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Sleep Apnea Detection And Non-Invasive Brain Tissue Oxygen Monitoring

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Abstract- This paper introduces a non-invasive method for monitoring the respiratory patterns of the patients and the specifications of apnea monitor hardware. The microcontroller based apnea monitor consists of a sensor system interfaced with a microcontroller to detect the apnea from the heat changes in the oro-nasal air flow and simultaneously measure the brain tissue oxygen level by Near Infrared spectroscopy(NIRS).Near-infrared spectroscopy (NIRS) has the potential to noninvasively monitor brain tissue oxygen saturation (SO₂), and changes in concentration of oxyhemoglobin [O₂Hb], deoxyhemoglobin [HHb] and total haemoglobin [tHb] with real-time resolution. We hypothesized that brain tissue oxygenation would be worse during sleep in OSA relative to controls and sought to determine the practical use of NIRS in the sleep laboratory.

Index Terms: Sleep Apnea, Oro-Nasal, NIRS, SO₂, HHb, O₂Hb.

I. INTRODUCTION

Sleep is essential for humans although its basic physiological function remains obscure. Disturbance of the normal breathing process can cause the development of severe metabolic, organic, central nervous and physical disorders. Respiration monitoring allows the continuous measurement and analysis of breathing dynamics and thus, the detection of various disorders. There are a number of breathing disorders, but *sleep apnea syndrome* (SAS) is probably the most common amongst them. Sleep apnea is defined as cessation of airflow to the lungs during sleep for 10 sec. or more[1],[2]. It normally results from either upper airway collapse [obstructive sleep apnea (OSA)] or lack of neural input from the central nervous system to the diaphragm [Central sleep apnea (CSA)] [2]. OSA is the more common form of sleep apnea. Common symptoms of OSA are fatigue, daytime sleepiness, heart problems, and systemic hypertension [2],[3]. It is usually associated with loud, heavy snoring [2]. According to a recent study [4], 4% of the man and 2% of the women between 30- to -60 years may meet the minimal diagnostic criteria for the sleep apnea syndrome. Also, one of the most common respiratory patterns in premature infants is known as periodic breathing, which denotes brief recurring

periods of apnea in a sequence of breaths. While no significant changes in heart rate or body temperature occur during periodic breathing, infants with prolonged periods of apnea frequently suffer bradycardia and hypothermia [5]. Apnea can be induced by a number of disorders, though its exact physiological cause is undefined; even the withdrawal of caffeine received in uterus from a coffee drinking mother has been implicated [6]. Apnea of greater than 30 seconds duration occurs in about 84% of very low birth weight (under 1000g) infants in the first ten day of life[7] . Bradycardia

Using transcranial Doppler to determine cerebral blood flow velocity, there is some evidence that apneas during sleep are associated with profound changes in cerebral blood flow to the extent that cerebral auto regulation may be insufficient to protect the brain.[8][9] Apnea-induced hypoxemia combined with reduced cerebral perfusion may predispose to nocturnal cerebral ischemia in patients with OSA.

Since the brain is very sensitive to hypoxia, it has been suggested that the cerebrovascular morbidity seen in OSA results from chronic, cumulative effects of intermittent nocturnal hypoxia.[8] Although computerized tomography and magnetic resonance imaging have failed to consistently demonstrate brain structural abnormalities in patients with OSA, impairment in cerebral metabolism, especially in the white matter, has been demonstrated using magnetic resonance spectroscopy in patients with moderate to severe OSA. The degree of metabolic impairment correlates with the severity of OSA, supporting the notion that the repetitive hypoxemia associated with OSA leads to anoxic injury and cerebral dysfunction. Consistent with this concept, a recent cross-sectional comparative study demonstrated that the pattern of cognitive impairment seen in severe untreated OSA is similar to the pattern of sub cortical brain damage seen in patients with multiple infarct dementia.[10]

Although arterial blood oxygen saturation (SaO₂) may decrease due to hypoventilation during an apnea, if cerebral blood flow increases simultaneously, it is possible that the increased

flow can compensate for the reduced SaO_2 , thereby maintaining oxygen supply to the brain. Therefore, it is important to measure changes in cerebral tissue oxygenation during obstructive apnea events to ascertain whether repetitive hypoxia during sleep induces anoxic brain damage. Unfortunately, earlier methods of quantifying cerebral blood flow, cerebral blood volume (CBV), and metabolism during sleep such as Xenon-133 computerized tomography, transcranial Doppler ultrasonography, and magnetic resonance spectroscopy[15] are cumbersome, not readily available, and technically difficult to use.

