Optimal Spectral Analysis for detection of sinusitis using Near-Infrared Spectroscopy (NIRS)

S. Kamatchi*1, Dr. M. Sundhararajan*2

[1] Research Scholar, Sathyabama University,
Chennai, Tamilnadu, India
Kamatchime@gmail.com

[2]Principal, Alpha College of Engineering & Technology,
Kannikoil toBahour Main Road,Bahour,
Puducherry-607 402.
India.
msrajan69@gmail.com

Abstract

Optical recording technique overtakes neural recording technique for simplicity, non-ionization, portability, non-invasiveness and cost effectiveness. Many optical techniques like FMRI, DOT, SPR, ERP and PPG are in use now-a-days. Among them, Near Infrared Spectroscopy become popular because of its high temporal resolution and reasonable spatial resolution. Keeping this in mind, NIRS can be used to detect the brain activities. As an initiative, a prototype head band for NIRS has been developed and it can be used to detect sinusitis in an easy manner. Signals have been captured from various persons and their statistical parameters have been analyzed. Signals have been captured before and after sleep for normal and sinusitis persons and the difference between them in various statistical parameters were clearly identified. Spectral analysis was done using parametric and non-parametric methods and the best method was identified for detecting sinusitis. Best method is used to analyze normal and sinusitis persons and the increase in peak value and dynamic range for sinusitis person is identified from the waveform.

Keywords— FMRI, DOT, SPR, ERP, PPG, Near Infrared Spectr oscopy, sinusitis, spectral analysis, peak range, dynamic range.

I. Introduction

Recently, Optical neural recording technique has become a promising tool. Neural recording technique may be structural or functional. Structural technique gives anatomical details of the brain and the functional imaging gives information about the functionality of the brain. Thus brain activities can be easily done with the help of functional imaging. Traditional neural recording technique is lagging behind for so many reasons. This can be overcome by optical neural recording technique. Many techniques like Functional Magnetic Resonance Imaging (FMRI), Diffuse Optical Technique (DOT), Surface Plasmon Resonance (SPR), Event Related Potential (ERP) and Photoplethysmography (PPG) are in use. Optical neural recording technique can also be categorized as Extrinsic and Intrinsic. Extrinsic technique deals with fluorescent signals representing neuronal activity through chemical and genetic variations of the neural cells. But the Intrinsic technique depends upon the change in the optical properties like blood flow or oxygenation, change in refractive index, change in blood volume, hemodynamic change. Those properties can

be detected using various optical techniques including laser Doppler flowmetry (LDF), Near-infrared (NIR) spectrometer, functional optical coherence tomography (fOCT), photoplethysmograph (PPG) and surface plasmon resonance (SPR). Each of this technique has its own advantages and demerits. Functional techniques like MEG and ERPs offer very high temporal resolution but very weak spatial resolution whereas FMRI, SPECT and PET offer high spatial sensitivity [1] but very low temporal resolution. But NIRS has been a compromise between the two, because of its high temporal resolution and signal to noise ratio (SNR) and better spatial resolution. Thus Diffuse Optical techniques like NIRS, NIRI, and DOT got popularity in functional imaging. Jobsis [2] was the first to demonstrate that the blood and tissue oxygenation in the brain of the cat. This paved a new way for brain activity detection.

NIRS is used to measure the blood oxygenation changes in the muscle and the brain tissue. NIRS[3] is used to measure the change in the concentrations of the oxyhemoglobin (HbO_2) and de-oxyhemoglobin (HbR). It depends on the number of absorbed photons with respect to the scattered photons back to the surface of the scalp. But FMRI measures change in deoxyhemoglobin alone. In Functional Near Infrared Spectroscopy

(FNIR), the term functional refers to the functionality of the brain signal. It is a non-invasive technique which is used for continuous and portable monitoring of any change in blood oxygenation and volume in the brain.

This paper discusses about the principles, methods, light absorption and chromophore concentration and the prototype developed to detect the sinusitis patients. LED NIRS sensor has been developed and the spectral analysis was done with various techniques to compare and the best method was identified for sinsusitis analysis. Thus NIRS can be used to detect the neural activity easily.

