# Design of Portable Functional Near-Infrared Spectroscopy-based Brain Monitoring System

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***Abstract*—In this paper, we introduce a functional near-infrared spectroscopy-based brain-monitoring system consisting of a data acquisition board, photodiode units, and dual-wavelength near-infrared LED units. The ADS8688A analog frontend-integrated circuit-based data acquisition board provides reliable high-resolution bio-optical measurements for portable brain monitoring. Moreover, its isolated linear regulator-based low-noise power supply circuit allows maintaining low-noise measurement quality by blocking inter-circuit crosstalk. From the system evaluation via a mental arithmetic experiment, a clear decreasing trend of deoxy-hemoglobin was found for the high-brain workload state during a cumulative subtraction task.**

***Keywords— Functional Near-infrared Spectroscopy; Brain Monitoring; Portable Instrument***

## I. INTRODUCTION

With recent advances in biomedical technologies, various brain imaging techniques such as electroencephalograms, magnetoencephalograms, and functional magnetic resonance imaging have been developed for the neurophysiological study such as the mechanisms of thinking and decision-making. In recent years, with the development of wearable devices and the Internet of Things, endeavors have been made to integrate these techniques with telehealth technology [1]. Among the brain imaging techniques, functional near-infrared spectroscopy (fNIRS) has recently attracted more attention due to its cost-effectiveness and easy application in portable devices [2]. fNIRS measures changes in the local concentration of oxygenated and deoxygenated hemoglobin by utilizing low-energy near-infrared (NIR) radiation at two different wavelengths. Although this technique demonstrates a slower response compared to the other brain imaging methods, it enables access to the metabolic and microcirculatory neuronal activity of the cerebral cortex region. Therefore, this technique can intuitively provide information of the brain workload on the local cortex region without any complicated signal-processing procedures.

In this paper, we introduce an 8-channel fNIRS-based brain-monitoring system which is portable, cost-effective, and non-invasive. The detailed hardware design method of the proposed system is presented in Section II, and the evaluation results with mental arithmetic experiments for the capability validation of human brain monitoring are contained in Section III.

## II. SYSTEM DESIGN

The proposed fNIRS-based brain-monitoring system consists of a data acquisition board and a NIR light source-sensor set including monolithic photodiode units and dual-wavelength NIR LED units.

### *A. Design of the Data Acquisition Board*

The data acquisition board was designed to integrate a 32-bit low-power microcontroller (STM32L4, STMicroelectronics), an analog front-end integrated circuit (AFE IC) (ADS8688A, Texas Instruments), and an LED driving circuit for 8-channel fNIRS measurements. The AFE IC is based on a 16-bit successive-approximation register analog-to-digital converter with many embedded peripherals, including an 8-channel input multiplexer, programmable gain amplifiers, and second-order low-pass filters. Thanks to its high degree of integration, a complicated signal conditioning circuit was not necessary, and enhanced system reliability and miniaturization were also achieved.

For mixed-signal systems where both analog and digital circuits are contained in the system, the noise generated by the digital circuitry can affect the analog measurements, and careful power supply design is needed to minimize this effect. To achieve high-fidelity analog-data measurements, a linear regulator-based fully-isolated power supply circuit was designed to provide low-noise DC power for the AFE IC.

### *B. Design of the NIR Light Source-Sensor Set*

The NIR sensor units were based on Texas Instruments' OPT101 monolithic photodiodes. A built-in trans-impedance amplifier directly outputs a linear voltage proportional to the acquired optical radiant power, which enables noise-robust analog measurements. Chip-type dual-wavelength (730 and 850 nm) AlGaAs LEDs (Opto ENG OE-MV7385-P) were used as the NIR light source. These photodiodes and the NIR LEDs were soldered onto each customized printed circuit board along with decoupling capacitors and were then housed in a 3D-printed casing. Eight bio-optical channels were obtained by placing the photodiodes in two rows and three columns and placing two NIR LEDs between the optical sensors. The photodiode-LED set is attached to a subject's forehead via transparent double-sided tape.