In this paper, we present and discuss design issues of a portable, battery-operated, low-cost, low-noise apnea detector by simple approach using Oro-Nasal thermistor and the change in the thermal plot of the respiration gives us a clear idea about the patient normal respiration process or any abnormality. Along with the apnea detector system we have fast continuous wave NIRS (cwNIRS) system which has been designed for bedside cerebral hemodynamic monitoring of brain tissue oxygen level in various clinical studies. To our knowledge, none of the reported NIRS systems provide these features taken together, which is a crucial factor in transferring the technology to NICU for continuous bedside clinical monitoring, particularly, of regional brain metabolism. Moreover, the system provides access to raw photon data coming from detectors for further off-line signal processing. There are a number of open biomedical signal processing questions such as removing physiological noise and motion artefacts from NIRS data as well as hemodynamic detection of evoked events which are still waiting to be explored by biomedical signal processing experts. None of the system has both the measuring parameter integrated, and the advantage of this system is that at the same it can tell us the patient having apnea syndrome showing any oxygen concentration change in brain or not. So it will help the doctor to take care of the patient before any severe condition occurs like cerebral haemorrhage or brain tissue death.

II. DESIGN AND HARDWARE IMPLEMENTATION

Mainly it is divided in to two modules such as: Apnea detection by thermistor and NIRS system for brain oxygen monitoring.

Fig 1. **General block diagram** :- Apnea Detection by Oro-Nasal Thermistor method where the thermistor out put given to the amplifier and amplifier is connected with the micro controller and in the above part, the NIR Spectroscopy system for Brain Tissue Oxygen monitoring having two 'L' refers to the Led and 'p' refers to the photodiode placed in the probe and ACD, MUX are in the Transmitter section where as the AG, AF are in the Receiver section.

A. THERMISTOR METHOD (APNEA DETECTION)

Oro-nasal airflow is defined as the continuity of airflow from the nose and the mouth. The cessation of air flow indicates the existence of apnea. The existence of congestion in the nose reveals that the airflow stops, thus it can be evaluated as an apnea incorrectly. Oro-nasal air flow is measured with heat sensitive electrodes named as nasal thermistor and located on the both nostril and mouth arc. Thermistor is a semiconductor device that its resistance changes with temperature. Resistance of thermistor can both increase or decrease with temperature depending upon its inner structure. Because of its stable characteristics, the NTC type of thermistor is selected in designing apnea monitor. It must be played attention while placing the thermistor to the patient nose in which it must not touch to the inner nose epitel. Otherwise, the increase of heat can be evaluated as an existence of apnea incorrectly and causes a false alarm. The thermistor and its connection to the patient is shown in ' Fig.1'.

A.1. THERMAL CHANGE IMPULSE IN THE RESPIRATION

Breathing Function

Respiration in a man involves three well-defined stages [16].The first stage is breathing. It comprises inspiration, taking oxygenated air into

the lungs, and expiration, discharging air that is rich in carbon dioxide. The second stage involves the transport of the oxygen to the cells of the body using the heart and the vascular system. The third stage is called *cellular respiration*; in this stage, oxygen is used in the process of generating energy for physiological activities.

The breathing cycle consists of inspiration, expiration, and post expiratory pause. During quiet breathing, inspiration begins due to negative pressure created inside the chest cavity by the contraction of the diaphragm. Expiration is a passive process where the air flow occurs due to the elastic recoil property of the lungs.

Breathing cycle is defined as the time interval between the beginning of inspiration and the end of post expiratory pause. During quiet breathing, the breathing rate may vary from 12–20 breaths/min and, after physical activity, 30–40 breaths/min in healthy individuals.

Fig 2a. Respiration Thermal change Plot during quite breathing.

Due to the low amplitude of the respiration signal, there exists an amplifier circuit. The operation voltage of the amplifier is selected $V_{cc}=9V$. The positive input resistance of the thermistor is equal to $1\text{ K}\Omega$, and the feedback resistance of the thermistor is equal to $5.1\text{ M}\Omega$. In this way, we are able to process the respiration signal by amplifying it 5100 times. The amplitude of the signal is measured $-1.5V$ during the inhale, $0.9V$ during the exhale and $-0.2V$ in the no respiration condition. The amplified signal is then applied to the ADC pin of the microcontroller and converted into the digital form. The microcontroller also controls the voltage level during the respiration continuously and comments the signal whether the apnea exists or not. The thermal change curve is shown in 'Fig.2b'.

