FUTURE OF CPPG-EEG CONCURRENT MODALITY

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Abstract

Non-invasive monitoring is the growing interest in the biomedical field using various classical as well as modern sensors. Many researchers are working on brain signals, to find out the low cost, non-invasive, simple and easy technique to predict various parameters related to the brain and or whole body. One of the most widely studied electrical brain signal is electroencephalogram (EEG); it is the rhythm produced by numerous brain cells when they are depolarized simultaneously. EEG measures voltage fluctuations resulting from ionic current flows within the neurons of the brain. EEG is very commonly used signal in the various brain related studies. Near infrared spectroscopy (NIRS) based optical signal captured from brain is known as cranial photoplethysmogram (CPPG).PPG signal is generated because of arterial blood volume change with each heartbeat. This optical technique is widely used to detect various cardiovascular diseases and microcirculation related diseases. EEG-CPPG concurrent modality can be used to investigate the synchronized activities of neurons and the subsequent hemodynamic response in human subjects. This simple and comparatively low-cost setup allows to measure hemodynamic activity in many situations when fMRI measurements are not feasible, e.g. for long-term monitoring at the bedside or even outside the lab via wireless transmission, in intensive care unit and in the operation theatres. This concurrent modality is used to study the various brain and heart related parameter and can be used in future for predicting the Head-Heart Interaction.

Key words: Photoplethysmogram; Cranial Photoplethysmogram, Electroencephalogram; Brain Signals; Optical Technique; Head-Heart Interaction.

I. INTRODUCTION

EEG and PPG both are non-invasive signals. EEG is an electrical brain signal while CPPG is an optical brain signal. Pulsation of arteries through the interaction between oxy-haemoglobin, deoxy-haemoglobin and photons is reflected in the PPG signal. PPG signal can be captured from any body location. Analysis of PPG waveform is majorly carried out in circulatory and respiratory monitoring.

A. Electroencephalogram (EEG):

EEG is a kind of biological electric activity generated by a large number of neurons, in other words, it is a rhythm produced by numerous brain cells when they are depolarized simultaneously. Thus synchronization of EEG to study the cooperation mechanism of neural network and reveal temporal and spatial characteristics of brain. Ionic current flows within the neurons of the brain results into voltage fluctuations; recorded as EEG signal. This electrical activity of brain is recorded usually for 20 to 40 minutes with multiple electrodes placed over the scalp. The spectral content of EEG are generally used for diagnostic applications. EEG signal after decomposition into various sub-bands is mainly analysed in frequency domain. Various estimates based on the EEG signal are: Power Spectral Density (PSD) of various EEG sub-bands, Coherence between the various EEG channels, Entropy, and Variance etc.

B. Photoplethysmogram (PPG):

It is an optical signal generated because of arterial blood volume change with each heartbeat. It has great potential in various clinical applications due to non-invasiveness, compactness, simplicity and low cost. This technique is widely used to detect various cardiovascular diseases and microcirculation related diseases. PPG signal can be analysed in time domain or frequency domain. Time domain analysis allows the detection of physiological parameters such as Heart Rate (HR), Blood Pressure (BP), Blood Oxygen Saturation (SpO_2), Haemoglobin (Hb). PPG originates from optical properties changes in the banana-shaped tissue path between the source of light and the photo detector.PPG signal varies

in amplitude, shape and upstroke time with respect to the measurement site. [1]

Table 1: Types of Photoplethysmograms and Application

Type	Application
Photoelectric	• Monitoring Heart Rate, Respiratory Rate, and Oxygen Saturation • Assessment of Cardiac Output, Venous Function, Venous Reflux, and Blood Viscosity • Measuring Ankle Pressure, Blood Pressure, and Cold Sensitivity.
Impedance	• Study related to blood flow disorders • Assessment of fat free mass of the human body.
Stain Gauge	• Evaluation of peripheral circulation, acute/chronic venous insufficiency, and peripheral vascular disease. • Measurement of deep venous thromboses and venous incompetence. • Assessment of capillary filtration, volume change in venous diseases.
Air	• Measurement of venous functions like: Residual volume fraction, Ejection fractions, Calf venous volume, and Venous filling index.
Water	• Measuring maximal blood flow, Pulmonary blood flow.

