DESIGN OF A PROTOTYPE FOR THE BRAIN ACTIVATION FUNCTIONAL STUDY USING NEAR INFRARED SPECTROSCOPY

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Abstract: In the last few years Near Infrared Spectroscopy (NIRS) has been increasingly considered by scientific world like a powerful tool for non-invasive monitoring of the cerebral hemodynamics and oxygenation changes due to functional brain activation. NIRS technique measures concentration changes in oxy and deoxygenated hemoglobin which are assumed to be the basis of fMRI BOLD (functional Magnetic Resonance Imaging Blood Oxygen Level Dependent) contrast blood oxygenation level-dependent; it can provide excellent temporal sensitivity (ms) as well as reasonable spatial sensitivity (cm). In this paper we describe the design and realization of a low-cost, battery operated, continuous wave system for the non invasive human brain study with NIRS in order to obtain information regarding visual or tactile areas activation. The presented prototype is magnetic resonance (MR) compatible, so it can be used during a functional MR imaging for brain activation studies.

Introduction

The current techniques for diagnostic brain imaging can be broadly classified into structural and functional imaging approaches. Structural imaging of the brain aims to obtain purely anatomical information while the goal of functional imaging of the brain is to provide information on the physiological state of cerebral tissue.

Recently, a functional imaging approach based on near-infrared light was proposed. This technique is notes as Near InfraRed Spectroscopy (NIRS): first described by Jobsis in 1977 [1], the optical method of non-invasively assessing cerebral oxygenation changes has newly gained interest by the ever enlarging evidence that hemodynamic changes evoked by functional activation of the brain are an excellent means to image functional cortical anatomy.

NIRS measures concentration changes in oxy and deoxygenated hemoglobin; the method is therefore an excellent tool to validate assumptions on the physiological basis underlying the fMRI (functional Magnetic Resonance Imaging) signal, due to its high specificity as to the parameters measured.

NIRS technique has a higher temporal resolution than fMRI, allows long time and repetitive measurements, real time newborn monitoring, it is insensitive to movement artefacts, uses small dimensions equipment and, finally, doesn't require a particular exam environment. However, fMRI has an excellent spatial resolution respect to NIRS and allows a perfect anatomy reconstruction of the head.

Hence, integrating NIRS data with fMRI analysis, it is possible to obtain further information on brain activity, using the advantages of both techniques [2].

In this work in progress, we propose a first prototype of a portable MR compatible system for the non invasive human brain study to obtain information regarding visual or tactile areas activation, using the NIRS technique, during a fMRI acquisition. A preliminary test outside the scanner room is described here.

Materials and Methods

The NIR technology uses light sources in an optic range from 700 to 900 nm (near infrared); in this interval the light penetrates in the biological tissues and is absorbed by the major chromophores (pigments which absorb the light in the wavelength range of interest) (Figure 1).

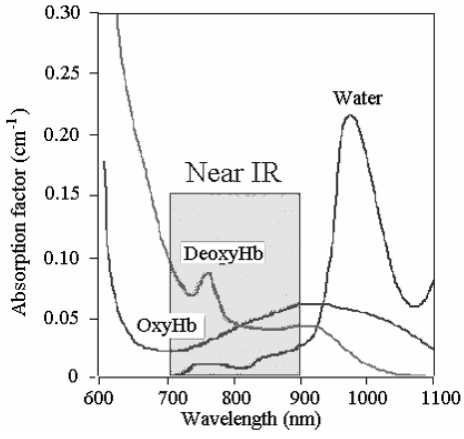

Figure 1: Absorption factor of Water, OxyHb and DeoxyHb

ISSN: 1727-1983

The two dominant chromophores for the NIR wavelength range just happen to be two biologically relevant markers for brain activity: oxyhemoglobin (HbO_2) and deoxyhemoglobin (Hb).