Fig 2b. Thermal change curve

B. CwNIR SPECTROSCOPY (BRAIN TISSUE OXYGEN MONITORING)

B.1. Principles of cwNIRS Measurement Device

The change in the amount of blood chromospheres in the tissue can be predicted by means of Modified Beer Lambert Law as explained below .[11][12]

Fig 3. Propagation of photons between source and detector and parameters for Modified Beer Lambert Law

When the NIR light source and detector are located as in 'Fig 3', the detector receives backscattered photons. Some of the injected photons are lost as a result of scattering and absorption due to different structures in the tissue. The attenuation of light between the source and detector can be formulated as follows:

$$I_{out} = I_{in} \cdot 10^{-OD_{\lambda}} \quad (1)$$

Where I_{in} is incident light, I_{out} is the detected light and OD_{λ} is the optical density for wavelength λ . Therefore, OD_{λ} can be defined as attenuation in intensity of light as a function of wavelength λ . This attenuation is the superposition of absorption (A_{λ}) and scattering (S_{λ}) of light with wavelength λ . Thus,

$$OD_{\lambda} = -\log_{10} I_{out}/I_{in} = \text{attenuation} = A_{\lambda} + S_{\lambda} \quad (2)$$

B.2. Description of system design

1. Transmitter

The transmitter part of the control circuit is composed of an adjustable LED driver and wavelength selector. The purpose of the adjustable LED driver is to regulate the light output of the LED in order to compensate for absorption differences in various tissue types. For subjects with lighter skin colour, sufficient amount of output can be achieved by applying lower power light whereas larger intensity of light is necessary for darker skin colour. This is because of the

relative amount of melanin in skin. Since melanin concentration is constant during the measurement, it does not affect the results related to concentration change. However, darker skin colour causes a decrease in signal to noise ratio (SNR) by absorbing more light. Therefore, the same level of SNR can be achieved by adjusting the intensity of NIR light. Light intensity can be changed by varying the current passing through the light source. The user determines the amount of current and programmed the microcontroller in that way. Then, the software adjusts the current by changing the resistance of a digital potentiometer in driver circuit. The range of current that can pass through the light source is from 0 to 100 mA. Values larger than 100 mA have potential to damage the light source; therefore, the software warns the user about these values and does not initiate the operation. The device also has an indicator light on the electronics box which turns on to warn the user when a current larger than 100 mA passes through the light source due to an undesired short circuit. As described in the previous section, two different wavelengths are required to resolve two types of blood chromophores.

We employed these two wavelengths together by means of time multiplexing. This is implemented by a multiplexer IC which is controlled by microcontroller. At the same time, data from corresponding detector channel were registered to satisfy coherent detection. The multiplexer was not directly connected to the light source, since current in the order of 10 to 100 mA passes through the source. Relatively higher RON resistance of the multiplexer causes a large voltage drop and necessary voltage may not be supplied to light source to turn it on. Instead, we connected multiplexer to operate an analog switch with a very low resistance value to turn on/off the light source. During each cycle, after time multiplexing two wavelengths, we allow an idle period where no wavelength is turned on. The reason for this idle period is that NIR light source is a semiconductor junction and heats up during the operation. Experimentally, it has been shown that an idle time helps light source to cool down to safe ranges (see system performance part). Moreover, when NIR light is shone through the tissue, detector readings are composed of ambient light penetrating through the tissue and the offset of the electronic components in addition to optical information coming from the brain.

These offset values can be determined by recording detector output when NIR wavelengths are turned off. During each cycle, detector reading for idle period is used to correct the mentioned

offset values in order to increase the accuracy of the readings. Furthermore, detector output during dark period can be used to monitor the optical isolation of detectors from direct incidence of the ambient light. If offset values are larger than expected, the probe is reattached to the skin for better coupling and isolation.

