A portable fNIRS system with eight channels

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ABSTRACT

Abundant study on the hemodynamic response of a brain have brought quite a few advances in technologies of measuring it. The most benefitted is the functional near infrared spectroscope (fNIRS). A variety of devices have been developed for different applications. Because portable fNIRS systems were more competent to measure responses either of special subjects or in natural environment, several kinds of portable fNIRS systems have been reported. However, they all required a computer for receiving data. The extra computer increases the cost of a fNIRS system. What's more noticeable is the space required to locate the computer even for a portable system. It will discount the portability of the fNIRS system. So we designed a self-contained eight channel fNIRS system, which does not demand a computer to receive data and display data in a monitor. Instead, the system is centered by an ARM core CPU, which takes charge in organizing data and saving data, and then displays data on a touch screen. The system has also been validated by experiments on phantoms and on subjects in tasks.

Keywords: Brain, near infrared spectroscopy, diffuse optical imaging

1. INTRODUCTION

Functions of the brain have long been investigated to explore the mechanism of the most complicated system on the earth [1]. Electrophysiology and hemodynamics are two non-invasive directions neuroscientists attempting. Non-invasive electrophysiological signals originate from inside of a brain, but are measured on the scalp. Eventually, these outer tissues, scalp, skull and cerebral spinal fluid, distort by brain outer tissues, which. Hemodynamics is an alternative way because they accompany neuronal activity to support neurons with necessary oxygen. Neuroscientists have been utilizing it to investigate brain's function. The functional magnetic resonance imaging (fMRI) and functional near infrared spectroscope (fNIRS) are two imaging modalities to capture the signal [2-4]. The fMRI measured BOLD signals to indicate hemodynamic response, but its heavy weight and rigorous scanning regulations make it infeasible to some subjects or to some tasks. On the contrary, an fNIRS device is light weight and is designed portable or even wearable, which make it suitable to more general cases, such as for infants [5].

That near infrared was first discovered sensitive to changes of oxygenated hemoglobin and deoxygenated hemoglobin dates back to 1977 by [2]. Then it was employed to measure the concentration of oxygenated hemoglobin or deoxygenated hemoglobin so as to interpret hemodynamic response in the brain of neonatal or adults [6, 7]. A measurement at one position was not sufficient to investigate functional integration involving multiple brain regions. Hence it stimulated a multiple-channel fNIRS to come out by which hemodynamic response could be observed at ten measurement positions of head surface [8]. The measurement at multiple sites improved fNIRS to capture an image of hemodynamic response within a region of cortex. So a trend of system development of fNIRS was to design a system with over many channels [9, 10]. The more channels it had, the heavier weights it was in. The alternative trend was to improve its portability. Several kinds of portable fNIRS have been developed [11-14].

However, the evolution of fNIRS system never disconnected it with a computer via either a wire or wireless. The computer was dedicated to receive and save data. The extra requirement made an fNIRS system bigger and heavier than

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expected. In some cases, the requirement would make fNIRS non-applicable in a limited space, like in an ambulance. It is no doubt that a self-contained fNIRS is in need, which is capable of measuring, processing, displaying and saving data only in the system. That is the system which we propose and design here.

We designed a self-contained eight channel fNIRS. The system is centered by an ARM core, which takes charge in receiving and processing data. Then data is sent out to save into a Micro SD card. Meanwhile, it is transmitted to a touch screen to display. The touch screen is, besides to display data, to receive configurations from a user. In addition, the system has little cross talk and all channels are sampled at higher rate simultaneously because of the integration of advanced techniques, such as ADC synchronization, frequency-division multiplexing and in-phase (I) and quadrature (Q) demodulation. The fNIRS system also provides interfaces for multi-modal imaging, such as EEG and stimulation device.

2. INSTRUMENTATION

The system based on a modular design with adjustable channel placement and can be ordered in manageable configurations, which comprises an acquisition cap, 1 emission module with four laser sources (each source has two wavelengths: 690nm and 830nm), 2 detection module with two APD detectors each, 2 demodulation and acquisition modules, 1 central control unit (ARM core CPU), 1 power supply module, and 1 panel module(serial screen display module). All these modules are flexible, reusable, can be replaced readily. Each of the system component will be illustrated in more details below. The architecture of the system is presented in Fig.1

