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Development of Double Density Whole Brain fNIRS with EEG System for Brain Machine Interface

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Abstract—**Brain-machine interfaces (BMI) are expected as new man-machine interfaces. Non-invasive BMI have the potential to improve the quality of life of many disabled individuals with safer operation.**

The non-invasive BMI using the functional functional near-infrared spectroscopy (fNIRS) with the electroencephalogram (EEG) has potential applicability beyond the restoration of lost movement and rehabilitation in paraplegics and would enable normal individuals to have direct brain control of external devices in their daily lives. To shift stage of the non-invasive BMI from laboratory to clinical, the key factor is to develop high-accuracy signal decoding technology and highly restrictive of the measurement area.

In this article, we present the development of a high-accuracy brain activity measurement system by combining fNIRS and EEG. The new fNIRS had high performances with high spatial resolution using double density technique and a large number of measurement channels to cover a whole human brain.

I. Introduction

For medical and welfare use, robotics, information engineering and so on, brain-machine interfaces (BMI) are expected as new man-machine interfaces. One of the important component technologies for BMI is brain activity measurement technology. The functional near-infrared spectroscopy(fNIRS) [1-4] can examine the brain function localization by the response of stimulation because it measures the concentration change of oxygenated and deoxygenated hemoglobin on the surface of the brain.

The electroencephalogram (EEG) can be used to measure evoked potentials associated with specific functional activities [5,6]. Both the fNIRS[7] and the EEG[8] are easier to use and have fewer restrictions during measurements than other brain function measurement systems such as MRI, MEG and PET. They have the ability to provide complementary information of the brain function and are effective for the improvement of BMI decoding of the brain signals.

In this paper, we describe the development of the double density whole brain fNIRS with EEG system achieving simultaneous measurement and data integration. The new fNIRS had high performance with high spatial resolution using double density technique and a large number of measurement channels to cover a whole human brain. We evaluated the performances of the new system by a phantom and a healthy subject. It would contribute to improve the accuracy of the BMI decoding of the brain signals.

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II. System Description

A. Overall System Parameters

Current advancement in fNIRS technologies enabled several types of fNIRS instruments such as continuous wave (CW) measurements, time-resolved spectroscopy (TRS) and phase resolved spectroscopy (PRS). The new system has been developed as the CW system. It illuminates tissues with a continuous stream of light where the attenuation of the transmitted light is measured by the detectors. The fNIRS data analysis relies on the Modified Beer-Lambert Law (MBLL) assuming spatially homogeneous absorption changes in extra cerebral tissues. The simplicity and low-cost nature makes them an ideal candidate for screening of large populations as well as in treatment management using BMI.

One of the main design criteria for the system is to be able to measure simultaneously both fNIRS and EEG in a whole human brain, and improve spatial and temporal resolutions of previous fNIRS. The whole brain measurement is important when performing dynamic studies not only functional localization but also the clarification of a function that is more wide-ranging to have exceeded localization and the clarification of local network.

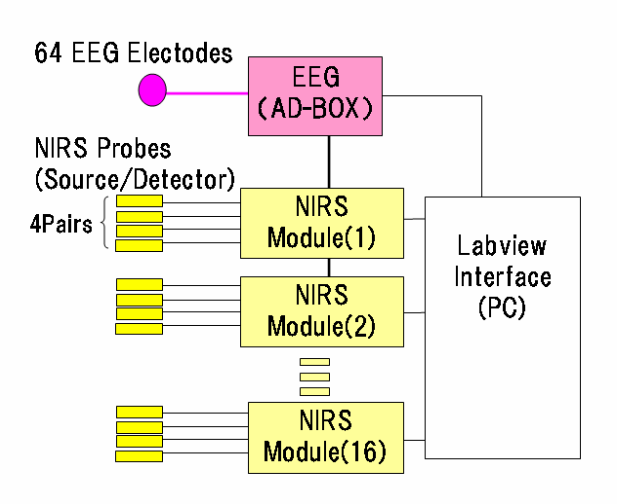
. To cover a whole human brain, 64 sources and 64 detectors are used as fNIRS with 64 electrodes as EEG in the system. This system uses three-wavelength technology. It advances improve accuracy, repeatability. The wavelengths used for the system are 780,805 and 830nm. The fibers from the three light sources are grouped into one fiber bundle (source fiber) that delivers light to tissue. The wavelength of the irradiation was switched by 1ms interval. The optical signal detected at the brain surface by fiber bundles (detector fibers 2 mm in diameter). The sampling rate for the measurement is 250Hz as maximum. In EEG block, the

system used active electrodes to minimize the unwanted power line interference in recording. Table 1 outlines the system parameters.

