Non Invasive FNIR and FMRI system for Brain Mapping

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Abstract- Functional near-infrared spectroscopy (fNIR) is a neuroimaging modality that enables continuous, noninvasive, and portable monitoring of changes in blood oxygenation and blood volume related to human brain function. FNIR can be implemented in the form of a wearable and minimally intrusive device, it has the capacity to monitor brain activity under real life conditions and in everyday environments. The principle advantage of optical technique is its noninvasive nature. It provides information about functional oxygenation and volume changes that are directly comparable to fMRI, but the apparatus is much less costly and confining. Optical technique is performed in pediatric populations much more easily than fMRI and it can be transported to the bedside for clinical evaluations. Because NIRS signals are detected several centimeters from the cortex, however, the spatial resolution of the technique is low (~1-2 cm). Spatial coverage can be increased by using arrays of emitters and detectors. Paper proposed a system for measurement of haemodynamic response from skull.

Index Terms- Functional MRI (fMRI), fNIR: Functional Near-Infrared Spectroscopy, Mapping, deoxyhemoglobin (Hbr), oxyhemoglobin (HbO2)

I. INTRODUCTION

Neuroimaging techniques such as functional magnetic resonance imaging (fMRI) and positron emission tomography (PET) have been widely used to image brain functions in humans. These techniques have greatly increased our knowledge about the neural circuits that underlie cognitive and emotional processes [1,2]. However, each of these neuroimaging technologies has both strengths and limitations. fMRI is noninvasive and has excellent spatial resolution, but is also expensive, highly sensitive to motion artifact, confines the participants to restricted positions inside the magnet, is difficult to integrate with other imaging modalities [such as electroencephalogram (EEG)], and exposes participants to loud noises. PET also requires a restricted range of motion and confinement, and requires the injection of radioactive materials. These characteristics make these imaging modalities unsuitable for many uses, including use with children, the elicitation of positive affect, and the monitoring of ongoing cognitive activity under routine working conditions.

Optical imaging of intrinsic signals maps the brain by measuring intrinsic activity related changes in tissue reflectance. Functional physiological changes such as increases in blood volume, hemoglobin oxymetry changes result in intrinsic tissue reflectance changes that are exploited to map functional brain activity. Optical imaging of intrinsic signals do not directly measure neuronal activity. Instead they detect activity related changes in perfusion and metabolism, such as increases in cerebral blood flow and changes in hemoglobin oxygenation.

II. THEORY

A. fMRI :Functional Magnetic Resonance Imaging

The Functional Magnetic Resonance Imaging (fMRI) is used to examine the anatomy of the brain. It can detect precisely which part of the brain is handling critical functions such as thought, speech, movement and sensation,which is called brain mapping. It is used to assess the effects of stroke, trauma or degenerative disease (such as Alzheimer's) on brain function. fMRI uses the same machine as in MRI and same approach with the difference that rather than designing it to look at the static structure of the brain it is designed to look at the flow of blood in the brain. It is also used to measure the velocity of the blood movement in the brain since blood contains a lot of water and moves through the blood vessels. It can also differentiate between the saturated blood with oxygen and unsaturated blood [3]. The images taken in fMRI technique are not high resolution images compared to MRI images. The reason is that fMRI technique is mainly concerned to measure the change of blood oxygen content with time so we capture different images at different intervals. Since we cannot wait longer for an image the resolution is not high compared to static images in MRI. Figure. 1 shows the fMRI image where it shows the active areas of the brain at different time intervals. When the subject is made to listen to a single speech like Spanish the active region in the brain will be different from the region if subject listen mixed speech like Spanish and French together. Therefore, fMRI can be used to study psychological response to identify different active regions in brain for different tasks [4-5]. This technique has a high spatial resolution but poor temporal resolution.