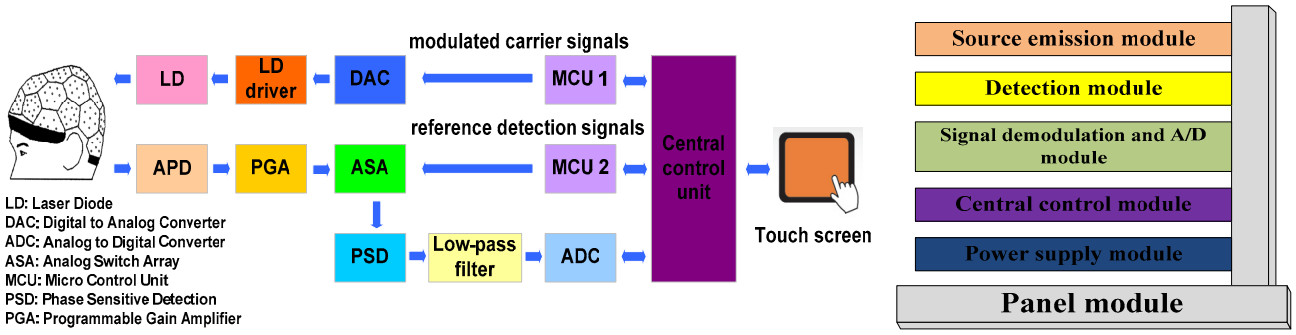


Fig.1 A) The block diagram of the proposed self-contained fNIRS system. B) the modular architecture of the system. C) the aluminum enclosure of the main instrument with a size of 25 cm × 15 cm × 31 cm.

The emission module is equipped with four laser diodes (LD), whose power and frequencies can be tuned individually and flexibly by users for distinct applications. In order to decrease cross talk, on the one hand, we choose 690nm and 830nm wavelengths of NIR; on the other hand, all near infrared light is encoded by distinct frequencies following the frequency-multiplexing technique. The detection module was consisted of Avalanche Photo Diodes (APD) followed by corresponding DC separation circuit and programmable gain amplifier (PGA) circuit. 4 APD (Hamamatsu,C5406-01) were used for their high sensitivity to detect the attenuated light; DC separation circuit was used to separate DC signals in order to eliminate the influence of ambience light; Moreover, the PGA circuit was designed to magnify the signals, aiming at taking good use of the dynamic range of a 24-bit analog to digital converter (ADC) module and improving signal to noise ratio. Additionally, we used an analog switch array to allow the configuration of optical channel flexibly and conveniently. These sources and detectors allow to simultaneously acquire from up to 16 optical channels, when each detector is coupled to 4 sources. But in our system, we just used a reduced-channel version with 8 optical channels. In particular, 4 sources and 4 detectors constitutes 8 optical channels simultaneously (see Fig.2).

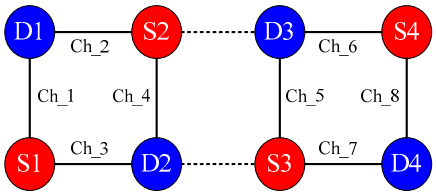


Fig.2 Construction of optical channel between sources and detectors.

The demodulation and A/D module was composed of phase-sensitive detection circuit, low-pass filter circuit, single-to-differential circuit and 24-bit A/D circuit. What is different from the traditional technique is our phase-sensitive detection circuit, which was illustrated with more details in the following.

Thus, we designed a unique demodulation system to overcome the above mentioned problems. The proposed demodulation system composed of two main parts: carrier signals generation assembly and detection signals generation assembly. The two assemblies were controlled by two individual microcontrollers based on the same brand and one common clock source. One microcontroller was used to generate square-wave carrier signals while the other was used to generate square-wave demodulation signals. The two microcontrollers interact with the master chip via communication interface. The duty cycle and the frequency of carrier signals and demodulation signals were deployed flexibly by software.

3. EXPERIMENTS

Aiming at evaluating the feasibility and validity of our self-contained fNIRS system, the performances of our system were evaluated by in-vivo experiment.

Seven healthy volunteers participated in this study (5 males and 2 females, aged between 21-43), 6 participants were right-handed, while 1 was left-handed (handedness determined using Briggs and Nebes (1975) inventory). Throughout the experiments, the participants were instructed to seat on a comfortable chair in a relaxed position approximately 60cm in front of the computer screen, which was used to presented stimuli via Eprime. Optodes were placed over head around C3 and C4 point (according to the international 10-20 system for the EEG electrode placement) in order to cover the underlying contralateral- and ipsilateral- sensorimotor area, respectively. The whole experiment paradigm consisted of an initial baseline period (30 s long) followed by 10 blocks alternated by finger tapping task periods (20 s long at a frequency rate of 2Hz, right hand) and rest periods (30 s long). As a result, a complete paradigm lasted 530 s. The placement of optodes, which comprises 4 sources and 4 detectors, totally yielding 8 optical channels (4 channels for each hemisphere) for each of the two wavelengths, as shown in Fig.3. The distance between neighboring source and detector pairs was 3cm and the probe covered an area of 3×3 cm for each hemisphere.