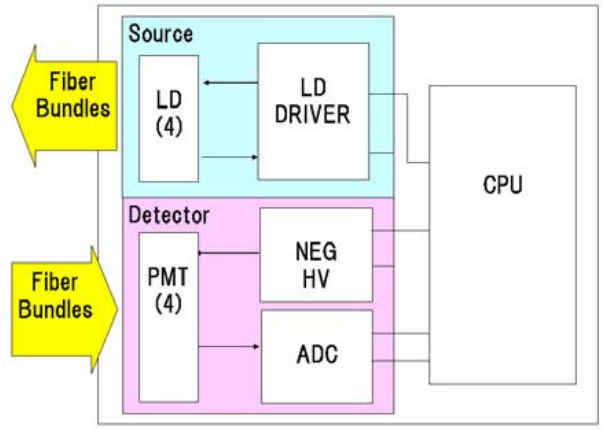
Figure 1 shows the diagram of the overall system. The main components are 16 fNIRS modules and one EEG module and the host computer. The host computer is responsible for the user interface that allows the user to control the system as well as to monitor the measured data. The rest of the system communicates with the host computer via TCP/IP. A fNIRS module unit has 4 light delivery units, 4 light detection units, and ADC front end circuit, and CPU. We used laser diodes (LD) as light sources, and operated by custom made the LD driver board. We have selected photomultiplier tube (PMT) as detectors, which typically offer much higher sensitivity than solid state detectors. PMT had wide range combined with controlling applied high-voltage, and controlling the amplifier gain of latter part.

TABLE I
SUMMARY OF SYSTEM PARAMETERS

Patrameter	Value
Size	610(W)x730(D)x1080(H)mm
Mesaurements	Concentration change of oxy-Hb,deoxy-Hb,total-Hb
Mode of Operation	CW
Number of Sources	64
Number of Detectors	64
Number of Wavelengths	3
Wavelenghth values	780,805,830 nm
Minimum Sampling interval	3ms
Maximum logical channel	256
Optical fiber	Bundle fiber 2mm ϕ
Number of Electode of EEG	64



(a)



(b)

Fig. 1. Block diagram of the system setup (a) System is mounted 16 fNIRS modules and EEG unit..(b) A fNIRS module includes source and detention and ADC and control unit.

B. *Implementation*

Figure 2 shows front and back view of the system. The interface that related to the system operation was consolidated in the front side part. The interface block for system operation and EEG were located in the front side.

16 fNIRS modules were aligned in the system and port of the fiber bundles were located in the back side. The fNIRS module size was 250(W)x400(D)x130(H)mm, and the system size was 610(W)x730(D)x1080(H)mm.