Full human functional brain imaging requires techniques for studying both cerebral hemodynamic and neuronal responses to stimulation. Blood oxygenation level dependent (BOLD) functional magnetic resonance imaging (fMRI) studies have become one of the most important methods of investigating hemodynamics in human brain since they provide high-resolution images associated with multiple physiological parameters closely related to cerebral activity [7,8]. BOLD fMRI studies also suffer from relatively low temporal resolution dictated by the hemodynamic response, and this makes it difficult to study the fast response of neuronal activity. In contrast, near-infrared spectroscopy (NIRS) not only provides direct measurement of changes in oxy- and deoxyhemoglobin

concentrations (the so-called "slow" signal), but also provides information regarding neuronal responses (the "fast" signal) by measuring changes in the light scattering coefficient [9] on a

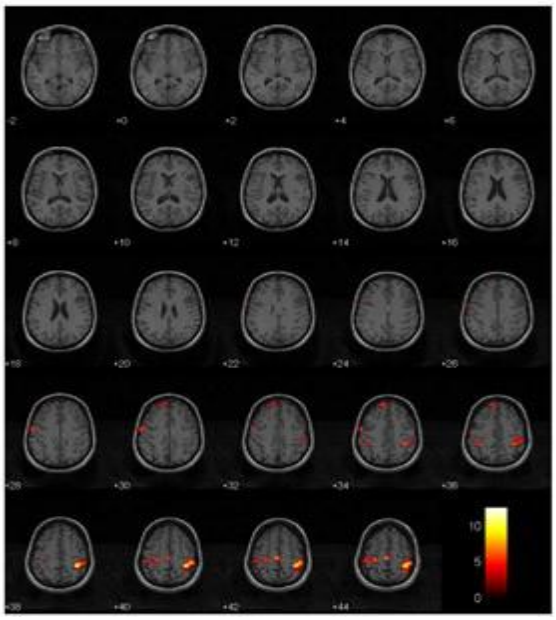

Figure 1: Functional Magnetic Resonance Image of brain [6]

timescale of the order of milliseconds. Previous studies have demonstrated that the integration of fMRI and NIRS can uncouple the contributions due to blood flow and deoxyhemoglobin concentrations to the BOLD signal [10,11]. However, NIRS is not a true imaging technique in the sense that its achievable spatial resolution is essentially the source-detector distance, typically 1-3 cm laterally and worse longitudinally [12].

B. fNIR: Functional Near-Infrared Spectroscopy

NIRS is a non-invasive optical technique for assessment of functional activity in the human brain. The technique uses an optical window (630–1300 nm), in the NIR light spectrum [13].Light can penetrate the cranium and reach sufficient depth [14] to allow investigation of the metabolism in the cerebral cortex [13]. NIR light, which invades tissue at a particular place at the head, interacts with the tissue in several ways. The beam becomes diffuse through photon scattering in the tissue. Scattered photons follow a random path through the tissue, resulting in partial absorption of these photons [e.g., through chromophores such as deoxyhemoglobin (Hbr) and oxyhemoglobin (HbO2)]. Another part is reflected back and leaves the head several centimeters away from the source location [14].These changes, such as increased or decreased blood flow and changes in tissue oxidation, are associated with brain activity and modify the tissue characteristics. This means that the absorption and scattering of photons change and hence affect the detected light. Therefore, a qualitative measure of brain activity can be obtained.

C. Major Components of Optical Signals

- Blood volume changes: Signals measured at 570nm originates primarily from blood volume changes
- Hemoglobin oxymetry changes: Intrinsic signals in the 600 to 630 nm range reminiscent of the changes expected in deoxyhemoglobin concentrations.
- Light scattering: at longer wavelength

Figure 2 shows the Hemoglobin absorption curves.

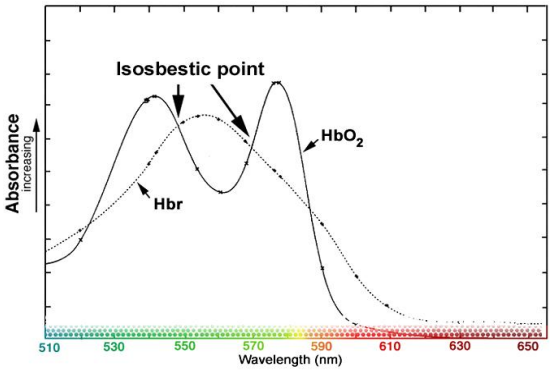

Figure 2: Hemoglobin Absorption Curves [16]

Optical intrinsic signal imaging relies on changes in cortical light reflectance produced by the hemodynamic response. The most important absorber in the visible spectrum is hemoglobin (Hb). Because oxy- (HbO2) and deoxyhemoglobin (Hbr) absorb light differentially, FNIR is wavelength dependent. By selecting different imaging wavelengths, different aspects of the hemodynamic response can be assessed. Both Hb species absorb equally at isosbestic points (549, 569 nm), so reflectance changes at these wavelengths emphasize changes in total Hb, a measure of blood volume. The increased absorbance of deoxyhemoglobin in the 605-630 nm range permits estimation of oxygenation changes by imaging in this range.[16]

