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Portable single-channel NIRS-based BMI System for Motor Disabilities' Communication Tools

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***Abstract*—A portable near-infrared spectroscopy (NIRS) –based brain-machine Interface (BMI) system featuring single-channel probe, BMI controller and Infrared-emission apparatus was developed. As a switching technology for external devices, the threshold logic was proposed, which detects the blood volume change in the operator's frontal lobe. Experiments showed that the operator was able to change the TV programs or get forward the toy robot within 16 s (the mean is 11.77 s and the standard deviation is 2.35 s) after the mental calculation. In addition, the menu selection program was proposed for motor disabilities and the preliminary test showed that he could successively select the sentence from several candidates. It was shown that this system would provide the external device's control capabilities for motor disabilities.**

I. Introduction

Direct Communication between human and machine has been an object of admiration for computer researchers since the second half of the 20th century. To date there have appeared several techniques, such as brain-machine interface (BMI) and brain-computer interface (BCI). The initial BMI provides an invasive, neuron-based method which exploits the neural activity for communication [1] [2]. Since this method does not require motor activity, people with locked-in states are able to control a cursor on the screen or other devices by their thoughts [3]. In addition, the BCI has been developed mainly in medical schools and clinical fields to provide people with severe motor disabilities with communication tools [4] [5] [6] [7]. The BCI features non-invasive, electroencephalography (EEG) signal-based technique, that are realized by either training the user to control his brain waves or exploiting neural responses of the brain to external stimuli. Recent works include BCI2000 by Wolpaw et al. [8] that presented a general purpose BCI system, and improved P300-based BCI by Serby et al. [9] which achieved high communication rate with an accuracy over ninety percent.

In addition to previous works, new interface technologies have been emerged such as hierarchical variation Bayesian method in combination of functional magnetic resonance imaging (fMRI) and magneto encephalography (MEG) [10] [11]. In 2006, Kamitani et al. developed fMRI-based decoding system of neural representations [12], which exploits fMRI signals for computer processing and extracts the feature vectors for hardware movement. They demonstrated operator's ability to control robot-finger shapes in remote site by his own finger movement. However, above techniques have serious limitations in size and scale for rehabilitation purpose, since it requires physical training in an open environment to help people live a healthy, useful, or active life again after they have been injured or very sick. For example, EEG signals suffer from high noise levels due to the low conductivity of the human skull and required a measurement in the shielded-room to obtain stable signals. In case of fMRI, subjects are restricted to the bed side during signal acquisition and unable to talk or move around the room.

In recognition of these situations, we have developed a non-invasive single-channel near-infrared spectroscopy (NIRS)-based BMI system featuring an easy probe attachment and a short measuring time, which is different from recent NIRS BCI systems [13] [14]. Our method is based on the work by Haida et al. [15], who measured the brain activity from an amyotrophic lateral sclerosis (ALS) patient by use of Optical Topography (OT) [16] [17] and demonstrated that he was able to communicate with the family when requested to provide an affirmative answer. Our approach is to use the change of blood volume in the brain as a switching trigger for external devices. In this system, when the subject starts the mental calculation as his own intention, the threshold logic detects the initiation point for switching and transmits the signal from the Infrared-emission apparatus, realizing the movement of external devices.

II. Methods

A. NIRS-based BMI System

Figure 1 shows a NIRS-based BMI system consisting of single-channel probe, a BMI controller, and an Infrared-emission apparatus (IrDA standard compliant). The BMI controller uses one laser module as a light source and one Avalanche Photo Diode (APD) as a detector. The laser module has two laser diodes (one for wavelength of 780 nm, and one for 830 nm), and their intensities are modulated at 1 KHz and 5 KHz, respectively. Mixed lights are transmitted to a probe through optical fibers, and the light scattered by the brain is detected at the APD. The output of the APD is