C. Brain Signals CPPG and EEG:

In this paper specifically only two brain signals are studied; i.e. cranial photoplethysmogram (CPPG) and electroencephalogram (EEG). CPPG is captured by using near infrared spectroscopy (NIRS) based optical technique. NIR range 660 nm-1000 nm can be used to record the dynamic changes in the cerebral oxygenation and blood flow in the brain region. EEG-CPPG measurement depends on various physical properties such as conductivity, absorption and scattering coefficients of the head tissues such as scalp, skull, gray matter, white matter and cerebral blood flow (CBF). EEG-CPPG concurrent modality can be used to investigate the synchronized activities of neurons and the subsequent hemodynamic response in human subjects. This simple and comparatively low-cost setup allows to measure hemodynamic activity in many situations when fMRI measurements are not feasible, e.g. for long-term monitoring at the bedside or even outside the lab via wireless transmission, in intensive care unit and in the operation theatres. By combining the various modalities together, we can exploit the strengths and flaws of individual brain imaging methods. In future this concurrent modality can be used for interpreting the Head-Heart Interaction. [2][3]

II. MATERIALS & METHODS

Quality of PPG signal depends on the location of measurement. It also gets affected by skin colour, skin structure, blood flow rate, skin temperature at the measurement site. Appearance of the PPG pulse is divided into two phases: Anacrotic (rising edge of the PPG, concern with systole) and Catacrotic (falling edge of the PPG, concern with diastole).

A. Sensor Specifications:

Authors have developed sensor for the PPG acquisition. The specifications of the designed sensor are as shown in the table 2. [4]

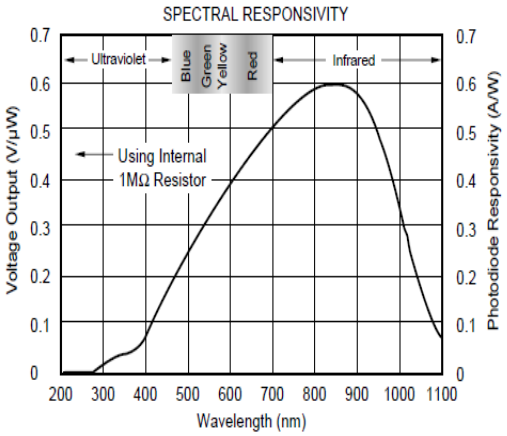
Table 2: Sensor Specifications

Category	Specification
SENSOR	
Type	Reflection type of sensor
Source	860 nm (5 mm LED)
Detector	OPT 101 (Burr-Brown SiliconPD)
Sensor Casing	Black Polyurethane
Optode Distance	1.5 mm
Supply	10V DC-Signal Conditioning Circuit; 5V, 2KHz AC to source
APPLICATION	
Measurement Site	Anywhere on the human body from head to toe.

B. CPPG Acquisition:

Figure 1 shows the sensor developed by the authors and the spectral response of detector OPT 101. OPT 101 works for the source wavelength from visible region to near infrared region, with peak response at 820 nm wavelength. [5][6]

(a)



(b)

Figure 1: (a) CPPG Sensor (b) Spectral Response of OPT 101

Figure 2 shows the PPG captured from various body sites using the sensor shown the figure 1. Bone thickness at the head region is higher so the captured cranial PPG looks noisy as compared to other body sites.