II. METHODS OF NEAR INFRARED SPECTROSCOPY

A.Principle

The principle behind all diffuse optical technique is almost the same. NIRS is based on the Beer Lambert'S Law which states that the attenuation in the light intensity is proportional to the concentration of an absorbing material in a non-absorbing medium and the path length of the photons [4].

$$A = \alpha\, l_c \qquad (1)$$

where,

A ------ attenuation in decibels

α ------- absorption coefficient of the chromophore

l -------- distance of light travelled inside the material

c -------- Concentration of the chromophore

When a light is throne on the scalp, some of the photons are absorbed inside the head by various tissues like brain, scalp and the skin and the others are scattered by the tissue which follows a banana shaped [5] path inside the head which is shown in the figure. Thus the photons follow various paths inside the head.

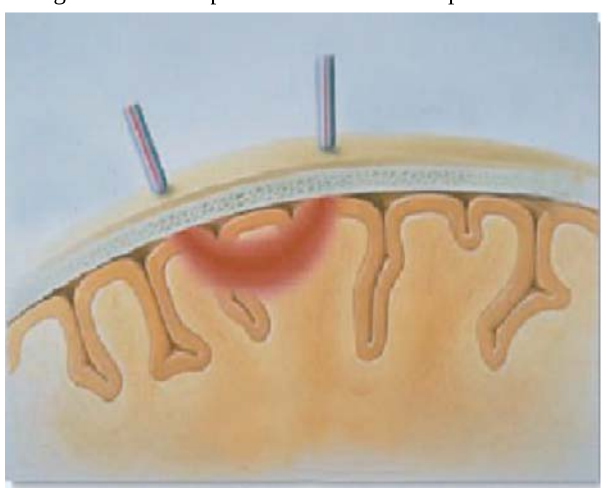


Fig. 1. Banana shaped path of the photon inside the head [6]

Near Infrared light has very low penetration on the head as the biological tissues are weakly absorbed in this range. So it works like an Optical Window, which allows light to penetrate few centimeters and can also be detected effectively. This property makes NIRS to be useful in detecting brain activity. The other characteristics is that the two chromophores i.e. oxyhemoglobin and deoxyhemoglobin have predominant absorption in NIR range. The variations in the concentrations of the chromophore were identified. Thus the characteristics were helpful in detecting the neural activity easily. Beer Lambert's Law doesn't consider scattering effects which do occur inside the brain. Based on this, a new law has been framed known as Modified Beer Lambert's Law which considers the scattering effects also.

It is given by,

$$A = \alpha\, l_c\, DPF + G \qquad (2)$$

Where,

DPF ---- Differential path length factor due to scattering, G ----- Scattering losses

B. Modes of Operation

Source emits the light on to the surface of the scalp and the emitting signal will be detected by the detector. Based on the position of location of the reflecting detector, it can be classified into three modes of operation. In transmission mode NIRS, the NIR light source is placed at a distance (i.e.contralateral) to the detector. It is basically used in case of infants. For adults, this seems to be an inefficient method as the exiting

NIR light has reduced intensity. Thus it is less sensitive as well as signal to noise ratio (SNR) is very less. So it is not used often except for infants. In reflectance mode NIRS, NIR light source is placed ipsilateral to the detector. Thus it overcomes the problem of transmission NIRS. This assumes homogeneous light absorption and there is steady scattering effect. The mean path length of the receiving photons will follow an ellipse and the penetration depth is 1/3rd of the source-detector spacing [8]. In multidistance NIRS approach, two detectors are placed. This approach is used to differentiate the attenuation of light by the skull and the cerebral tissue.