III. TECHNICAL APPROACHES FOR FNIR

Typically, an fNIR apparatus consists of a light source by which tissue is radiated and a light detector that receives light after it has interacted with the tissue. According to the modified Beer-Lambert Law [15], the light intensity after the photons have interacted with the biological tissue is expressed by the equation:

$A = \varepsilon \times c \times d$

A= Light attenuation

ε = Extinction coefficient

c = Concentration of absorbing molecule

d = Distance between light source and detector

In a typical transcranial study of the human brain ,the mean path length of light is about six times as long as the distance between sender and receiver. In order to account for the longer path length, in modified Beer-Lambert Law (B) is introduced.

G is also introduced because the detector cannot differentiate between the loss due to absorption and that due to scatter.

Modified Beer Lambert Law

$A = \varepsilon \times c \times d \times B + G$

Assuming B and G constant

$\Delta A = \varepsilon \times \Delta c \times d \times B$

An equation frequently used for the assessment of concentration changes.

Using the modified Beer-Lambert law and fNIR measurements performed at two different wavelengths within the near infrared light range and at different times, the relative changes in the concentrations of deoxy- and oxy-Hb can be obtained. Using this technique, several types of brain function have been assessed, including motor and visual activation, auditory stimulation and performance of various cognitive tasks.

IV. SYSTEM OVERVIEW

Near infrared studies may be performed either in transmission or in reflection mode. When the diameter of the object is small e.g. forearm or neonate's head transmission of nearinfraded light through the sample is feasible.

Larger object reflection mode is used. Studies on the adult brain can be performed by pacing the light source and detector on the same side at a distance of 3-6 cm as shown in the figure 3.

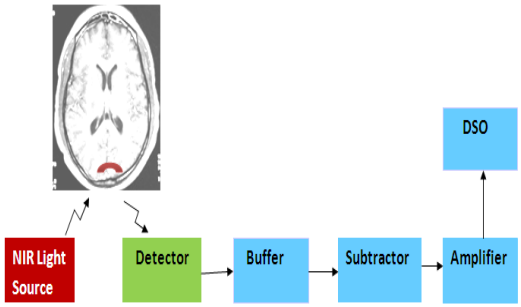

Figure 3: System Block Diagram

The sensor consist of two light source and one detector . The sensor is placed on the cranial mask. The NIR light source consist of two wavelength for oxy- (HbO2) and deoxyhemoglobin (Hbr) absorb light differentially and are time multiplex.

Detector is a NIR detector which should detect both the wavelength. Amplification of the signal is done with the help of amplifier. And signal for the two wavelengths has to observe on the DSO.

V. ASSESSMENT OF PHYSIOLOGICAL PARAMETER

Brain tissue concentration changes in oxy-Hb and deoxy-Hb. Dominate the optical changes evoked by brain activity. The typical behavior of oxy-Hb and deoxy-Hb with brain activity consist of increase in oxy-Hb and a decrease in deoxy-Hb. these concentration caused by a focal blood flow increase. This pattern has been observed shown in figure 4

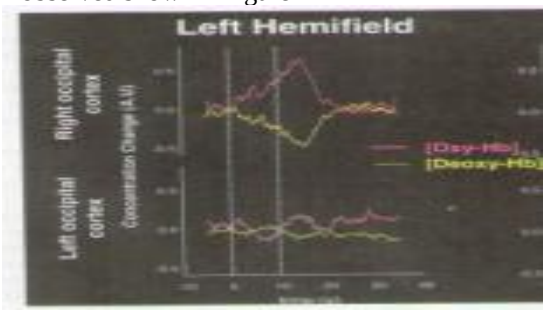

Figure 4: functional activation with NIRS [16]

VI. CONCLUSION

fMRI is a non invasive method for investigating the structure and function of the brain. The activation sites in fMRI maps represent areas with significantly higher hemodynamic changes than the control. For the motor activity measure the FMRI signal. The image shows the activation in the respective lobe. For the same motor activity and by using the proposed fNIR system detect the haemodynamic response. Compare the fNIR and fMRI haemodynamic response.

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