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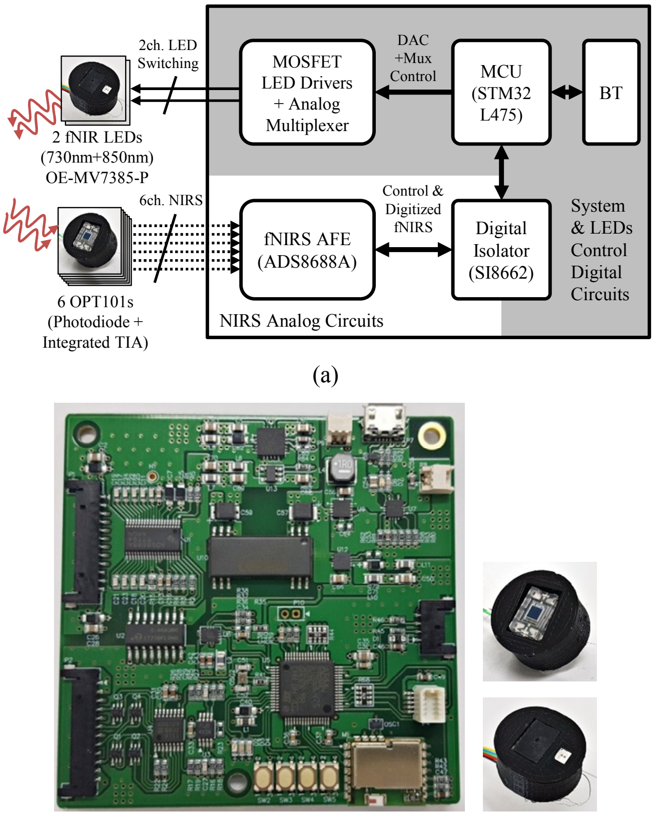

(a)

(b)

Fig. 1. (a) A block diagram of data acquisition board and (b) photos of the fabricated data acquisition board and the NIR light source-sensor set.

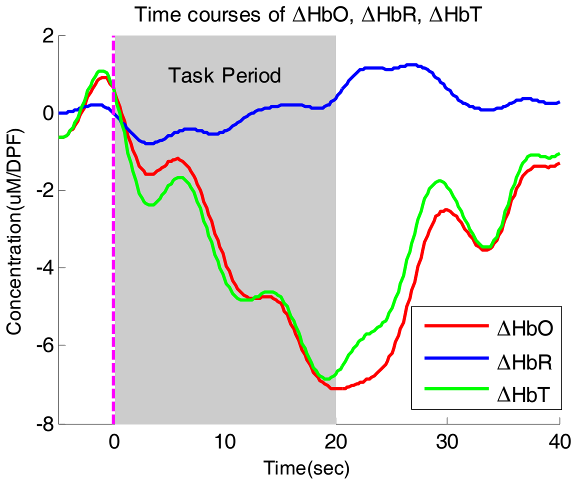

Fig. 2. Average time courses of hemodynamic concentration changes for oxy-, deoxy-, and total hemoglobin (ΔHbO,ΔHbR, andΔHbT, respectively) during the mental arithmetic experiments.

## III. EXPERIMENTAL AND RESULTS

### *A. The Mental Arithmetic Experiment*

The mental arithmetic experiment [3] was designed to examine hemodynamic differences between the high-brain workload and the resting states. These differences appear as hemodynamic concentration changes in the oxy- and deoxy-hemoglobin which were investigated using an offline time-course analysis of the fNIRS measurements.

Three subjects (three males, average age: 26.3 ± 1.7 years) voluntarily participated in this experiment. A total of 10 trials were performed with an arithmetic task for boosting subject's mental workload. In the trials, the resting state was first measured for 22.5 ± 2.5 s, during which the subjects were instructed to gaze at a center cross sign maintaining a low mental workload. After the resting state, a mathematical task was given to the subjects who then cumulatively subtracted a two-digit random prime number from a three-digit random number in the range 500–999 for 20 s.

### *B. The Analysis of fNIRS Measurements*

fNIRS data, including local concentration changes in the oxy- (ΔHbO), deoxy- (ΔHbR), and total hemoglobin (ΔHbT), were converted from the raw bio-optical measurements which contain only radiant power intensities through a modified Beer-Lamberts law[4]. Afterward, a 4th order zero-phase 0.01–0.2 Hz Butterworth bandpass filter was applied, and each epoch was extracted based on a recorded event trigger with baseline correction. The average hemodynamic trend was derived by averaging each of the hemodynamic time courses.

In the results of the offline analysis, we found a clear decreasing trend in ΔHbO in the high-brain workload state induced by the cumulative subtraction task. The diminished ΔHbO level was then rapidly restored to the resting state after the task period. In contrast, ΔHbR showed a weaker inverse pattern and a more delayed response compared to the ΔHbO trend.

## IV. SUMMARY AND CONCLUSION

In this paper, an 8-channel fNIRS-based brain-monitoring system is proposed. An ADS8688A-based data acquisition board provided bio-optical measurements of both reliable and sufficient resolution. A low-noise regulator-based isolated power supply design achieved low-noise bio-optical measurements by physically blocking inter-circuit crosstalk. In a human subject study involving a mental arithmetic experiment, we found a task-related decreasing trend in ΔHbO and a weaker inverse pattern for ΔHbR. In future studies, we will optimize the performance and portability of the proposed system and then use it in other workload-monitoring applications.

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