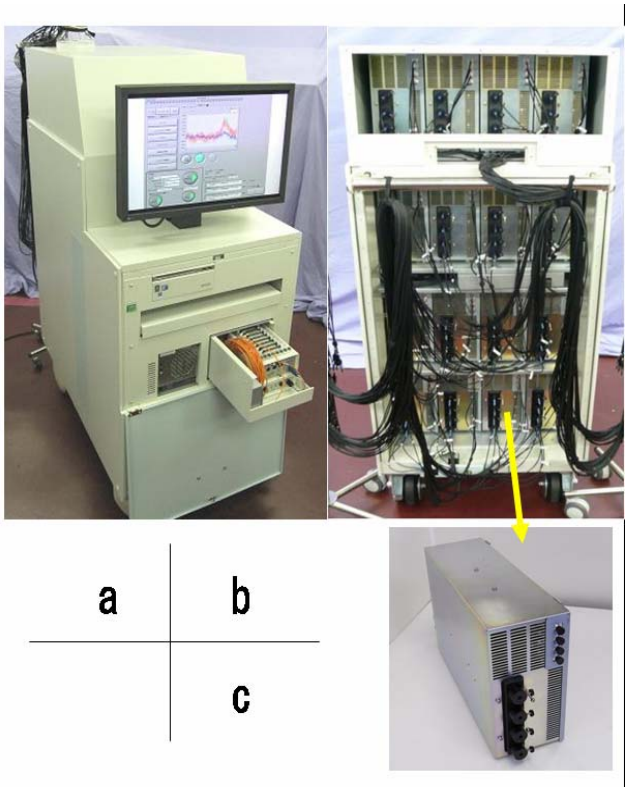
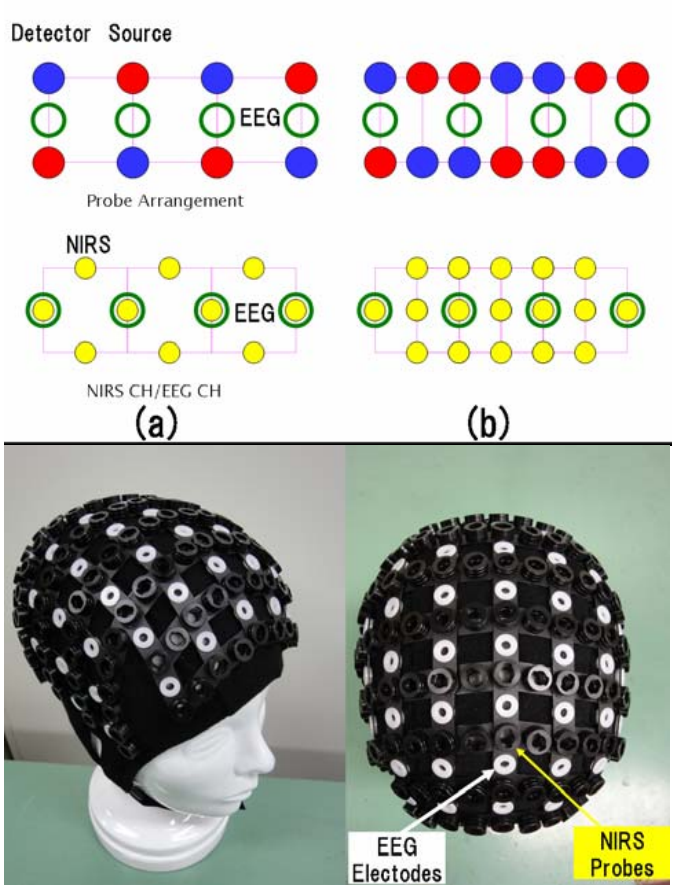


Fig. 2 Photograph of the system.(a)Front side has operation units and EEG,(b) Back side has port of fNIRS fibers,(c) Complete view of a fNIRS module unit.

C. *Optode Holder*

Optode holder caps generally fabricated from thermoplastic resin has been used to hold the fiber bundles of fNIRS systems, because the distance between a light source fiber and a detector fiber needs to be constant. However it can not fit the various heads of all subjects because of their shape and size differences. Consequently, it results in the deterioration of signal-to-noise ratio and lower reliability data. In our previous work, we reported a novel holder cap for fNIRS, which was called flexible adjustable surface holder (FLASH) to solve this problem [9]. The basic structure of FLASH consisted of some sides and some nodes which construct quadrangles. And the sockets of the fibers were located on the nodes. The material of the sides was flexible, but not stretchable. The sum of the interior angles can be changed by allowing the rotation of the sides at the position of the sockets. Therefore, the shape of FLASH can be defined by holding the interior angles at the position of the sockets. In this work, we developed a double density whole-head cap to hold both electrodes and optodes by revising FLASH in order to establish the technical basis of the simultaneous fNIRS and EEG study.



(c)

Fig. 3. Arrangements of NIRS probes and EEG electodes. (a) . In the standard probe arrangement, four source probes(red) and four detector probes(blue) were alternatively attached at 30 mm interval lattice points.EEG probes(green) were attached center between source and detector points (b)In the double-density probe arrangement, same source and detector probes were added to shift half diftance points in the same imaging area as that of the standard probe arrangement. The interval between each measurement point was 15 mm.
(c) Implemented cap to measure hole brain measurement using FLASH technique.

We implemented double density fNIRS and EEG holder from FLASH based fNIRS. The double density[10] need twice arrangement of the conventional method, the other arrangement is shifted at half of the optode distance from the origin. In grillage construction, electrode holders were put in the midpoint of slides of FLASH to raw direction and fNIRS optodes were put in the midpoint of slides of FLASH to column direction.

Figure.3 shows the development of the whole-head cap for simultaneous fNIRS and EEG. In addition, it was attached to an original shield-cap made from polyurethane to shield ambient light and to improve holding performance to head. It allowed the simultaneous measurements more than 64 EEG channels and 255 fNIRS measurement channels.

