DESIGN AND IMPLEMENTATION OF CRANIAL PPG SENSOR FOR BRAIN MAPPING USING FMRI AS GOLD STANDARD

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Abstract

Cranial PPG sensor is designed to capture the signal due to blood flow variation in cranial mask for different activity. Various parameters are considered in the designing of optical sensor, those are source wavelength, photodetector and the type of excitation. The designed PPG sensor is used to capture the cranial PPG signal during the eye blinking activity. The analysis is performed by using wavelet domain method and Mean square spectrum. The result shows that the designed sensor can be used for brain mapping noninvasively. MSS (Mean square spectrum) reflects the power in the signal at a given frequency. The Mean Square Spectrum of a signal is the fourier transform of that signal's autocorrelation. The mean square spectrum based analysis of oxy and deoxyhaemoglobin can be used for brain mapping using optical sensor. During brain functioning as blood flow increases oxyhaemoglobin increases and deoxyhaemoglobin decreases this can be detected using proposed system. A six level wavelet decomposition of CPPG signal is performed using Daubechies 9 and statistical features are calculated. Wavelet analysis shows that D_3-D_1 scales consists of predominantly the noise part of the signal. The difference between the statistical parameters of CPPG signal for A_6 and D_6 level differ during rest and activity. The other detail subbands contain the noise part of the signal and hence not considered for calculation. These features can be used for classifying the activated and non activated region in prefrontal lobe. The system is related with the fMRI the second brain mapping technique.

Keywords- Discrete cosine transform (DCT), CPPG(Cranial Photoplethysmography), Reflectance type, MSS(Mean Square Spectrum), Wavelet analysis**.**

I. INTRODUCTION

A. Brain mapping Methods

Hemodynamic response related to neural activity is detected by NIRS system. Blood flow increased due to functional activity. NIRS measures the blood flow changes by detecting the light absorption for the oxygenated and deoxygenated blood in a various brain area. To detect blood volume changes signal is measured at 570nm, signals in the range of 600 to 630 nm range is used to detect changes expected in deoxyhaemoglobin concentrations. NIRS system is having freedom of movement, better temporal resolution, silent (auditory system), easy to use, test young infant and cost of operation is cheaper. Is a Continuous monitoring, portable and small system. NIRS system has worse spatial resolution (cm), detects only surface cortical activity .The most successful method for use with infants and children. NIRS and FMRI techniques measure the phenomenon of increased blood flow to detect to functional brain activity [1-4].

fMRI is a non invasive technique for investigating human brain function. Brain regions that are associated with certain motor and sensory tasks are identified. This measurement of neural activity is based on blood oxygen level dependent contrast. fMRI detects the blood flow variations by measuring the magnetic signal for the deoxygenated blood in the brain area.

Issues in fMRI system are thermal and electromagnetic noise from the subject, head movement and motion artifacts (problem especially for speech tasks). fMRI is not suitable for Patients with metal implants , for infants and children. fMRI system is having high cost [5-6].

Functional fNIRS allows the ability to monitor brain activity by measuring changes in the concentration of oxy and deoxyhaemoglobin in the spectrum range of 600-950nm. Near infrared light ranges from 600-950nm is

strongly absorbed by two chromophores (HbO,Hb). The oxygenation response over an activated area of the cortex by decrease in Hb with a simultaneous increase in HbO. Increase in HbO is usually two to three times that of the decrease in Hb. The total volume of haemoglobin is expected to increase locally in the activated areas. Recording Hb can be related to compared fMRI BOLD response. Increase in BOLD contrast is highly correlated with a decrease in Hb.

Work is carried out for the two brain mapping methods for functional brain activity are shown in fig.1. Optical sensor is designed which measures the signal for 660nm and 860nm wavelet. Functional activity is detected using MMS and wavelet domain analysis. The functional activity is detected using fMRI, by applying threshold on power and period of time series of fMRI images.