To quantify changes in concentrations of absorbing species, a model of light diffusing through tissue is required (see Figure 2). A traditional approximation to the full photon migration theory is called the modified Lambert-Beer law, which is an empirical description of optical attenuation in a highly scattering medium:

$$I = I_0 \cdot e^{-\varepsilon \cdot C \cdot l \cdot DPF + G} \quad (1)$$

where I is the detected light intensity, I_0 the incident light intensity, ε the absorption coefficient of the medium, C the concentration of the medium, l the distance between light emitter and detector, DPF the differential path length factor and G the constant attenuation factor relative to the optical properties and geometry of the tissue [3].

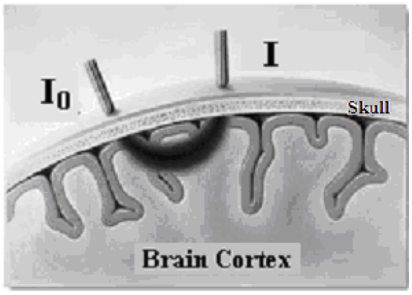

Figure 2: Infrared light propagation in the brain

Assuming that l, DPF and G to be constant in the absorbing medium, we can calculate the changes in the medium concentration by the following equation :

$$\Delta C = \frac{\Delta OD}{\varepsilon \cdot l \cdot DPF} \quad (2)$$

where OD is the optical density defined as:

$$OD = \ln \frac{I_0}{I} \quad (3)$$

and

$$\Delta OD = OD_{final} - OD_{initial} \quad (4)$$

The final condition is relative to the brain stimulation state while the initial condition corresponds to the rest condition: in this way ΔC is the variation of the absorbing medium due to the functional brain activation.

According to the absorption spectrum of the major chromophores, we can choose an incident light wavelength to evaluate the changes in concentration of oxy or deoxy hemoglobin in the brain cortex.

In this way is possible to perform only relative measurements but, in the case of functional brain activation studies, this would typically be sufficient.

NIRS devices can be classified in three main categories: time domain, frequency domain and continuous wave. Time domain systems use a very short (picoseconds) incident pulse light and detect the temporal distribution of output photons. Frequency domain systems use amplitude modulated light and record the amplitude decay and phase shift of the output light signal, respect to the incident signal. In continuous wave systems the incident light is emitted by a source continuously with a constant amplitude; they can only measure the amplitude decay of incident light signal [4].

The designed prototype is constituted by one light emitting diode (LED) that emits light at wavelength of 880 nm (in the near infrared range, in correspondence with the absorption peak of oxy hemoglobin) (SFH 485P, Siemens) and four photodiodes PIN that detect the output infrared light from the brain surface (SFH 203, Siemens). The LED and the four detectors are mechanically and optically coupled with optic glass fibers (emitting fibers diameter of 1 mm and detector fibers diameter of 2.7 mm) to transport the infrared light from and to the subject brain inside the scanner room, while the device is placed in the console room. This designing specific assures the MR compatibility of the system: in fact, the glass optic fibers are MR safe and compatible because do not contain metal parts. Figure 3 shows the placement of fibers on the brain using a square semi rigid brain/probes pad interface: the distance between each detector and the emitter point is 3 cm and it has been chosen to have a penetration depth in the tissue of about 1.5-2 cm [5]. The interface pad covered an area of 4.24 x 4.24 cm.

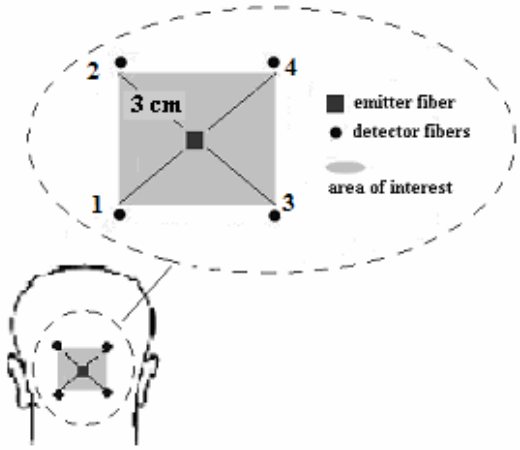

Figure 3: Fibers/brain pad interface and its position on the occipital area

This placement permits point measurements at four different points, for the investigation of four different zones of brain cortex.