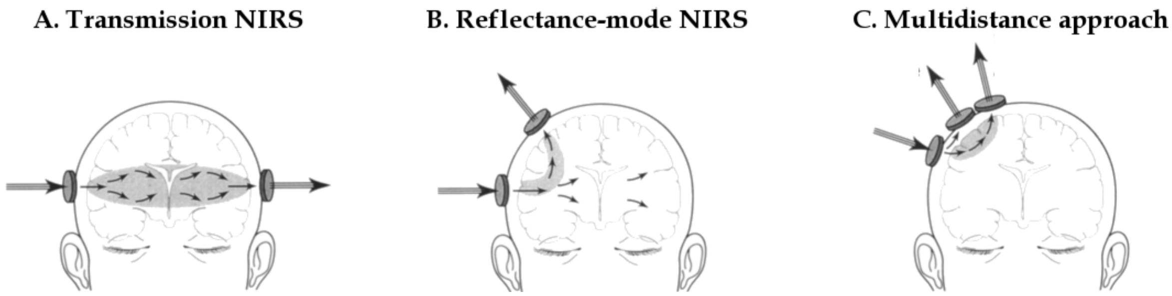


Fig.2. Various modes of operation of NIRS device [9]

C.Measurement Methods

Near Infrared Spectroscopy can be measured in various ways like Time Domina Near Infrared Spectroscopy (TD-FNIRS), Frequency domain NIRS (FD-FNIRS) and continuous wave NIRS (CW-FNIRS)[10]. Time domain systems provide information about the shifts in amplitude and phase of the system with respect to the incident light. This gives information about the absorption and scattering of the tissue inside the scalp.

(i) Continuous Wave Functional Near Infrared Spectroscopy (CW-FNIRS):

CW-FNIRS uses a multiple wavelength or filtered white light source that is amplitude modulated and the scattered and absorbed light inside the tissue. The change in light intensity is measured. The attenuation measured at the detector is not quantified as it has light loss due to scattering in the tissue and increase in absorption because of increase in the path length. CW-FNIRS has many interesting features like instrument is compact, weightless, simple, cheap, non-invasive and the sampling rate is easy to change. It also got excellent temporal resolution, moderate spatial resolution, simultaneous measurements with various imaging techniques, and prolonged uninterrupted measurements at real time and at short intervals. This makes it ideal for many applications and for continuous bedside monitoring besides its drawback. It has some limitations like depth of penetration cannot be changed which is 1/3rd of the distance between the source and the detector and also it is not possible to differentiate scattering and absorption effects. This method actually gives the amplitude decay of the light. So the exact volume of the tissue is not known. Thus it is not possible to measure the absolute values of the chromophore concentrations [11].

The strengths and advantages of CW-type instruments are as follows: (i) temporal resolution is high (less than 1 s) and non-invasive, which allows long-time continuous measurements in real time and repeating of measurements at short intervals, (ii) measurements can be performed with fewer motion restrictions and in natural environments, and (iii) simultaneously measurements with other techniques for neuroimaging and/or other physiological methods is possible.

(ii) Time Domain Frequency Near Infrared Spectroscopy (TD-FNIRS):

TD-FNIRS is used to determine the path length of the light from any sensor. It emits very narrow pulses and observes the distribution of photons with respect to time. One of its types is Time resolved Spectroscopy(TRS) which employs a short light pulse and detects the average time of the photons as they attenuate inside the tissue [12] and the detected light is a function of time. The broadening and attenuation of the diffused reflected light pulse are measured. Tissue absorption and scattering can be detected from the shape of the Temporal Point Spread Function (TPSF)[13] of the pulse. This method provides change in attenuation with respect to the change in scattering. Its main attractiveness over the other two methods is that it actually separates the light from scattered or absorbed signal. Thus it provides the absolute values of chromophore concentration. Photons with high flight time penetrate deeper in to the brain than the short flight time photons.

(iii) Frequency Domain Functional Near Infrared Spectroscopy (FD-FNIRS):

FDFNIRS emits sinusoidally modulated intensity light source with some amplitude and phase. The light introduced into the system is amplitude modulated and it observes the amplitude and phase delay of the detected light. It also determines the path length but the light sources are frequency modulated. It renders low temporal resolution [14], high SNR and time resolution. Absorption and scattering properties of the tissue can be detected from the frequency and the phase shift [15]. FD-FNIRS measures the same information as that of the TD-FNIRS with respect to frequency. It works under three principles, but all were based on the diffusion theory. It uses a single wavelength and a fixed distance between the electrode or multiple wavelengths and a fixed distance or a single wavelength and multiple inter-electrode distances to detect the variations in the intensity, phase and modulation of the signal.