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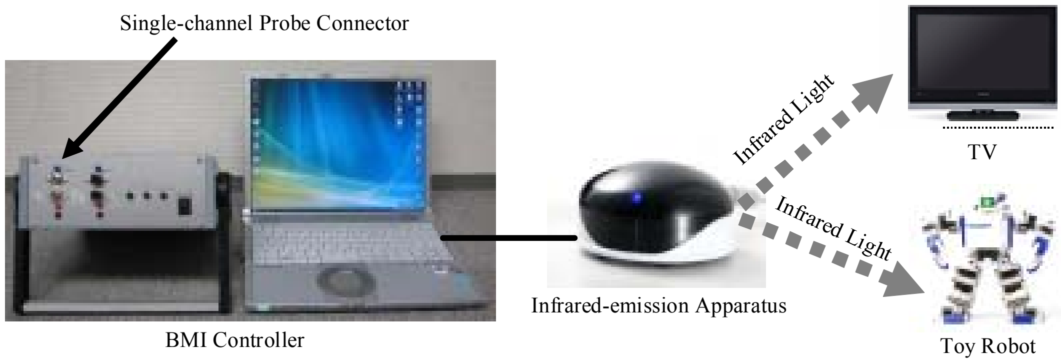


Fig. 1 NIRS-based BMI with single-channel probe, BMI controller, and Infrared-emission apparatus

distributed as two signals and sent to locked-in amplifiers, where signals are separated into signals corresponding to two original wavelengths. The separated signals are then sent to an A/D converter, and sent to a computer at a sampling rate of 10 Hz.

Figure 2 shows the typical activation pattern for a normal subject using the single-channel NIRS-based BMI System., where the x-axis denotes the sampling step and the y-axis means the oxy-hemoglobin change. Since the sampling rate is 10 Hz, 100 sampling steps correspond to 10 s. The task paradigm in this case is firstly rest (12 s) and then task (12 s) and finally rest (12 s). As is seen in Fig.2, the signal amplitude depicts the abrupt change according to the task paradigm.

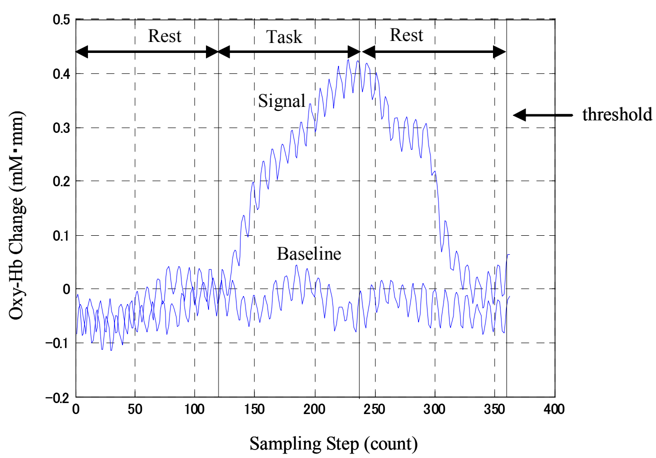


Fig. 2 Typical activation pattern for a normal subject, where rest (12 s) – task (12 s) – rest (12 s) paradigm was used.

B. Device Control Sequence

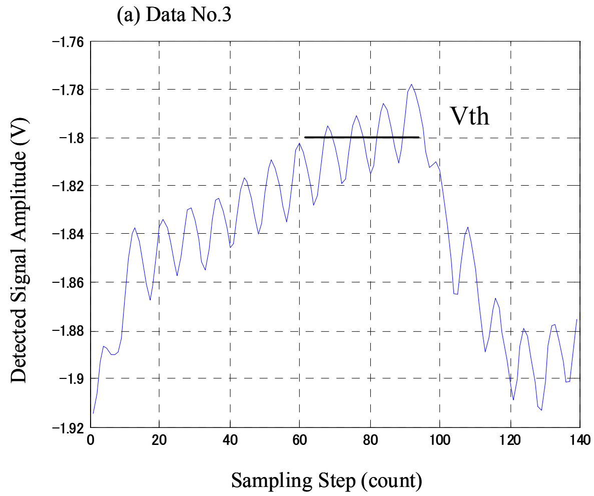
One of the principal requirements of the BMI is to control external devices such as TV controller and toy robot without operator's muscle movements. Since the BMI controller detects the change of brain activities at a sampling rate of 10 Hz, and also the operator is able to activate the brain by his/her intention, the operator can creates the abrupt change at the time he or she wants to control external devices. Our idea is to use this abrupt change as a switching trigger, and upon this idea, we have developed the threshold logic which enables the control of external devices. In the threshold logic, the threshold cursor is set at the position of 0.8 between the baseline and the peak signal amplitude, and if the signal exceeds the threshold cursor, the BMI controller sends the command to the Infrared-emission device enabling the onset of TV or the walking of the robot.