The electronic circuit for the driving of the infrared source by means a continuous wave, is constituted by a constant current generator with an amplitude regulator

ISSN: 1727-1983

to vary the emitted light intensity. The electronic circuit for the processing of the signals received by the four detectors, is constituted by four current/voltage converters and amplification/filtering blocks.

The processed signals are then acquired by an acquisition card (DAQ6024E, National Instruments) for the visualization and elaboration on a PC. An user interface was designed in LabView for the elaboration of the received signals: by means a mathematical algorithm that uses the modified Lambert-Beer law, voltage signals by the four detectors are converted in changes of oxy hemoglobin. The results can be visualized like concentration change in arbitrary units (relative measurement) versus time.

The designed software also acts further signal elaborations as a low pass filtering with 1 Hz high cut frequency in order to eliminate noise and signal fluctuations due to physiological activities (i.e. systemic arterial pulse oscillations and respiration) [6].

Results

During the experiment, the fibers support was placed on the head of a 30 years male bald subject and fixed by a band around the head.

The fibers/brain semi rigid pad interface was positioned on the occipital region according to the 10/20 standard for the placement of EEG electrodes (see Figure 3) [7,8], with the central emitter fiber placed on the inion.

The subject was sitting on a chair and had to relax with his eyes closed. The stimulus was given using a neon lamp: in rest condition the lamp was on and placed in front of the subject but it was covered with a dark panel, while in stimulation condition the dark panel was removed and the light illuminated the subject face.

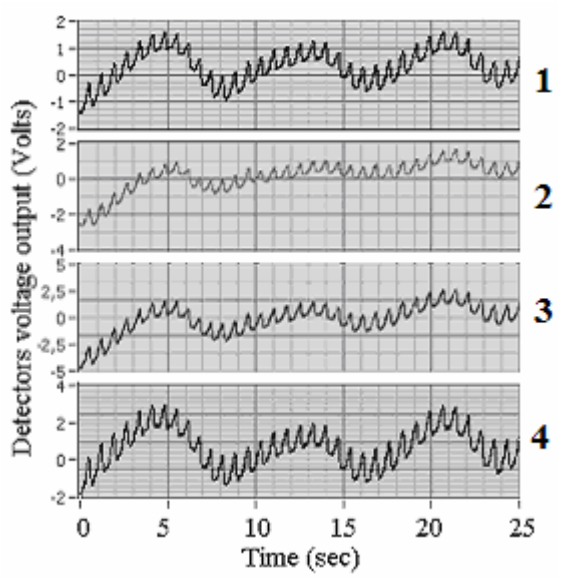

Figure 4: Detectors voltage output versus time during rest condition

During the rest condition it was possible to note in the signals (see Figure 4) the presence of HbO_2 variation due to heart beat and Mayer waves (waves due to the breath and metabolic activity of the brain, with a lower frequency than to the heart beat one) [4].

Figure 5 shows the four detectors voltage output during the visual stimulation task: after few seconds of rest condition the visual stimulus was proposed to the subject removing the black panel above the neon lamp.

It can possible to note that, in correspondence of the light stimulus, two of four detectors voltage output increased. For the others two detectors the voltage do not show any increase: this fact may be occurred because the different position of the four sensors on the area of interest. In fact, detectors number 1 and 3 were placed in the area under the inion, while detectors number 2 and 4 were positioned over the inion, in correspondence of visual cortex (Figure 3). Light stimulus was maintained for about 10 seconds and then was removed: in correspondence of neon lamp turn off, the detectors 2 and 3 voltage outputs decrease up to the rest condition value (the voltage decrease in the stimulus interval and the undershoot in the successive interval, are probably due to the signals acquiring electronic).