III. Implementation

A. *Hardware*

Optical NIRS sensor can be used to study the brain activities [16]. A prototype head band has been developed using LED. NIRS sensor head band contains sources and detectors. Light Emitting Diode (LED) is selected as transmitter as it is very cheap and works at very low power input than Laser diodes. Avalanche Photodiode (APD) is selected as detector to observe the light reflected or scattered from the surface of the scalp. In this prototype, 4 sources and 8 detectors are used to work at a wavelength of 850nm spaced at convenient intervals of 3cm. Signals can penetrate to a depth of approx. 2cm below the surface of the head. Subjects are asked to wear the headband and the signals recorded for post processing. Light entering the scalp are absorbed or scattered by the blood, tissues and muscles inside the brain. The reflected light is measured to determine the amount of blood flow, changes in the concentration of oxyhemoglobin and deoxy-hemoglobin [17] and the change in blood volume which provides the indirect measure of the neural activity. The LED NIRS sensor headband used to detect the signal is shown in the figure below.

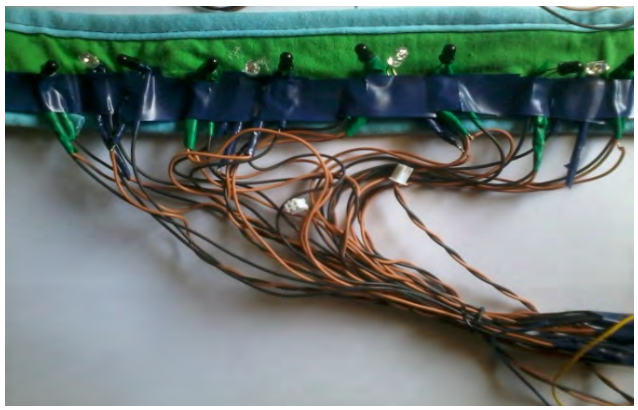


Fig. 3. Prototype LED NIRS headband

B. *Subjects*

Some volunteers have been selected to record brain signals for detecting sinusitis. Each of the volunteers has been informed about the sensor and the method of recording signals. Each person's signal was recorded safely and everyone has been informed well in advance about the method of recording. Brain is composed of billions of neurons to carry the signals and the largest part of the brain is covered by cerebral hemisphere. Cerebral cortex consists of four lobes such as Frontal lobe, Parietal lobe, Occipital lobe and the Temporal lobe. Most of the major organs are covered by the cerebral cortex. In which, the Frontal lobe is responsible for planning, reasoning, self control and thought control. So it is appropriate to fix the head band in the frontal lobe to capture major brain signals. NIRs sensor can be used to detect maxillary [18] and frontal sinusitis. Thus LED NIRS sensor headband is fixed to the frontal lobe of the person's forehead. Light emitted from the source is throne on the scalp and reflected from the surface of the scalp. The amplitude of the signal reflected varies with the amount of blood flow. Blood flow decreases for sinusitis persons than for normal persons. Based on the amount of blood flow, various statistical parameters change. Mean and the standard deviation decreases and the peak range and the dynamic range will increase for sinusitis patients than for normal persons. Spectral analysis has been done for sinusitis and normal persons for the above parameters using parametric and non-parametric spectral analysis and the differences were analysed.

C. *Signal Processing*

NIR sensor consists of a NIR LED and a photo detector. The source and the detector are separated by 2 to 4cm. LED sensor is preferred than Laser diodes, as it is safe and very economic. Avalanche Photodiode is used as a photo detector because of its high sensitivity [car]. Subjects signal's are captured using NIR sensor headband before and after sleep and analyzed to detect sinusitis. Raw signal captured using sigview software and the noise and the low frequency signals are removed using filter and Fast Fourier Transform is applied to remove heart signal, breathing signal and low frequency signals and noise from the original signal and the statistical parameters are analyzed to detect whether the person is suffering from sinusitis or not.