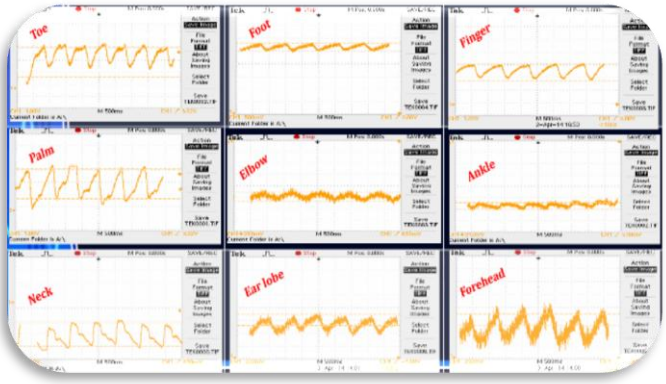


Figure 2: PPG captured from various body part

C. *EEG Acquisition:*

In endeavour towards better understanding of brain functions, the analysis of information transfer between the various brain lobes plays a crucial role. Electroencephalogram (EEG) is an electrical signal in micro volts from brain, which provides important and unique information about the brain. Frequency of EEG signal lies between 0-100Hz. EEG signal is acquired using 16 channel Neurowin EEG machine having sampling frequency of 500 Hz. EEG signal is used to [7]

a. Monitor alertness, coma and brain death.
b. Locate areas of damage following head injury, stroke, tumour, etc.
c. Monitor different cognitive engagements and classification of various cognitive activities.
d. Control anaesthesia depth (“servo anaesthesia” and to study biofeedback.
e. Investigate epilepsy and locate seizure origin. To test epilepsy drug effects.
f. Assist in experimental cortical excision of epileptic focus.
g. Monitor human and animal brain development.
h. Investigate sleep disorder and physiology.
i. Detect various mental states and assess work load.

III. PARAMETER ESTIMATION

PPG signal has lot of importance in the field of biomedical engineering. Various brain and heart related parameters as listed below can be estimated using captured PPG signal.

A. *Heart Rate (HR):*

Heart rate measurement is the very basic check carried out by the physician in any disease. PPG signal captured from various body sites can be used for the HR estimation. PPG is a rhythmic signal, so it can be used in time domain as well as frequency domain for the estimation of HR. [8]

B. *Respiratory Rate (RR):*

PPG captured from any location on the body can be used for the respiratory rate prediction. For RR prediction PPG must be analysed in frequency domain. Fast Fourier Transform (FFT) of PPG signal shows the second dominant peak corresponding to RR around at 0.2 Hz corresponding to 15-20 cycles per minute in time domain. Estimation of RR is important in the various

breathing/lung related diseases. Cardiac output increases with increase in respiration.

C. Blood Pressure (BP):

Now aday's circulatory diseases like BP is very common in adults and young adults and is a major cause of death. Classical method of BP measurement is by using sphygmomanometer. It is a non-invasive cuff based method; which cannot be applied for the continuous BP monitoring. Classical BP cuff based measurement method is not good for the patients in Intensive Care Unit (ICU). For such patient's continuous cuff-less BP estimation is carried out. For such estimation ECG and PPG signals are captured simultaneously and Pulse Transit Time (PTT) is calculated. Thus PTT based indirect measurement of systolic and diastolic BP is carried out. [8][9][10]

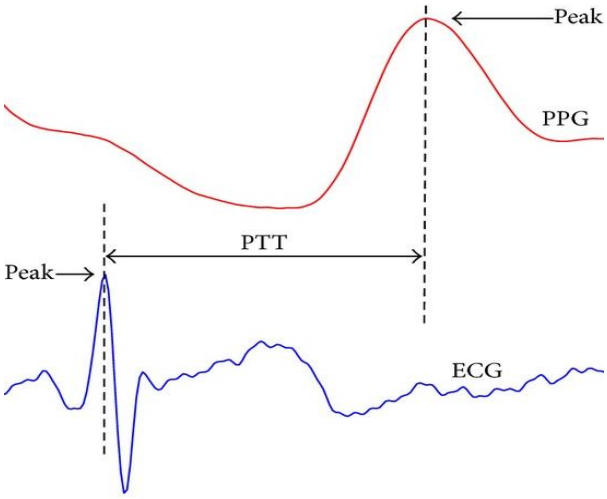


Figure 3**:** PTT from ECG and PPG Waveform [9]

D. Blood Volume:

Activity related blood volume change is widely studied by the various researchers these days. Integration (area under the curve) of the PPG signal gives the blood volume estimation.