III. Instrument Performance

A. Phantom and Human Experiments

To evaluate performance of the new system, we developed a new phantom. Figure.4 showed developed the phantom. It has optode fixation on the bottom surface, and has the mechanism that small absorber can be moved in three directions in a uniform absorption space. As uniform absorption space, we filled 10% intralipid liquid. To give the adsorption change, the blach rod absorber of 10mm diameter were installed externally.

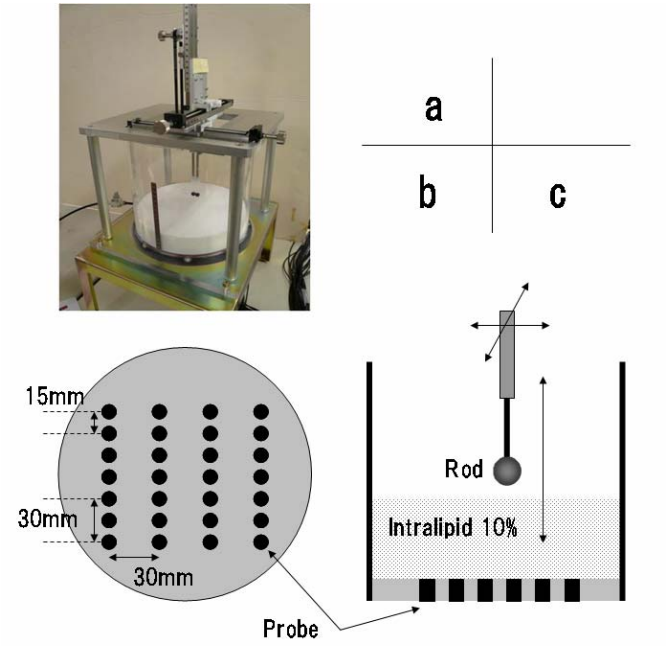


Fig. 4 (a)Photograph of the phantom.(b) Probe arrangement of bottom side.(c) Schematic diagram of relation between liquor and rod movement

We realized preliminary phantom measurement and human measurement to test use of the system for double density methods. First we performed phantom studies. We evaluated 2D tomography when the change was given to the absorption distribution while measuring. The adsorption change of position A and position B in Figure 5 was caused in case of conventional and double density methods.

Rod location A is center of source and detector optodes in both methods. Rod location B is the center point of the lattice in the conventional, and is the center of source and detector optodes in the double density method.

Topography map of location A showed same sensibility change and spatial resolution. Topography map of location B showed sensibility of 1/5 level in the conventional method compared with position A, and it was equal compare with point A in the double density method.

The ununiformity of the sensibility was improved in the double density method compared with the conventional methods.

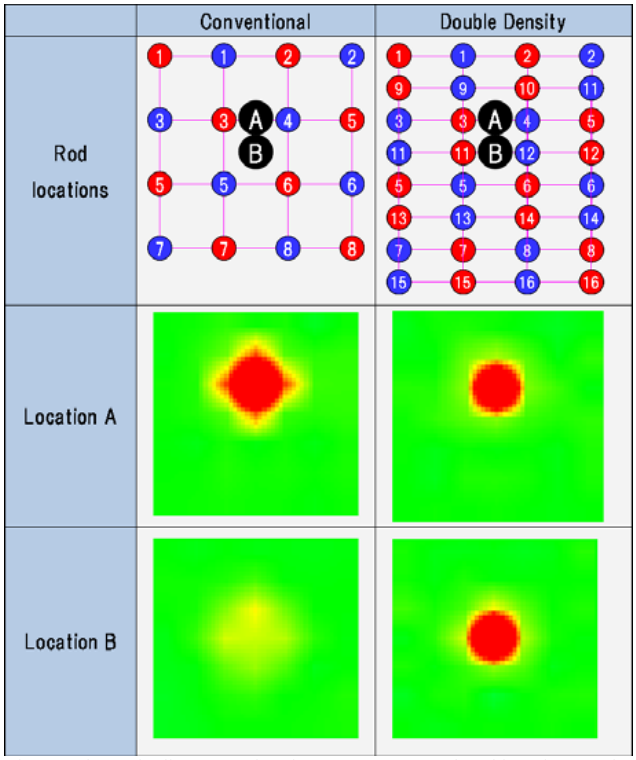


Fig.5. Schematic diagrams of probe arrangement and rod locations. Point A is located center of source and detector in both method. Point B is located on center of lattice in conventional method. Topographic images of point A showed same performance, and difference was shown in the sensibility from Point B.

