International Journal of Scientific & Engineering Research, Volume 6, Issue 7, July-2015
ISSN 2229-5518

Development of Anaesthesia Depth Monitor

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Abstract— Monitoring depth of anaesthesia during surgery is one of the important aspects in improving patient care. During surgery there is a huge variation in patient's physiological parameters. Thus during surgery patients parameters need to be monitored & maintained within an appropriate range. This paper presents a tool to monitor depth of anaesthesia of a patient noninvasively during surgery.

There are different subjective and objective methods to monitor the depth of anaesthesia. This study presents objective methods, such as electroencephalogram, heart rate variability and galvanic skin response. In this study physiological parameters (EEG, HRV and GSR) were captured from the patient with the help of patient electrodes and hardwares developed for them. These analog signals then fed to MSP430 which is an ultra low power microcontroller. In the controller analog signals were digitized with the help of an ADC and further signal processing was performed i.e. Fast fourier transform on EEG and statistical calculation on ECG. The results were displayed on LCD showing an EEG index, an analgoscore and the level of GSR. These results show the state of a patient during surgery so that it will help an anaesthesiologist to inject appropriate amount of drug dose to the patient to maintain its anaesthetic state.

Index Terms—Anaesthesia, EEG, Fast Fourier Transform, GSR, HRV, Statistical calculation

1 INTRODUCTION

Monitoring depth of anaesthesia is a newer advance in the monitoring of anaesthesia. It is an important consideration in maintaining quality of patient care. Anaesthetic depth is the degree to which the central nervous system (CNS) is depressed by a general anaesthetic agent. It refers to central nervous system depression and decreased responsiveness to stimulation.The essential features of a successful anaesthesia are hypnosis i.e reversible loss of consciousness with a lack of movement, lack of awareness and analgesia i.e. unresponsiveness to painful stimuli, lack of recall of the surgical intervention. Inadequate anaesthesia may lead to intraoperative awareness with recall or prolonged recovery or pain. Because of the rapid changes in patient status during anesthesia, qualified anesthesiologist shall be continuously present to monitor the patient. Thus anaesthesia depth monitoring system has developed to assist an anaesthesiologist. [2] There are many subjective & objective parameters available to monitor depth of anaesthesia. Subjective methods rely on the movement and autonomic response to stimuli and depend on the opinion and experience of an anaesthetist. The objective methods rely on the sensitivity of the monitor. Out of these objective parameters such as heart rate variability, galvanic skin response & Electroencephalogram were used for the development of anaesthesia depth monitor.[3] EEG indicates level of consciousness whereas HRV & GSR are the indicators of pain.

Analysis of heart rate variability (HRV), that is the variability of R-R in the electro-cardiographic (ECG) signal, has been widely used as a measure of activity of the sympathetic and parasympathetic components of the autonomous nervous system. Surgical stress stimulates the sympathetic nervous system and in some cases the parasympathetic as well. Suppression of this stimulation routinely is achieved by opioids during general anaesthesia, which markedly depresses HRV and therefore it has been used as a measure of depth of anaesthesia. The measurement of the Heart Rate Variability (HRV) is a technique to quantify the analgesia giving an Analgoscore.[1] Level of Galvanic Skin Response also indicates the level of pain. The Galvanic Skin Response (GSR) is defined as a change in the electrical properties of the skin. This parameter is used for capturing the autonomic nerve responses as a parameter of the sweat gland function. The measurement is relatively simple, and has a good repeatability. Therefore the GSR measurement can be considered to be a simple and useful tool for examination of the autonomous nervous system function, and especially the peripheral sympathetic system. Galvanic skin potential (GSP) refers to the voltage measured between two electrodes without any externally applied current. The activity of the sweat glands in response to sympathetic nervous stimulation (Increased sympathetic activation) results in an increase in the level of conductance. There is a relationship between skin impedance and pain. Pain stimulates sympathetic nerves, innervating the sweat glands to regulate their water content and electric conductivity. As a result of sympathetic nerve stimulation, skin resistance to electric current decreases. By measuring this change in skin impedance, a patient's level of pain may be objectively assessed. [5]The EEG is a recording of the brain's electrical activitydone by placing electrodes over the surface of the scalp. The recordings are the summation of volume conductor fields produced by millions of interconnecting neurons. EEG shows continuous oscillating electric activity. The amplitude and the patterns are determined by the overall excitation of the brain which in turn depends on the activity of the reticular activating system in the brain stem. Amplitudes on the surface of the brain can be up to 10 mV, those on the surface of the scalp range up to 100 µV. Frequen-

