wireless sensor Networks having MicaZ motes. The coding was done using the nesC programming language and TinyOS platform. The packet structure used is shown in Figure 7. The transmitted packet is divided into three main segments, the time stamp, sourceID and data segments. The time stamp helps to synchronize and reorganize the data and the source ID helps in identifying the source at the receiver. In order to increase the battery life of the node, the data was transmitted only when there was some signal activity.

A GUI was also developed to perform basic signal processing on the EMG signal is shown in Figure 8.

The functionality and integration testing of the modules will be completed shortly. Tests are planned to validate the functionality of the system with multiple nodes and all the modules integrated. The final system will be deployed at Amrita Institute of Medical Science, Kochi, India.

6 Conclusions

The paper provides a novel design for the monitoring and detection of sleep disorders. The main advantage of the system is that remote monitoring and diagnosis is made possible with the proposed system. The system can be manufactured at a very low price compared to the commercially available products in the market. Alerting mechanism provide a feed back to the bystander, if the sensors are not working properly. Since the design has three tier architecture, the system is scalable and robust. The system actually reduces the discomfort level in patients since they can take the test from the comfort of their home and by improving their mobility. The future works envisaged include securing the wireless transmission, QoS analysis considering multiple system implementations and system commercialization. The main aim of the system is to target the rural population of India thereby making them accessible to clinicians and providing better remote healthcare and reliable diagnostic opportunities at low cost. This system can be used for determining different other ailments such as depression, post traumatic stress and relief work.

7 References

[1] Sleep – Wikipedia http://en.wikipedia.org/wiki/Sleep.

[2] National Heart, Lung, and Blood Institute (NHLBI) , National Institutes of Health, USA. Available from: http://www.wrongdiagnosis.com/s/sleep disorders/basics.htm.

[3] V.M. Kumar, “Sleep Disorders: Current Understanding”, The Indian Journal of Chest Diseases & Allied Sciences, 2008, Vol 50 pp 129-135.

[4] Conquering Depression :Facts and Figures,Mental Health and Substance Abuse, ,World Health Organization. http://www.searo.who.int/en/Section1174/Section1199/Section1567/Section1826_8101.htm

[5] Garbarino S.,"Sleep disorders and road accidents in truck drivers",G Ital Med Lav Ergon,2008 Jul-Sep, Vol30(3), pp:291-6.

[6] V.M.Lubecke, O. Boric-Lubecke, “Wireless technologies in sleep monitoring”, Radio and Wireless Symposium, 2009. RWS ’09. IEEE. pp.135 - 138.

[7] A. S. Karunajeewa, U. R. Abeyratne, S. I. Rathnayake, V. Swarnkar, “Dynamic Data Analysis in Obstructive Sleep Apnea¨ , Engineering in Medicine and Biology Society, 2006. EMBS ’06. 28th Annual International Conference of the IEEE, pp.4510.

[8] A. Burgos, A. Goi, A. Illarramendi, J. Bermudez, ”Real-Time Detection of Apneas on a PDA”, Information Technology in Biomedicine, IEEE Transactions, Volume 14,Issue 4, pp.995.

[9] PubMed Health, National Center for Biotechnology Information, U.S. National Library of Medicine, http://www.ncbi.nlm.nih.gov/pubmedhealth/PMH0001803/

[10] American Academy of Sleep Medicine; European Sleep Research Society, Japanese Society of Sleep Research, Latin American Sleep Society (2001). "The International Classification of Sleep Disorders, Revised: Diagnostic and Coding Manual". 2001 edition, ISBN 0-9657220-1-5, PDF-complete, Library of Congress Catalog No. 97-71405. Retrieved 2010-08-08.

[11] Thorpy MJ, Glovinsky PB. Parasomnias. Psychiatric Clinics of North America, Dec1987, Vol10, Issue 4,pp. 623-39.