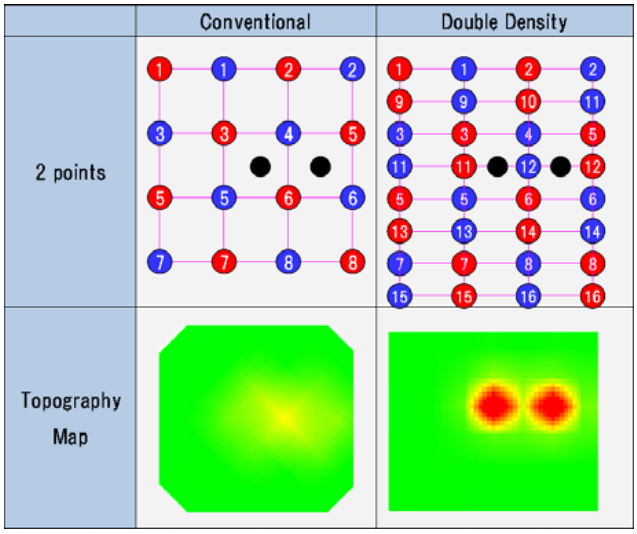


Fig.6. Schematic diagrams of probe arrangement and two rod locations. Black points is located on center of lattice in conventional method. Topographic images of two points showed difference in the sensibility and resolution

Next, we evaluated the performance of separation using

two rods. Figure.6 shows the resolving performance of two rods at the position where the sensibility was low in conventional method was measured. To rods were correctly separated in the double density method though the separation was impossible in the conventional method.

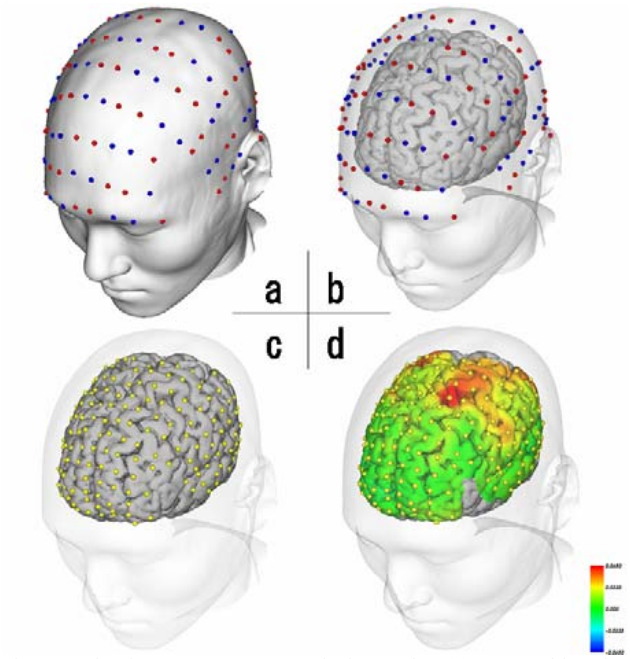


Fig. 7. Fusion images[11] on anatomical MRI data.(a) Imported location data which measured using 3D digitaizer(Polhemus Fastrak digitizer).Source showed red points and detectors showed blue points.(b) Result of displaying brain surface and scalp surface in same space.(c) logical channel (yellow) points are estimated on the brain surface from probe locations.(d) Topographic mapping on the brain surface which obtained while right finger tapping.Red color showed increase of oxy-Hb in the task duration.

As a human study, we have recorded the fNIRS signals during a right hand self-paced finger tapping. For a experiment, we employed 207 channels of fNIRS covering the whole brain with the double density method. The subject performed 5 trials in which a trial consists of 20s rest, 20s task, 20s rest.

The topographical image of [oxy-Hb] changed at 20s after the start of the right-finger-tapping. The results indicated task-related activity in oxy-Hb singals shown in Figure 7. Using the double density method, spatial resolution of image was improved than conventional one.

IV. Conclusion

In this study, we integrated the EEG and the fNIRS , and developed fNIRS+EEG as non-invasive brain functional system that implied simultaneous measurement and data integration. The new fNIRS had high performances with high spatial resolution using double density technique and a large number of channels to cover whole brain. The functional data which has highly-spatial resolution and wide field of view would contribute to improve the accuracy of the BMI decoding of the brain signals.

Acknowledgment

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