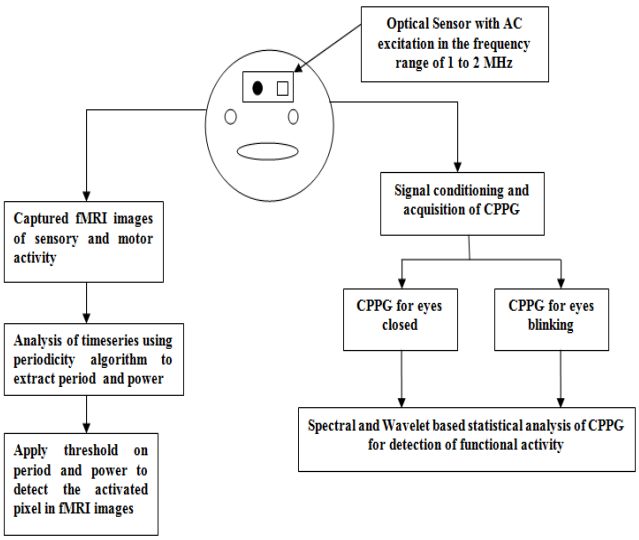

Fig.1. Brain Mapping Methods

II. OPTICAL SENSOR (PPG) DESIGN

The plethysmography produces a waveform similar to the arterial pressure waveform. The relative blood volume changes in the blood vessels close to the skin are measured by a non invasive optical method known as photoplethysmography. As the blood absorbs infrared light many times more strongly than the remaining skin tissues this technique is used for measurement of blood volumetric changes in the skin perfusion by means of PPG

There are two types of photoplethysmography one is transmittance type in which source and detector placed on the opposite side, other is reflectance type in which source and detector are on the same side as shown in Fig.2. The infrared light is emitted into the skin. Depending on the blood volume, the amount of reflected light changes. Blood volume changes can then be measured based on the amount of reflected light .Various parameters can be measured using PPG sensor are blood pressure, pulse transit time, pulse rate measurement, oxygen saturation [7].

The optical system is based on the beers and Lambert law. The light intensity after the tissue interaction is given by:

$$A = \in \times c \times d \qquad \text{Equation 1}$$

A = Absorbance

c = Concentration of absorbing molecule

d = Distance between light source and detector.

Equation 1 is used for detection of concentration change. The two different wavelength of near infrared light range and the relative change in the Hb and HbO_2 is used for the detection of brain function in optical brain mapping[8].

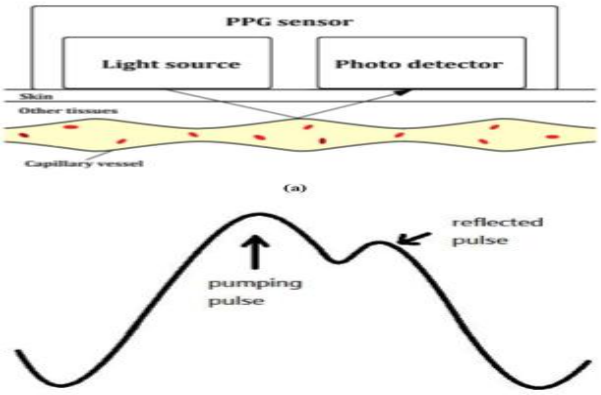

Fig.2. Reflectance type PPG sensor

A .Based on source wavelength

In Photoplethysmography (PPG) wavelengths in visible to infrared range, those are 570nm, 660 nm, 860 nm, 940nm used for measurement of blood flow, volume and oxymetry component.

A optical sensor with specially designed probe for two wavelengths 660 nm and 860/940 nm is designed for measurement of change in deoxy-Hb and oxy-Hb respectively. Fig.3 shows Oxy and deoxyhaemoglobin spectrum.

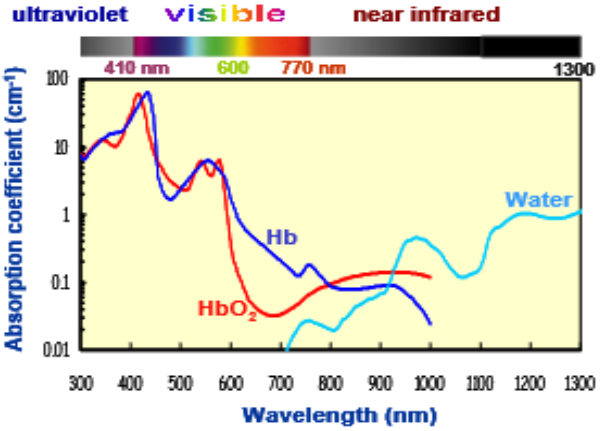

Fig.3. Oxy and deoxyhaemoglobin spectrum

Single wavelength optical sensor is designed 860nm Infrared LED and the multi wavelength sensor is designed using 660nm red and 860nm Infrared source with OPT 101 as detector. As the sensor is of reflectance type Fig.3 shows the schematic of the sensor.