E. Arterial Diseases:

Lot of attention is recently received by the arterial stiffness problem, it is majorly associated with the diabetes, dementia, cardiovascular diseases and death. More and more number of people are getting detected with cardiovascular diseases and diabetes at a young age. Arterial pulse wave transmission (PWT) is affected by the blood pressure. PWT changes with stiffening of artery, aging and improper microcirculation. Estimation of arterial stiffness can be done in three ways as follows. These three are the non-invasive measurement techniques.

a. *Pulse Wave Transmission or Velocity (PWT or PWV):* Reasonable accuracy is provided by the technique. The drawback of this technique is that two physiological parameters (ECG and PPG) needs to be recorded for the estimation of PWT or PWV. At least three leads are required for the ECG acquisition. This makes a PWT estimation system a bit of bulkier. [9][10]
b. *Medical Imaging:* Accuracy of this technique is higher but it is expensive and specialized machines and experts are required.
c. *Derivative of PPG:*Aging affects all the body organs more or less. There is no doubt that it affects the vascular system as well. Effect of aging on the vascular system is calculated based on PPG derivatives. This technique is drawing lot of attention as it is cheaper, easy signal acquisition, and compact. First derivative (Velocity PPG) and second derivative (Acceleration PPG) related various ratios are used to estimate the vascular age of the patient. [11]

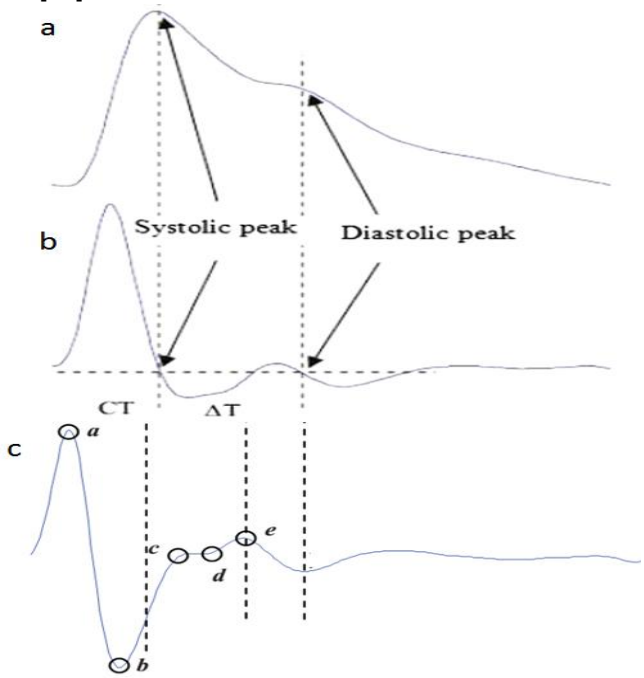


Figure 4: (a)PPG (b) First Derivative (c) Second Derivative [11]

F. Blood Oxygen Saturation (SpO_2):

Reflectance type of PPG probe (with two wavelengths; 660 nm & 850 nm) based non-invasive technique is used for the estimation of blood oxygen saturation within the tissue. It is widely known as pulse oximetry. Continuous monitoring of SpO_2 is very important during the cardiac surgery.[12]

G. Non-invasive Haemoglobin (Hb) and Glucose:

Body metabolite like haemoglobin (Hb), serum, plasma and urine can provide significant life information such as level of blood glucose, cholesterol, antibodies and disease diagnostic FFT of optical signal (2 wavelength PPG signal) can be used for the non-invasive estimation of blood glucose and Hb.[13]

H. Muscle Fatigue or Mental Stress:

Heart rate variability (HRV) analysis is widely used to predict the stress. To avoid the accidents and the economical cost (compensation of the workers' accident) by the work-related disorders, the stress/fatigue evaluation of worker is desired. Oxygenated and deoxygenated haemoglobin obtained by NIRS (optical technique) are employed for muscle fatigue estimation.[14] EEG signal based studies are carried out most of the researchers to predict mental stress. Now a day a lot of research is going on to study optical brain signal and its usefulness in mental stress prediction.[15]

I. Coherence between EEG-EEG/EEG-CPPG/CPPG-CPPG:

Simultaneously acquired (concurrent recording) CPPG and EEG signals would be having great impact in the following mentioned few areas.