2. Receiver

The receiver part transfers light information obtained from detectors to the computer after amplifying and analog filtering. The aim of the amplification part is to bring the signal level close to the top of the dynamic range of the analog to digital converter. This operation minimizes the error that occurs during quantization process. The amplification process is initiated by the user. The user hits a button on the user interface after obtaining a satisfactory probe-skin coupling during calibration process. The microcontroller reads the light output coming from the brain and adjusts the value of a digital potentiometer in the gain amplifier such that the signal value is amplified to the full dynamic range. A quantization SNR of 75 dB is guaranteed as the result of closed-loop gain adjustment procedure where quantization resolution is 12 bit. The gain value is also displayed on the user-interface. Typical photon sampling frequency is 60 kHz and wavelength multiplexing frequency is 10 Hz. Before digital conversion, the signal is low-pass filtered with cut-off frequency of 1.5 kHz to avoid aliasing during the sampling process.

3. Probe

The probe is the most critical part of the system design since it establishes the interface between electronics and the subject. It holds the light source and two detectors in an appropriate geometry. Detectors are positioned on opposite sides of the source with a source-detector distance of 2 cm as seen in fig 4. This geometry allows monitoring of two different locations of the brain, simultaneously. Approximate penetration depth is 1 cm for this configuration [13]. Alternatively, detectors can be located on the same side with different source-detector distances for multi-depth measurements. By monitoring different depths, absolute saturation of the brain tissue can be detected.

Fig 4. The first prototype of the "flexible" probe holding low power LED and detectors

III. SYSTEM IMPLEMENTATION

The microcontroller based apnea monitor Consists basically of a heat sensitive sensor, and an amplifier circuit, interfaced with a specific Microcontroller system connected with a computer by using RS-232 serial port. The microcontroller is used for interpretation of the signal to detect the apnea. The system works with two 9V battery and it has a portable property. The LM7805 regulator is connected to the power supply and the 5V voltage is obtained that is necessary for microcontroller. The aim in this application is not to increase the number of battery. A piezzo sounder and two led's, one of which is red and the other is green are connected to the microcontroller. The green led is "ON" while the patient continues the normal respiration. During the apnea the green led turns into "OFF", then the red led and the piezzo sounder turns "ON".

PIC16F877 is selected for microcontroller which includes an internal ADC(Analog to digital converter) and so there is no need to use an extra ADC. The microcontroller needs a square wave clock signal to operate the program instructions that are available in the memory. It reaches to each instruction in one cycle of the clock signal and loads the instructions to the registers[13]. PIC16F877 has two pins, OSC1 and OSC2 for clock signal inputs. The clock signals that are generated by different oscillators can be applied to these pins. The oscillators with crystal and capacitor are used in the circuits in which the timing is important such as apnea monitor. The apnea period is established averagely 10 sec. The system detects the apnea and provides alert if there is no signal exists after the respiration of the patient stops. The control mechanism of the system resets itself if the patient starts the respiration during these 10 s period. Also there exists a reset button to interfere to the alarm system manually. It is depicted a block diagram of the system in 'Fig.1'. On the other hand it will show the oxygen concentration and saturation related changes in the

Brain tissue during sleep apnea through user-interface.

IV. RESULT

Below graph 'Fig. 5' shows the Digital Display of Raw Data During NIRS Collection and the real time raw data as displayed on the PC monitor during NIRS recording.

The upper left corner shows instantaneous numerical readout of brain oxygen saturation (StO₂), total hemoglobin concentration (THC), oxy-hemoglobin concentration (oxy), and deoxyhemoglobin (De-oxy) in the 2 wavelengths on the right (Rt) and left (Lt) forehead.

Fig 5.

'Fig. 6', shows trend in brain tissue oxygen saturation during a 6-hour overnight NIRS recording in a study subject in the upper graph. The signal is separated into right (red) and left (green) based on probe location on the forehead. The bottom histogram shows derivation of the single average value of brain tissue oxygen saturation based on over 20,000 data points for the entire night on both sides of the forehead.

Fig 6.

V. CONCLUSION

The final design concept includes the categorization of the apnea intervals, and generate a real-time histogram of their frequency and duration which makes possible to investigate the relations between the EEG, ECG or other physiological signals and the respiratory patterns and the design present a low-cost, battery operated continuous wave NIRS system that is intended for continuous bedside brain hemodynamic monitoring in intensive care units. The system also communicates with a computer by using RS-232 serial port to make advanced researches on respiration signals. The system works with two 9V battery which makes it portable.

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