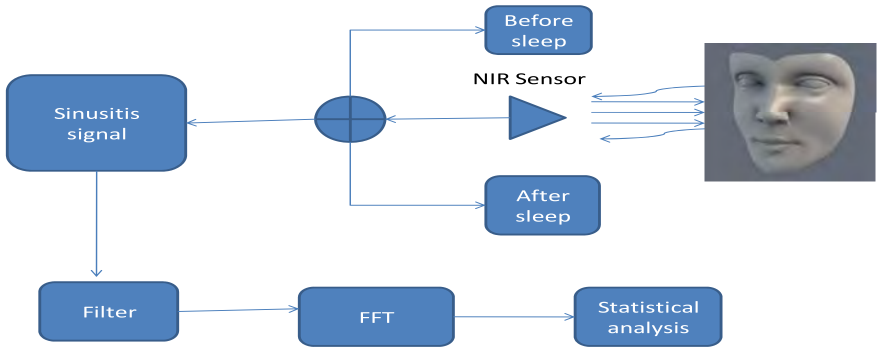


Fig.4. Block diagram of sinusitis detection using NIR sensor

The head band which consists of the sensor and the detector is interfaced through the sound card to the computer. NIR LED emits light into the frontal lobe of the person and the emitted light is detected using photo detector. The head band is interfaced through the sound card to the system. Sigview software is used to acquire the raw signal and it is processed using matlab. Low frequency components which accompany the signal are filtered through the wiener and band pass filter and Fast Fourier Transform (FFT) is done for the resulting signal. Head band interfaced to the system is clearly depicted in the figure.

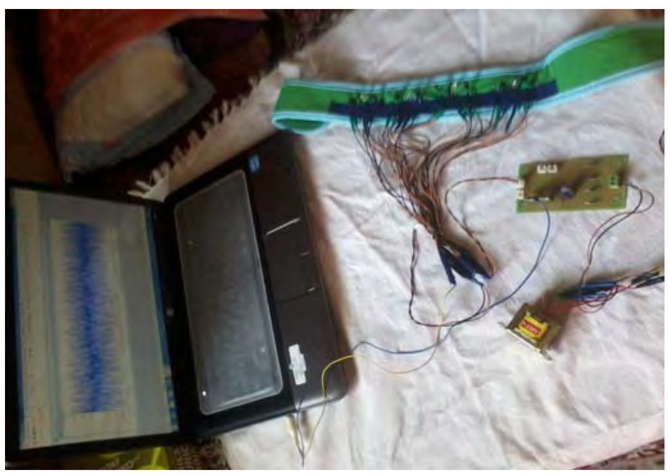


Fig. 5. NIRS headband interfaced to the labtop for capturing the signal from the subjects

Sinusitis and normal person's signals were acquired and processed using matlab. Spectral analyses were done using all parametric and non-parametric methods before and after sleep and the optimal method was identified.

Signals were recorded for 5secs with a sampling rate of 22050Hz taking 4096 samples at a time. Signals can also be recored for any length of time and processing can be done. Raw signals were processed using matlab and after filtering, FFT was performed and the statistical parameters like Standard deviation, σ (sigma), Mean,μ (mu), peak range and the dynamic range were noted down. Using the statistical parameters, various spectral analyses were done. Parametric and Non-parametric methods were applied to get the spectral waveform and the best method was identified and compared for sinusitis and normal persons and the variations are absorbed. Table below clearly shows the statistical parameters for various subjects for processing.

Table.1 Statistical parameters of various persons

Condition	Subjects	sigma	Mu	peak	dynamic range
	1	0.31829	-0.0007922	9.9436	54.4891
	2	0.32493	-0.0012904	9.7643	53.9775
	3	0.31187	-0.0019108	10.1203	64.3565
	4	0.31136	0.0042521	10.1341	63.972
Normal	5	0.3269	-0.0010308	9.7116	54.5505
	6	0.11882	-0.01559	18.3862	67.8152
	7	0.11685	-0.0070131	13.2724	75.3505
	8	0.10652	-0.0004734	13.7008	75.6923
	9	0.12958	-0.007839	12.7762	74.9155
	10	0.11475	-0.0046039	13.3592	75.1358
Cold	11	0.42895	0.049164	7.2953	56.8771
	12	0.04911	-0.0007161	16.5295	79.7739
	13	0.06829	-0.0053277	15.4747	81.5014
	14	0.01683	0.0019352	11.4272	90.309
	15	0.09024	0.0051471	20.877	79.8678
	16	0.06889	0.0002386	15.4481	90.3087
	17	0.0501	-0.0009409	16.4723	90.3087
Sinusitis	18	0.00416	0.0007514	13.8005	88.6751

Parametric methods like Welch Power Spectral Density (PSD) estimate, Periodogram PSD estimate, Modified Periodogram PSD estimate and the Thompson Multitaper PSD estimate were applied for the table above.