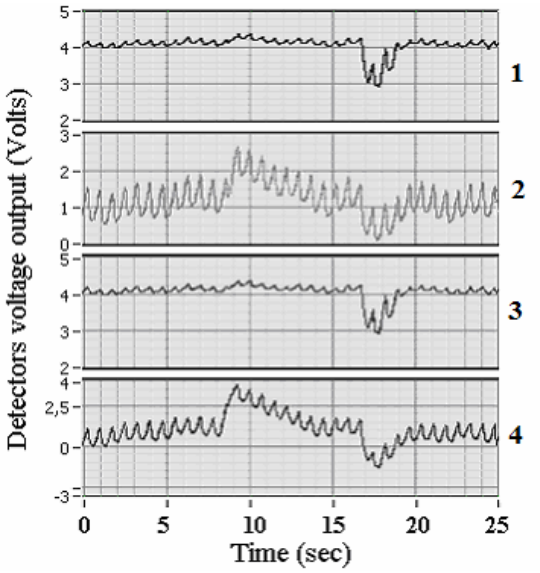

Figure 5: Detectors voltage output versus time during stimulation task

Figure 6 shows the variation of HbO_2 due to the activation caused by the visual stimulus, calculated by the LabView program for the voltage output of detector number 4, according to the modified Lambert-Beer law: it is possible to note the increase of the oxy hemoglobin concentration corresponding to the visual stimulus and the successive decrease corresponding to the rest condition return.

ISSN: 1727-1983

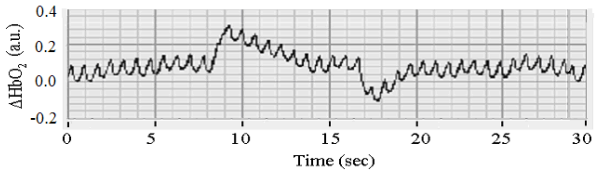

Figure 6: Change in HbO_2 concentration detected by detector number 4

The previous graph reports the oscillations due to the heart beat rate (with a frequency of about 1.2 Hz) that can be eliminated with a filtering operation performed by the designed software interface (Figure 7).

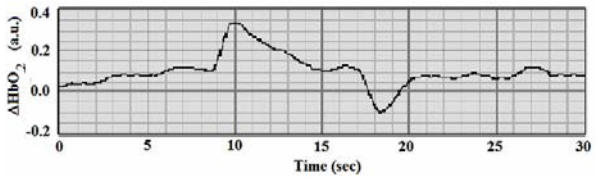

Figure 7: Change in HbO_2 concentration detected by detector number 4, after low pass filtering operation

Discussion

First test of designed prototype during a visual stimulation task on a volunteer, has been given good results: the variation of oxyhemoglobin concentration versus time during the stimulation paradigm, is consistent with that find in other publications and obtained with commercial instruments [5].

Further discussion with neurophysiologist is necessary to better analyze the correlation between the signals and the detectors position on the area of interest, and also the low frequency oscillations due to physiology activities like brain metabolism, arterial pulse oscillations and respiration.

Since the final goal of this work is the designing of a MR compatible NIRS system, the results reported here with the use of non magnetic glass fibers, are an optimal start point for the development of a low cost and dedicated system to be used in simultaneous fMRI-NIRS studies.

The use of a larger number of emitter/detector pairs and more emitted light wavelengths, can permit to obtain information on the concentrations changes of others chromophores in a wide brain area.

Conclusions

A prototype for the study of brain activation using NIRS technique is described. A particular characteristic of this device is the MR compatibility that allows to use it during functional analysis with fMRI. MR safety and compatibility criteria has been considered during the choose of material for the prototype design.

In order to evaluate the variation of oxy hemoglobin due to the brain activation caused by an external visual stimulus, we made a test with a bald subject: the results show an increase of oxy hemoglobin concentration corresponding to the cerebral activation.

Future works will regards the optimize of the optic fibres/brain pad interface in order to avoid relative movements and assure a perfect matching between the probes and the scalp. Moreover, we will test the prototype compatibility with the MR environment to ensure its safety for use during a fMRI acquisition on a subject and to avoid eventual artefacts in the images due to its presence in the scanner environment.

The designed prototype has small dimensions, low cost, it is battery operated and it will can be optimize in order to render it portable with a data storage or data radio transmission.

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ISSN: 1727-1983