Fig.4.(a) Single wavelength sensor (b) Multi wavelength sensor

Both are mounted on PCB and placed in the plastic casing. polyurethane packing was used to reduce the effect of ambient light only the reflected light is sensed. Noise effect is reduced using the shielded cable shown in fig.4 [8-10].

B: Based on Detector:

LDR: Light Dependent resistors are used to measure light intensity. The Dark resistance is very high is upto 1Mohm. When the light falls on LDR the resistance drops to a ohm. Sensitivity of LDR varies with the wavelength. Response is maximum around 600 nm wavelength. Fig.5 shows the LDR and its spectral Response.

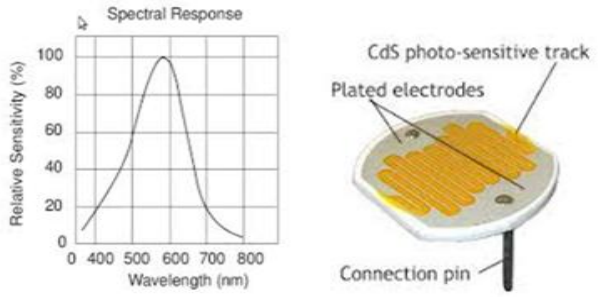

Fig.5. Detector LDR

OPT 101 is a monolithic photodiode with on-chip amplifier. Output voltage is directly proportional to the light intensity. Fig.6 shows the OPT 101 and its spectral response.

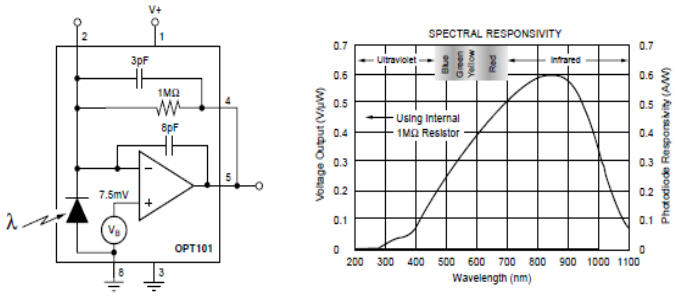

Fig.6. Detector OPT 101

LDR is the Light Dependent resistors are used to measure light intensity. LDR gives highest peak to peak voltage for source wavelength 660 nm, LDR behaves poor for the IR source. Peak to peak voltage for OPT101 was highest around 860 nm. OPT101 is best suited for source wavelength from 500nm to 1000nm. It concludes that OPT101 is best detector to capture PPG by using visible or infrared source [11-13].

C: Based on the AC and DC excitation

Cranial PPG (CPPG) signal is captured by placing the sensor on the prefrontal lobe. Power and wavelength of the light source are the two important parameters to penetrate the light inside the cranial surface the blood volume flow changes in the brain vessels. Source excitation plays important role in detecting the CPPG signal. Source with DC excitation is not sufficient to penetrate the light but the AC excitation in the range of frequency1 to 2 MHz and the current of 10 mA to 25mA can penetrate light and detect the blood volume change during the functional activity. CPPG for DC and AC excitation is shown in Fig.7.

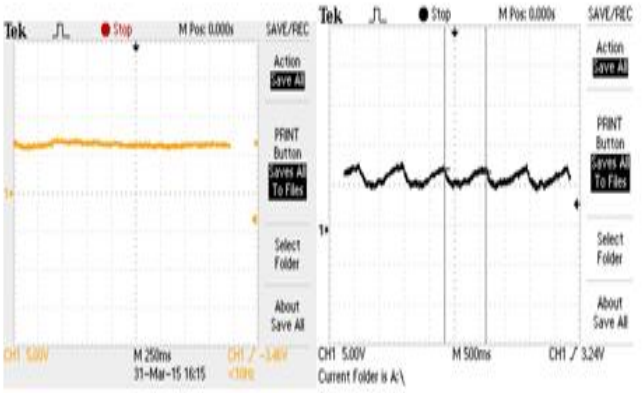

Fig.7. (a) CPPG of DC excitation (b) CPPG of AC excitation

ANALYSIS OF PPG SIGNAL

A: Mean square Spectrum:

The mean-squared spectrum (MSS) represents the discrete spectra. The peaks in the MSS reflect the power in the signal at a given frequency. The MSS of a signal is the Fourier transform of that signal's autocorrelation.

SpectrumType: 'Onesided': Nyquist interval over which the spectral density is calculated. . The interval for Onesided is [0, pi] depending on the number of FFT points, and for Twosided the interval is [0, 2pi].