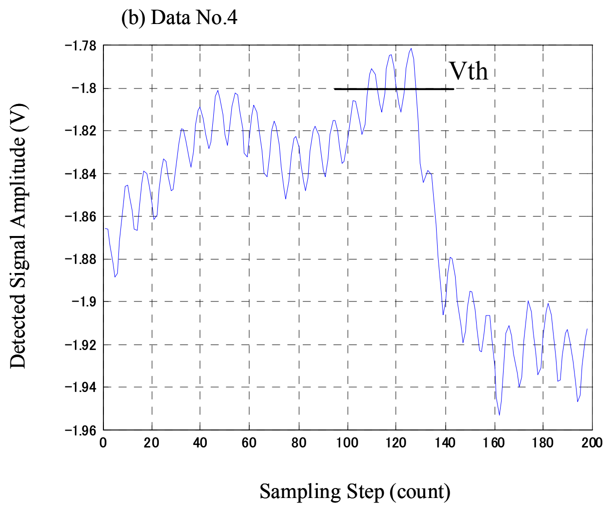
III. RESULTS

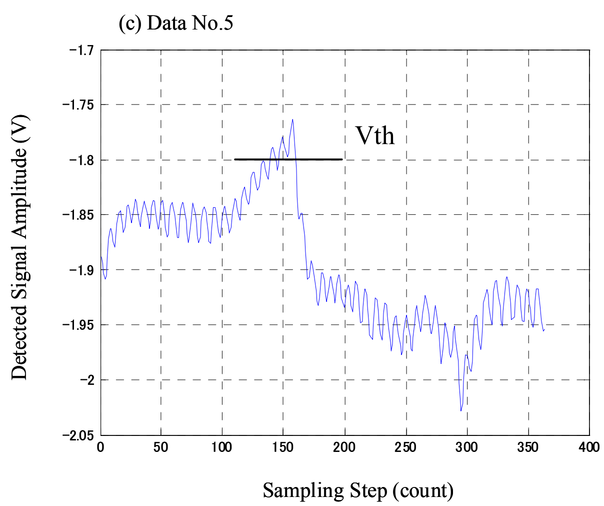
A. Device Operation

As for the subjects of experiments, the authors (aged between 40 and 60) tried alternatively the external device control using the threshold logic. The single-channel probe was placed on the subject's left forehead and it detected the change in blood volume in the frontal lobe. Fig.3 shows the typical four wave forms out of 15 trials. The threshold Vth was set at -1.8 V and each subject made a mental calculation (such as subtracting 3 successively starting from 100) from the zero sampling steps. From Fig.3, the initiation time, which is defined as the time when the detected signal amplitude exceeds the threshold, is 7.1 s (No.3), 11.7 s (No.4), 13.9 s (No.5), and 13.0 s (No.6), respectively.

Figure 4 shows the distribution of the initiation times for 15 trials with its probability density function (the mean is 11.77 s and the standard deviation is 2.35 s). In all cases, we were able to change the TV programs or get forward the toy robot within 16 s after the mental calculation. More detailed video will be presented at the conference. These technologies would open the way for disabilities in hospitals or homes who desire to control their personal devices by own intention.







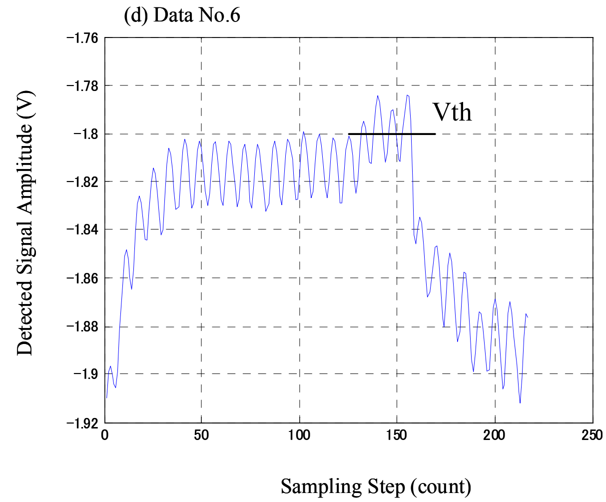


Fig. 3 Typical four wave forms for normal subjects, where the threshold position is indicated in each figure