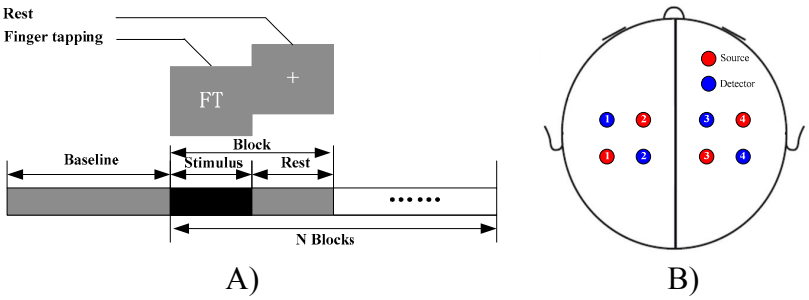
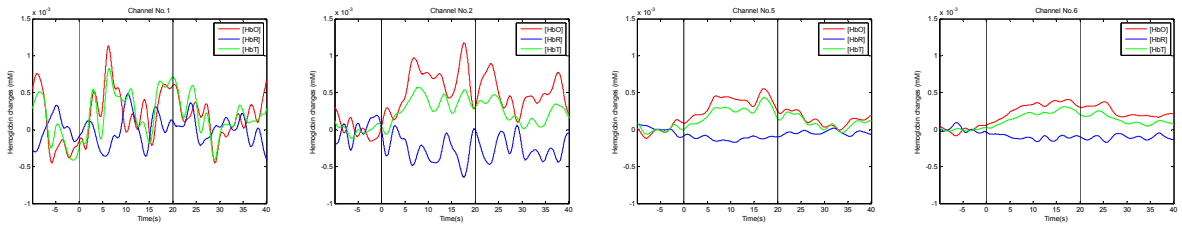


Fig.3 A) Experiment paradigm of finger tapping task.

4. RESULTS AND DISCUSSION

From Fig. 4, we know that during the baseline period, there was a relative uniform distribution in both hemispheres. During finger tapping period, there was a significant increase of ΔHbO and a corresponding decrease in ΔHbR were found in contralateral-hemisphere during the task, while no apparent changes occur in ipsilateral-hemisphere. In the recovery period, we observed an overall return to the baseline in both hemispheres. The increase in HbO concentration was greater than the decrease in HbR concentrations, the changes of HbT showed the similar trends to HbO.



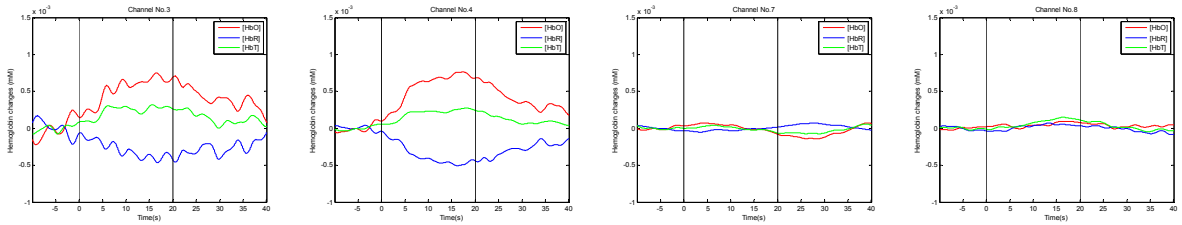


Fig.4 Block-averaged time course of hemodynamic responses of finger tapping task in subject.2 from the contralateral-(thick line) and ipsilateral-(thin line) hemisphere. The red, blue, and green lines show ΔHbO , ΔHbR , ΔHbT , respectively. Stimulus duration indicated in the range of two black lines.

For finger tapping task, hemodynamic responses from right hand were indicated by a local increase in ΔHbO and a corresponding decrease in ΔHbR in contralateral motor cortex, while no apparent changes occur in ipsilateral motor cortex. Our results were in line with the typical hemodynamic responses during finger movement in previous works. Moreover, the changes in HbO is more apparent than HbR, owing to its improved signial to noise ratio and reduced vulnerability to cross talk. The 690nm and 830nm wavelengths and the frequency-multiplexing technique was adopted in our system to optimize the signal to noise ratio and to minimize cross-talk. Accordingly, we took the significant increase of HbO to be the indicator for task-related hemodynamic response.

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