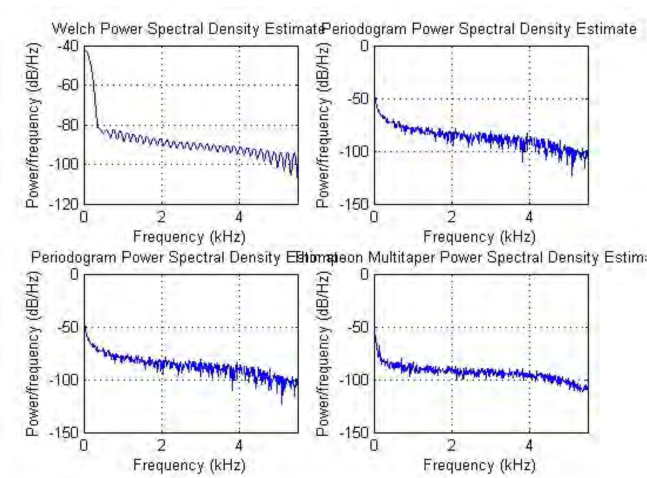


Fig. 6. Parametric Methods of Power Spectral Estimates
(a)Welch PSD estimate (b) Periodogram PSD estimate
(c) Modified Periodogram PSD estimate (d) Thompson Multitaper PSD estimate for sinusitis persons

Likewise Non-parametric methods were also adopted for the processed signal. Methods such as Yule Walker Power spectral density estimate, Burg PSD estimate, Covariance PSD estimate and the Modified Covariance PSD estimate were carried out and the spectral estimate is given below.

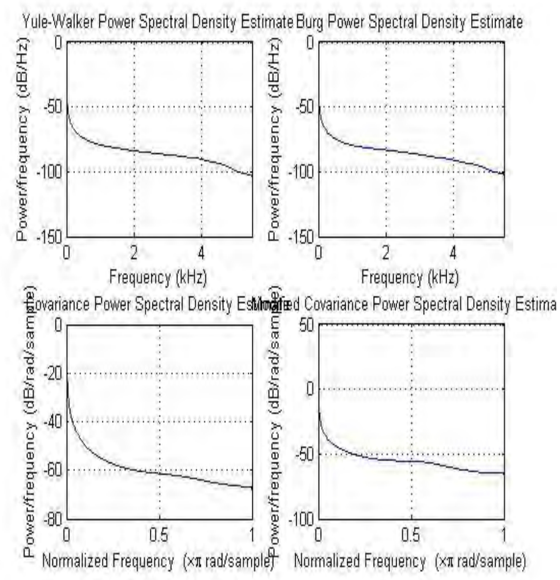


Fig.7. Non-Parametric Power Spectral Density Estimate
(a)Yule-Walker PSD estimate (b) Burg PSD estimate
(c) Covariance PSD estimate (d) Modified Covariance PSD estimate for sinusitis persons

Using the table, Welch and Yule Walker Spectral density estimate was done to compare sinusitis and normal as well as sinusitis and cold persons. It is evident that the power /frequency still goes low for the normal person than for the cold personwhich is shown in the figure below.