i. *Stroop Task:* Colour word interference task (Stroop Task) is a very commonly used paradigm in cognitive clinical psychology. Task involves reading, selective attention, language processing and colour word naming. During the task various parts of brain get stimulated. Stroop is a highly reliable and valid objective test which seems to have relevance for the practicing clinicians and the experimental psychopathologists. Proper understanding of brain connectivity is very important aspect of neuroscience. Stroop task is a reliable, low cost, efficient, effective, flexible and low maintenance clinical test for evaluating psychopathology and brain dysfunctions and can be used as a screen test for the diagnosis. Mainly study related to stroop task is carried out on only EEG signals by the various authors.[16]

ii. *Cognitive Tasks*: Electroencephalographic signals are used for the purpose of recognizing silent activity. There are situations where using spoken activity is undesirable or even unfeasible, for instance in quiet settings or environments where speech is impossible. There are people who are not able to utter speech due to a physical disability. Decomposition and synthesis of an EEG signal and statistical analysis (Variance, Approximate Entropy and Shannon Entropy) of the data can be carried out to differentiate between the mathematics cognitive activity and non-mathematical cognitive activity.[17]

iii. *Brain Computer Interface (BCI) related studies*:

iv. For neuroprosthetics non-invasive brain computer interface has been promoted. EEG based BCI studies show the need for high accuracy and high stability technique. So hemodynamic response combined with an electrical response of the brain fulfils the above mentioned need.[18]

v. *Attention Deficit Hyperactivity Disorder (ADHA) Epilepsy related studies*: Generally, EEG based (stroop task) study is carried out to differentiate between the ADHA or Epileptic patients and the normal heathy subjects. Damage to prefrontal cortex results in response inhibition deficits which is linked with several neurological disorders. Various parameters studied in these disorders are; response time, coherence, entropy and other statistical measures. These days' studies related to EEG as well as cranial PPG is carried out by the researchers to study the ADHA and epileptic patients.

IV. STATISITCAL ANALYSIS OF DATA

Statistics is important in the field of engineering and data collection, as it provides the various means to analyse the physical or non-physical collected data.

A. Parameters used for statistical analysis:

i. *Mean:* It is the average value of the data set. Addition of all the data points divided by the total no. of data points gives the mean value. It is also known as average value of the data. Min and Max: In statistics, min max is also called smallest and largest observation respectively.
ii. *Mode:* It is the value that appears most frequently in the given data set. Actually the mean, mode and median are the three kinds of averages.
iii. *Standard Deviation (SD):* It measures the amount of variation/dispersion from the average. Low standard deviation indicates that the data points are very close to the mean value and higher standard deviation shows that the data points are spread out.
iv. *Power Spectral Density (PSD)*:It is a widely used feature in signal processing, as it is easily observable, measurable and varies with the frequency. This property of PSD makes it a popular feature in the medical data classification.
v. *Coherence*: Coherence is a measure of the amount of phase stability between two different time series. Coherence combines something analogous to the Pearson product-moment correlation to the phase angles between two signals.
vi. *Cross-Correlation Function (CCF)*:It is the oldest and simplest classical measure of interdependence between the signals. Linear cross-correlation is the most widely used and simplest measure of synchronization. Cross correlation compares the two signals by shifting one of them relative to the other. It is the generalization of standard linear correlation analysis.
vii. *Entropy*:Approximate entropy (ApEn) or Shannon entropy are the widely studied entropies. ApEn is recently formulated statistical parameter to quantify the regularity of a time series data of physiological signals. Entropy is the statistical descriptor of the variability within the signal.