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cies range from 0.5 to 100 Hz. The pattern changes markedly between states of sleep and wakefulness. Five classes of wave groups are described: alpha, beta, gamma, delta and theta. Beta waves have a frequency range of 14 to 22 Hz, extending to 50 Hz under intense mental activity with amplitude of 2 to 20 µV. There are two types: beta I waves, lower frequencies and beta II waves higher frequencies which appear during tension and intense mental activity. Gamma waves have frequencies between 22 and 30 Hz with amplitude of less than 2µV and are found when the subject is paying attention or is having some other sensory stimulation. Alpha waves contain frequencies between 8 and 13 Hz with amplitude less than 10µV. They are found in normal people who are awake and resting quietly. Theta waves have a frequency range between 4 to 7 Hz with amplitude of less than 100 µV. They occur mainly in sleep and also in children when awake, during emotional stress in some adults, particularly during disappointment and frustration.Delta waves are having frequencies between 0 to 3 Hz with amplitude of 20 to 200 µv. They are found in people who are in deep sleep or in unconscious state.[6] EEG signal after application of radix2 FFT algorithm gives an EEG index(0 to 50) depending on which propofol (drug) will be delivered to the patient. ECG signal after application of spectral analysis & GSR by setting a threshold to it gives an analgoscore & level of GSR respectively. Depending on these two factors remifentanil (drug) will be delivered to the patient. These three parameters give an accurate assessment about depth of anaesthesia.

2 Methods

2.1 Hardware Implementation

Anaesthesia depth monitoring system was implemented as shown in figure below. The biosignals (ECG, GSR & EEG) from the electrodes connected to patient are given to the module1, module2 & module3 respectively as an input.

Module 1

Module 1 captures an ECG signal. Acquisition of ECG signal & peak detection was implemented in hardware. Pre amplifier was designed with gain 6 by using AD620 instrumentation amplifier. Further using LMC6044 which is a quad opamp the signal was maintained at the baseline, further amplified with gain 400, filtered using band pass filter for the frequency range of 8 to 25 Hz as QRS complex lies in this range. This QRS complex was given to absolute value circuit which returns the absolute value of the input i.e. negative peaks was converted to positive peaks. Then peak detection was performed where positive peak value in the ECG signal was detected. The output of peak detector circuit was given to voltage divider network which selects 2/3rd of the peak value. The higher value of the 2/3rd of the peak and 10% of the peak value was considered as a threshold. The output of absolute value circuit was given as an input to the comparator which was compared with the threshold value. Higher of the two values was given at the output of the comparator.Two Monostable multivibrators was designed. One with 300ms blocks the unwanted pulses & other with 10µs gives positive pulses for each output of the comparator. This analog signal (R Peaks) was given to microcontroller MSP430FG4618. Digitization in microcontroller was needed to perform because peak detection circuit gives either high pulse (1) or low (0) at the output. In microcontroller spectral analysis was performed by statistical calculation method which was resulted in LF/HF ratio which is nothing but an Analgoscore which indicates the level of pain.

Module 2

Module 2 captures GSR signal. Acquisition of GSR was implemented in hardware with the help of bridge circuit. Across two arms of the bridge circuit resistors of fixed value were connected. In the third arm patient electrodes were attached. In the fourth arm variable resistor is connected. This variable resistance was varied by using an analog multiplexer HEF4051B. The output of the bridge circuit was amplified with an instrumentation amplifier AD620. This amplified voltage was given to microcontroller MSP430FG4618 where the voltages were digitized with the help of an ADC. Then calibration was performed where patient's skin resistance was determined with the help of variable resistance. After which the patient's skin resistance was monitored. Whenever the resistance decreases that means conductance has increased i.e. more amount of sweat has accumulated in the sweat gland thus voltage at the output of AD620 increases. As the output voltage is directly proportional to level of pain it indicates that the pain has also increased. This module displays the level of GSR & it also indicates the level of pain.