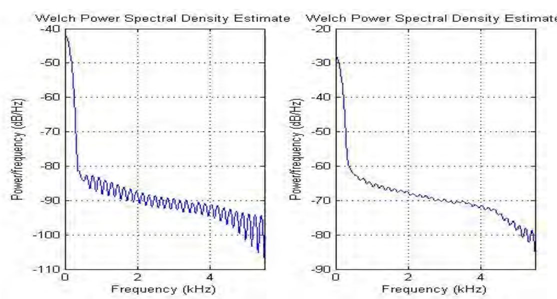
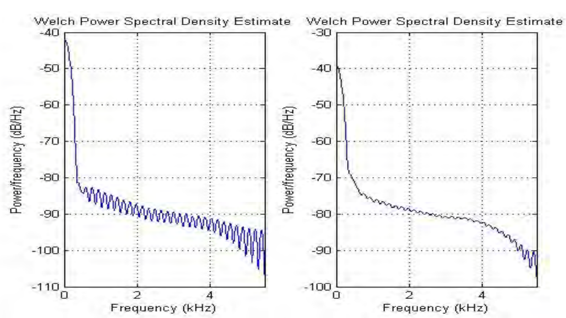


Fig. 8a. Welch Power Spectral Density Estimate for Sinusitis and normal persons



Fig, 8b. Welch Power Spectral Density Estimate for Sinusitis and cold persons

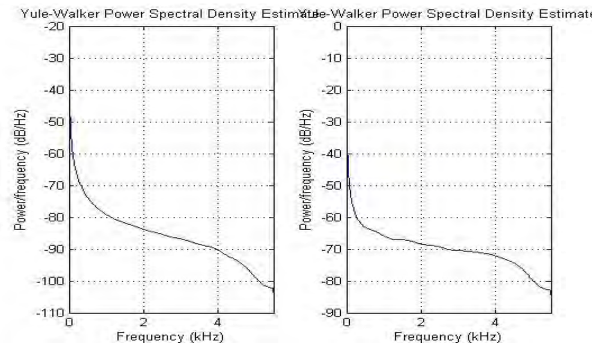


Fig. 9a. Yule Walker power spectral density estimate for sinusitis and normal person

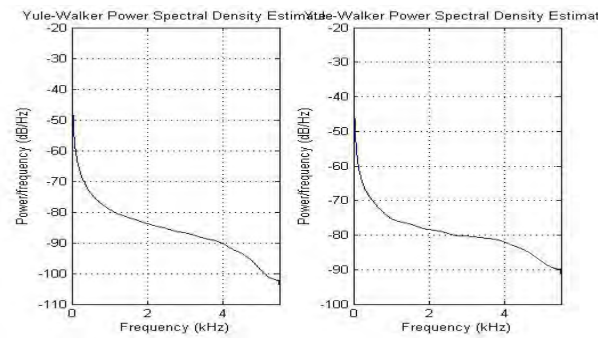


Fig .9b. Yule Walker power spectral density estimate for sinusitis and cold person

After Performing all PSD estimates, it was found that the sinus patients can be best detected using Welch PSD estimate and Thompson Multitaper PSD estimate from Parametric methods and Yule Walker method from Non- Parametric method.

IV. CONCLUSION

A prototype LED-NIRS headband has been developed and sinusitis was detected using the headband. This paper concentrates in the measurement of neural activity using NIRS sensor. NIRS technique is an emerging technique which is used to measure the changes in the concentration of the chromophores i.e. HbR and HbO_2 in the brain. Similar work has been performed using other imaging techniques like FMRI and other optical techniques. It is an initiative to detect the neural activity using NIRS for the first time. NIRS is used to detect sinusitis patients which imply that it can be used for neural activity detection. Sinus and normal persons will have change in blood flow which can be identified using prototype LED NIRS sensor headband. Blood flow differs extremely for normal persons before and after sleep but will have a slight change for sinus persons before and after sleep as the blood flow level is very less for sinus patients. The statistical parameter especially the dynamic range doesn’t have a change, as the blood flow is low for sinus patients when compared to normal persons. Thus the raw signals recorded using sigview software and the noise frequencies were eliminated and FFT was taken for the recorded signal and the statistical parameters were analyzed for various subjects. Sinusitis patients can clearly be identified with the help of this prototype NIRS headband.

It is concluded that NIRS sensor can be used to detect sinusitis which implies that it can be used to detect neural activities in the frontal lobe of the cortex. Thus in future LED NIRS sensor can be used to detect various brain activities under various circumstances.

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