V. NEED OF CONCURRENT MODALITY

In the last decade lot of study related to the neurovascular coupling is carried out by various researcher all over the world. Despite hemodynamic and electrical activities have been widely investigated individually, interesting physiological concerns could be clarified by considering them jointly. The considerable differences existing between hemodynamic and electrical signals, their different physiological nature and time dynamics, make it difficult to investigate neurovascular coupling as a whole. Electrophysiological techniques are characterized by a high temporal and low spatial resolution in opposition to the haemodynamic ones, that establish their investigation of the neuronal activity on a coupling function representative of a complex and only partially understood vascular mechanism. The combined use of two or more techniques, usually defined—multimodal approach‖ complements the information acquired. In this study, we used Electroencephalography (EEG) and CPPG acquisition based on Near Infrared Spectroscopy (NIRS) techniques.[2][19]

VI. DISCUSSION & CONCLUSION

Accessing functional state of brain by using a (fNIRS) functional near infrared spectroscopy is the recent advancement in neuroimaging. It is a non-invasive, safe and portable sensing modality that measures hemodynamic changes that occur in human brain. It is a good alternative to EEG for BCI research, owing to its simple and economical instrumentation and more efficient techniques for long-term recording. Moreover, fNIRS offers accurate and good signalto-noise ratio compared to EEG. It also provides detailed information of neural activity with high temporal resolution in a direct way. An fNIRS has already been partially used in estimation of various cardiovascular parameters. Concurrent recording of EEG and NIRS signals provides insights into both fast electrophysiological and slow hemodynamic activities. The electrical signal monitored by EEG is a superposition of all underlying neuronal electrochemical activity and consequently is very difficult to localize. In a non-invasive manner, combined diagnosis using NIRS and EEG reveals reliable clinical indicators, especially for the evaluation of the epileptogenic focus in the cerebral cortex.[20]

The relationship between neuronal activity in the cerebral cortex and the resulting haemodynamic response (neurovascular coupling), is not well understood and is the subject of ongoing research. It is, however,

beyond doubt that there is a strong correlation between mass neuronal activity and cortical blood flow, system which observes both simultaneously is of benefit to investigations of functional cortical activity and of neurovascular coupling. The complementary information that can be gained by simultaneously measuring electrophysiological changes at the scalp and changes in cerebral blood volume has been exploited by simultaneous recording of EEG and fMRI, and more recently by simultaneous EEG and NIR spectroscopy principle based CPPG signal. EEG and ECG are very commonly used for stress studies. Stress related changes in the hemodynamic response can be studied by using PPG waveform. PPG signal captured from various body parts (head to toe) can used for predictions of HR, RR, BP, Arterial Diseases, BCI, Cardiac Output, Hb, SpO_2, Blood Sugar, PWT etc. Thus this signal has lot of future in predicting cardiovascular health and brain health accurately; along with the information regarding head-heart interaction.

REFERENCES

[1] RevatiShriram, M. Sundhararajan&NiveditaDaimiwal, "Statistical Analysis of Pulse acquired from various body sites using Piezoelectric and Optical Transducer", XII Control Instrumentation System Conference (CISCON), 2nd- 4th November 2015, Manipal, India.

[2] RevatiShriram, M. Sundhararajan&NiveditaDaimiwal, "Brain Connectivity Analysis Methods for Better Understanding of Coupling", International Journal of Computer Science and Information Security (IJCSIS), Vol 10, No. 11, 2012.

[3] RevatiShriram, M. Sundhararajan&NiveditaDaimiwal, "Human Brain Mapping based on COLD Signal Hemodynamic Response and Electrical Neuroimaging", International Journal of computer Applications (IJCA), 63(5):27-31, February 2013.

[4] RevatiShriram& M. Shundhararajan, "Coherence Analysis of Pressure Pulse &Photoplethysmogram at various sites", International Journal of Applied Engineering Research (IJAER), Vol 10, No 6, PP 14959-14968, 2015.

[5] RevatiShriram, M. Sundhararajan&NiveditaDaimiwal, "Application of High & Low Brightness LEDs to Human Tissue to capture Photoplethysmogram at a Finger Tip", International Conference for Convergence of Technology (I2CT), 6th-8th April 2015, Pune, India.

[6] RevatiShriram, M. Sundhararajan&NiveditaDaimiwal, "Effect of Change in Intensity of Infrared LED on Photoplethysmogram", International Conference on Communication and Signal Processing (ICCSP), 4th -6th April, 2014, Chennai, India

[7] M. Teplan, "Fundamentals of EEG Measurement Measurement Science Review, Volume 2, Section 2, 2002.