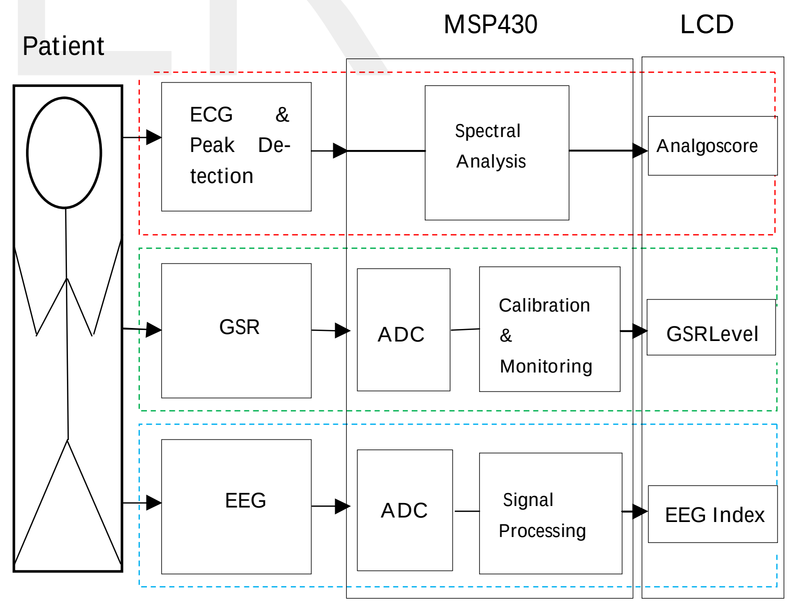
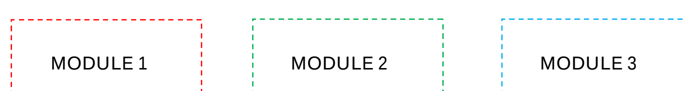


Fig. 1. Block Diagram of the whole system



Module 3

Module 3 captures an EEG signal. Acquisition of EEG signal was performed in hardware. For this pre amplifier was de-

ISSN 2229-5518

signed with gain 6 using an instrumentation amplifier AD620. Then using a quad opamp LMC6044, the signal was filtered using band pass filter for the frequency range of 0.5 to 50 Hz & the signal was further amplified with gain 3300. Then the signal was level shifted. This analog EEG signal was given to microcontroller MSP430FG4618 in which signal was digitized using ADC. Once the signal was digitized signal processing was performed. Fast Fourier Transform algorithm was applied to digitized EEG signal & the resulting FFT(0 to 50 HZ) was splitted into four frequency bands(0 – 6.25 Hz, 6.25 – 12.5 Hz, 12.5 – 25 Hz, 25-50 Hz) .Highest magnitudes of each bands were determined & then compared to get maximum repeated frequency (EEG Index) in the signal. Then EEG Index value was displayed. This indicates the level of hypnosis.[6]

Thus results obtained from 3 modules after analog acquisition & software processing of parameters ECG, GSR & EEG will give an Analgoscore, GSR Level & EEG Index respectively. In this way depth of anaesthesia of a patient can be monitored & maintained within predefined range so as to maintain hypnosis, analgesia & pain relief.

2.2 Microcontroller

Whole system was implemented in MSP430 of FG4618 series. It is an ultra low power microcontroller of Texas Instruments. It works on supply voltage of 3.3 volts The Texas Instruments MSP430 family of ultralow-power microcontrollers consists of several devices featuring different sets of peripherals targeted for various applications. The architecture, combined with five low-power modes, is optimized to achieve extended battery life in portable measurement applications. The device features a powerful 16-bit RISC CPU, 16-bit registers, and constant generators that contribute to maximum code efficiency. The digitally controlled oscillator (DCO) allows wake-up from low-power modes to active mode in less than 6 μs. The MSP430xG461x series are microcontroller configurations with two 16-bit timers, a high-performance 12-bit A/D converter, dual 12-bit D/A converters, three configurable operational amplifiers, one universal serial communication interface (USCI), one universal synchronous/asynchronous communication interface (USART), DMA, 80 I/O pins. Typical applications for this device include portable medical application.[9]

Fig.2.MSP430FG4618 IC

2.3 Software Implementation

Code Composer Studio is an integrated development environment (IDE) that supports all MSP microcontroller devices. Code Composer Studio comprises a suite of tools used to develop and debug embedded applications. It includes an optimizing C/C++ compiler, source code editor, project build environment, debugger, profiler, and many other features. Code Composer Studio combines the advantages of the Eclipse software framework with advanced embedded debug capabilities from TI resulting in a compelling feature-rich development environment for embedded developers. When using CCS with an MSP MCU, a unique and powerful set of plugins and tools are made available to fully leverage the MSP microcontroller.[10]