Hmss = dspdata.msspectrum (Data, Frequencies) uses the mean–square spectrum data contained in Data and Frequencies vectors. Using this function MSS of the PPG signal is detected. Fig.8 and Fig.9 shows the MSS for 660nm and 860nm wavelength respectively [14].

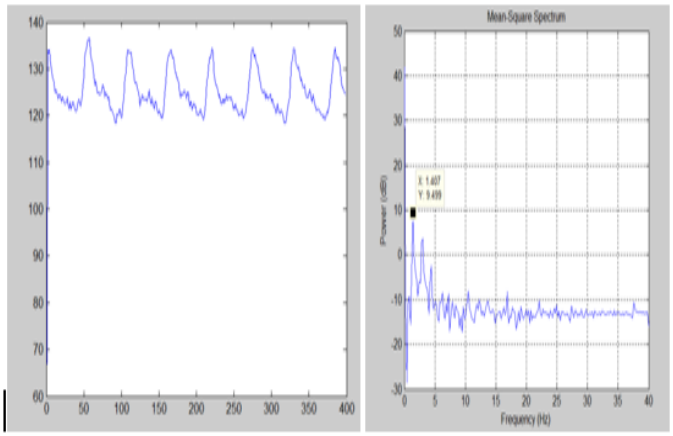

Fig.8. PPG signal of 660 nm and MSS of 660 nm

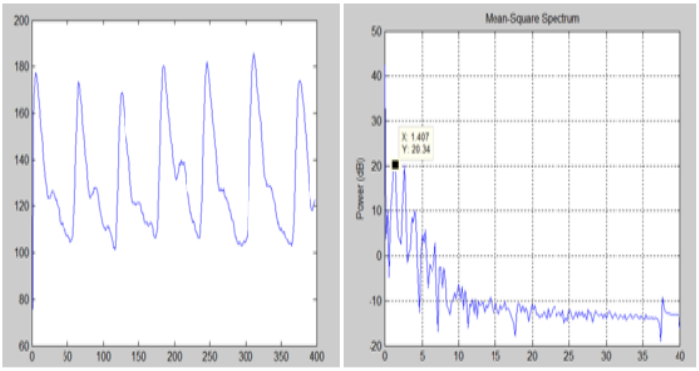

Fig.9. PPG signal of 860 nm and MSS of 860 nm

B: Multiscale Wavelet Analysis:

The wavelet transform represents the signal into the time frequency domain using building blocks. wavelet based analysis of signal represents the data points into different features. Each stage of wavelet consists of low pass and high pass digital filters and downsampler by 2. The downsampler provide detail D_1 and approximation A_1 component as shown in fig. 10.

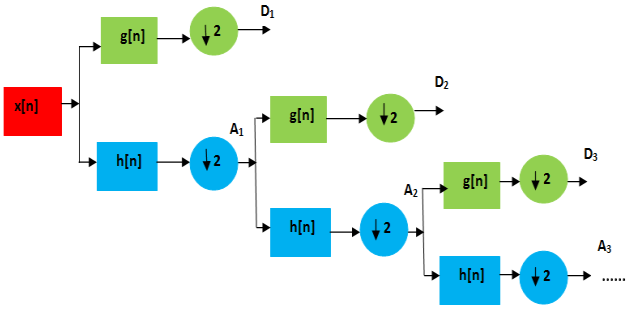

Fig.10. Wavelet Analysis of Signal

The CPPG signal Captured during EO (eyes open) and EB (eye blinking) activity is shown in figure 2. The analysis of the signal is done by using multiscale wavelet decomposition .The coefficient of each subbands are used to calculate spectral and statistical parameters

Six level of CPPG using Daubechies 9 is performed. Spectral and statistical components are calculated at different subbands.D_1-D_3 scales consists of noise part of the signal. The D_4 –scale shows the higher frequency at 17.58 Hz. Analysis of for A_6 level for mean ,variance and energy values of with eyes open are 4.7979, 32.9877, 141853 respectively where as mean ,variance

and ,energy values are for eye blinking are 3.99308, 47.5801, 159023 [15].

III. fMRI as a GOLD STANDARD

The structural information on certain abnormalities in the brain is obtained by normal anatomical imaging techniques. However, there are many neurological disorders for which only structural studies are not sufficient. In such cases it is required to investigate the functional organization of brain.

Brain functions and brain areas responsible for the particular activities like motor, sensory, speech and memory process could be investigated through fMRI studies.