[8] RevatiShriram, M. Sundhararajan&NiveditaDaimiwal, "Cranial PPG Brain Signal based Cardiovascular Parameter Estimation", XII Control Instrumentation System Conference (CISCON), 2nd- 4th November 2015, Manipal, India.

[9] RevatiShriram, AsmitaWakankar, NiveditaDaimiwal, DipaliRamdasi, "Continuous Cuffless Blood Pressure Monitoring based on PTT", International Conference on Bioinformatics and Biomedical Technology (ICBBT), April 16-18, 2010, Chengdu, China.

[10] RevatiShriram, M. Sundhararajan, NiveditaDaimiwal, "Wave Transit Time based Cuff-less Long-term Continuous Blood Pressure Measurement", International Conference on Recent Trends in Engineering Sciences (ICRTES), 23rd – 24th Nov, 2013, Nashik, India.

[11] Elgendi M, Norton I, Brearley M, Abbott D, Schuurmans D (2013) Systolic Peak Detection in Acceleration Photoplethysmograms Measured from Emergency Responders in Tropical Conditions. PLoS ONE 8(10): e76585. doi:10.1371/journal.pone.0076585.

[12] Justin P. Phillips, Panayiotis A. Kyriacou, Kuriakose J. George, John V. Priestley, and Richard M. Langford, "An Optical FiberPhotoplethysmographic System for Central Nervous System Tissue", Proceedings of the 28th IEEE EMBS Annual International Conference New York City, USA, Aug 30-Sept 3, 2006.

[13] Noor NazurahMohdYatim, ZainiharyatiMohd Zain, MohdZuliJaafar, ZalhanMdYusof, AbdurRehmanLaili, Muhammad Hafiz Laili, MohdHafizulfikaHisham, "Noninvasive Glucose Level Determination using Diffuse Reflectance Near Infrared Spectroscopy and Chemometrics Analysis based on In Vitro Sample and Human Skin", 2014 IEEE Conference on Systems, Process and Control (ICSPC 2014), 12 - 14 December 2014, Kuala Lumpur, Malaysia.

[14] YoshikiMuramatsu and Hiroshi Kobayashi, "Assessment of Local Muscle Fatigue by NIRS", 2013 Seventh International Conference on Sensing Technology.

[15] Y. Kageyama, M. Odagaki and H. Hosaka,"Wavelet Analysis for Quantification of Mental Stress Stage by Finger-tip Photo-plethysmography", Proceedings of the 29th Annual International Conference of the IEEE EMBS Cité Internationale, Lyon, France August 23-26, 2007.

[16] SukhadaUnde & RevatiShriram, "Coherence Analysis of EEG Signal using Power Spectral Density", Fourth International conference on Communication systems and Network Technology (CSNT) 2014, 7th – 9th April 2014, Bhopal, India.

[17] SupriyaShete & RevatiShriram, "Statistical Feature based Activity Classification", International Journal of Computer Applications 0975-8887 (IJCA), Vol 95, No 15, 2014.

[18] SiamacFazli, Jan Mehnert, Jens Steinbrink, Gabriel Curio, Arno Villringer, Klaus-Robert Müller, Benjamin Blankertz, "Enhanced performance by a hybrid NIRS– EEG brain computer interface", NeuroImage 59 (2012) 519–529.

[19] Bari V. & Calcagnile P, Molteni E, Re R, Contini D, Spinelli L, Caffini M, Torricelli A, Cubeddu R, Cerutti S, Bianchi A.M,

"Study of neurovascular and autonomic response in a divided attention test by means of EEG, ECG and NIRS signals", 33rd Annual International Conference of the IEEE EMBS Boston, Massachusetts USA, August 30 - September 3, 2011.

[20] Toshitaka Yamakawa, Takano Inoue, Yeting He, Masami Fujii, Michiyasu Suzuki, and Masatsugu Niwayama, "Development of an Implantable Flexible Probe for Simultaneous Near-Infrared Spectroscopy and Electrocorticography", IEEE Transactions on Biomedical Engineering, Vol. 61, No. 2, February 2014.