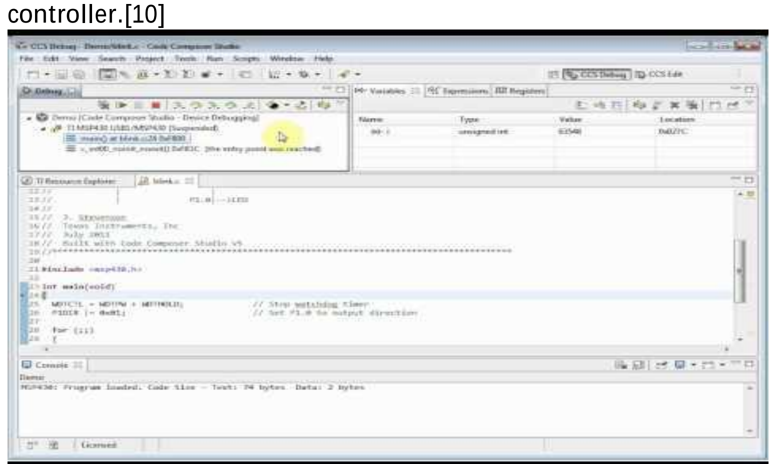


Fig .3.Code Composer Studio

3 Clinical Significance

3.1 TABLE 1
Heart Rate Variability

Analgoscore	Significance
-3 To +3	Excellent Pain control
-3 To -6 & +3 To +6	Good Pain Control
-6 To -9 & +6 To +9	Inadequate Pain Control

3.2 TABLE 2
Galvanic Skin Response

Awake State	Anaesthetic State
Skin Resistance is High	Skin Resistance is Low
Skin Conductance is Low	Skin Conductance is High

3.3 TABLE 3
Electroencephalogram

EEG Waves	EEG Index	Mental Activity
Delta	0 To 6.25	Deep Sleep
Alpha	6.25 To 12.5	Awake & Resting
Beta I	12.5 To 25	Mental Activity
Beta II	25 To 50	Tension & Intense Mental Activity

4 Results

The system described above was implemented & tested on different subjects. Readings were taken on three different subjects in awake & conscious state. For the purpose of testing one set of electrodes was connected on right arm, left arm & right leg to capture ECG. Another set of electrodes was connected on forehead, frontal & temporal region above the eyes to acquire EEG. Third set of electrodes was connected on right & left arm to aquire GSR. Once proper setup has been done readings were taken which are tabulized as follows displaying ECG Index, GSR Level & EEG Index on LCD.

TABLE 4
Results of ECG Index (Analgoscore)

Sr. No.	ECG Index (Analgoscore)
Subject 1	0.61
Subject 2	2.49
Subject 3	1.02

TABLE 5
Results of Galvanic Skin Response (GSR)

Sr. No.	Level of GSR
Subject 1	Normal
Subject 2	Normal
Subject 3	Normal

TABLE 6
Results of EEG Index

State of Subject	Subject 1	Subject 2	Subject 3
Sleep	6	6	6
Awake & Resting	12	8	11
Meditation	19	22	18
Mental Activity	33	46	38

5 Discussion

The results drawn above in table 4, 5 & 6 are compared with standard results in table 1, 2, & 3 respectively. As the readings were taken on normal subjects in awake & conscious state, the Analgoscore ranges between 0 to 3 and GSR level is normal. Also EEG index varies as per the state of subject

This system monitors the depth of anaesthesia of a patient by acquiring physiological parameters through hardware & processing the signals in software. While software processing of HRV spectral analysis was performed in time domain. In this parameters such as mean, standard deviation, variance, and power were calculated. After implementing the software for these time domain calculations it has been found out that the time duration for these calculations was about 3 to 4 minutes. This is a very long duration in which there could be significant variations in low frequency & high frequency of HRV. Thus in future more work can be done in implementing time saving method to calculate LF/HF ratio.

6 Conclusion

This paper describes an Anaesthesia Depth Monitoring system. The aim of the designed system is to assist an anaesthesiologist in providing adequate anaesthesia to the patient during surgery. For the purpose of depth monitoring important physiological parameters such as HRV, GSR & EEG were taken into consideration. Acqusition of signals was performed with hardware implementation of the system. Signals were further processed with implementation in software. At the output system gives index value for each parameter.If the index values goes beyond the preset range then the system can give trigger to the drug delivery unit to inject the drug.

Acknowledgment

The study was carried out at biomedical engineering department, MGM College of Engineering & Technology. Authors are thankful to Dr.G.D.Jindal, Professor & Head of Department & Prof. Nishant Patil & Prof. Mamta Rajput, Assistant Professors of Biomedical Engineering, MGM College of Engineering & Technology (MGMCET) Navi Mumbai for the ideas & constant encouragement throughout the development.

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