The most common fMRI technique used to capture blood oxygenation level Dependent BOLD contrast. The BOLD signal arises from the interplay of blood flow, blood volume and blood oxygenation in response to changes in neuronal activity. Under an active state the local concentration of oxygenated hemoglobin increase, which increases homogeneity of magnetic susceptibility, resulting in an increase in T2*-weighted MRI signal.

Time Series: The single image obviously does not give any functional information. In fact the variation of the image intensity are recorded with respect to time. In fMRI a number of images of the brain are recorded consecutively with respect to time in single fMRI experiment [16].

A. Temporal filtering and autocorrelation

The noise arises from physical sources, sometimes referred to as scanner drift, from physiological sources, from residual movement effects and their interaction with the static magnetic field. When the subject is performing task signal components are added to this noise.

The most obvious characteristic of noise in BOLD fMRI data is the presence of low frequency drift. This low frequency drift in an fMRI time series can be observed in the Fourier domain power spectrum.

The power spectrum is acquired by taking the Fourier transform of the time series. The X axis of the plot refers to different frequencies whereas the Y axis refers to the power or strength of this frequency.

High pass filtering: high pass filter is used to remove the low frequency components. The high pass filtering is done by using discrete cosine transform.(DCT).

Following results obtained from MATLAB Program on clinical fMRI data set for finger tapping activity. The processing is restricted in the Intracranial region only and hence a mask is applied to this region by considering the histogram of the intensity averaged image.Power spectrum of original time series shown in Fig.11, illustrate that the original time series exhibited low frequency noise. The spike in power spectrum at 50mHz corresponds to the frequency of the task (once every 20 seconds) in this experiment. Power (dB) is -5.441 [17-19].

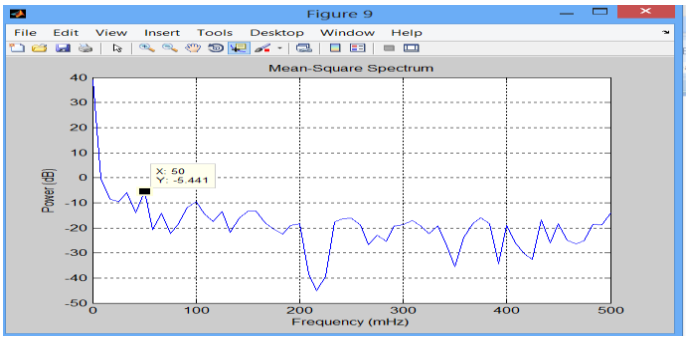

Fig.11. Power spectrum of original time series

Low frequency is removed by high pass filtering (DCT). Fig.12 shows activated pixel in the cranial mask for finger tapping using periodicity algorithm

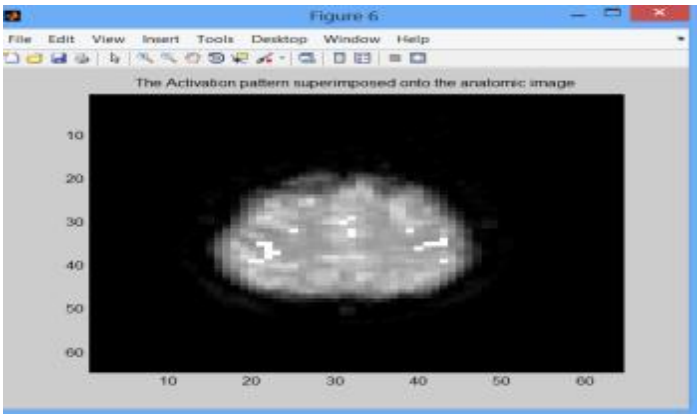

Fig.12: Activated pixel in the cranial mask

fMRI images were collected from Nanavati Hospital, Mumbai.Two subjects fMRI images for both upper limb motor activity. Two subjects fMRI images for both lower

limb motor activity were studied. It is observed that Spike power is more for the lower limb movement than upper limb movement.

IV. CONCLUSION AND FUTURE WORK

Designed CPPG sensor using red and infrared source with OPT 101 as detector. Sensor can captured the cranial PPG using AC excitation in the frequency range of 1 to 2 MHz. The CPPG is captured for eye blinking activity. The Mean square spectrum and wavelet domain analysis of CPPG before and after activity shows the different in the spectral and statistical features. Brain Mapping using fMRI images shows that the analysis is carried out using periodicity transform on timeseries . The timeseries whose period and power is above threshold the corresponding pixel is declared as a activated pixel. The features obtained by optical system can be used to train the classifier and the whole system can be used for brain mapping non invasively.

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