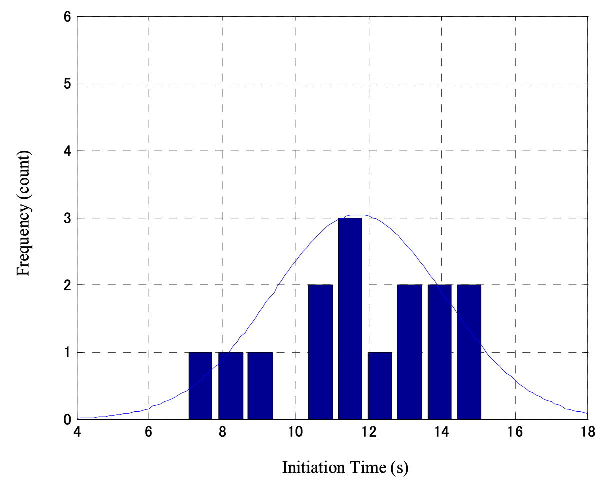


Fig.4 Distribution of the initiation times (the mean is 11.77 s and the standard deviation is 2.35 s)

B. Menu Selection

We have developed the menu selection program as one of the BMI applications for ALS patients in totally locked-in states who only have auditory abilities. Fig.5 shows the schematic task paradigm used in this program. Sentences are successively shown on the computer screen (such as A, B, C, …) with 20 s interval, and at the onset of the sentence, the voice guidance is announced for the subject's attention. For example, the sentence "Turn on the light" is read out from the speaker as soon as its sentence is displayed. The menu selection sequence is as follows; the subject is paying attention to the guidance, and if he wants to stop the sentence B, he starts the mental calculation just after the end of voice guidance. If the detected signal amplitude exceeds the threshold within 20 s, the program stops the circulation after the sentence C.

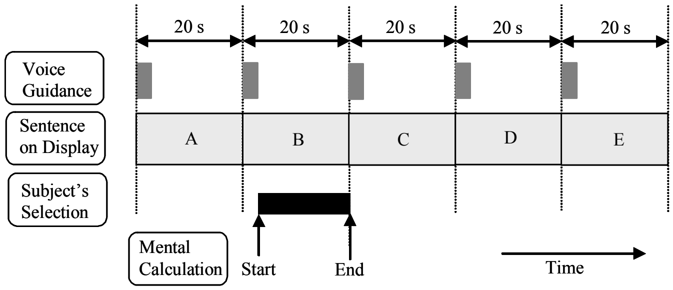


Fig. 5 Schematic task paradigm for menu selection

Figure 6 shows the image of the menu selection program, where the sentence "Turn up the volume" is selected. One of the authors tried this experiment several times and was able to select the sentence where he wants. As for the field trials, we are planning to perform the large-scale tests in 2009 after the permission of the Ethics Committee on Clinical Investigation of our institution.

Fig. 6 Image of the menu selection program, where the second sentence was selected (high-lightened)

IV. CONCLUSIONS AND FUTURE WORKS

In this study, a NIRS-based BMI system using single-channel probe, BMI controller and Infrared-emission apparatus was proposed and demonstrated. In this system, the operator could control the external devices by his/her intention within approximately 16 s. In addition, the possibility for menu selection program was presented for motor disabilities as one of the BMI applications.

In the previous study on the optical BMI systems [16], 20 to 30 channel arrangements were required to detect the brain activities in the frontal lobe which were used to extract the feature vectors for device control. But in the proposed system,
only single-channel probe was placed on the subject's forehead and the detected signals were analyzed by the simple threshold logic, enabling the usability of motor disabilities.
But there still remain several issues such as where to place the single-probe and how to decide the threshold value adaptively. To increase the accuracy of our methods, the large fMRI database for mental calculation to decide the accurate probe position should be established, and the algorithm to change the threshold value according to the subject's condition should be improved.

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