Towards the Brain-Computer Interface for Daily Life

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ABSTRACT

Brain-computer interface (BCI) is a system to detect user's intentions or "thoughts" from measured signal of brain and nervous activities. In this presentation, our studies to detect mental events (e.g., imagery or selective attention) and mental states (drowsiness, emergency, concentration) for realizing BCI are introduced and discussed.

1 Introduction

Brain-computer interface (BCI) is a system to detect user's intentions or "thoughts" from measured signal of brain and nervous activities. There is also a feedback pathway to provide information extracted from brain activation to the brain via sensation, and it can be used for neurofeedback to modulate (enhance or suppress) neural activations by learning at the neural network level. BCI is expected to be an alternative communication way for patients of severely paralysis or motor neuron diseases. Moreover, BCI studies has been highlighted because it can help and support our daily life by detecting various kinds of our mental states. (Fig. 1)

To improve the BCI technologies, we have been investigated the brain activities and biosignals elicited by the brain functions, including cognitive tasks in the visual and auditory VR environments.

In this presentation, our studies to detect mental events (imagery of motor functions, selective attention to sensory stimuli) and mental states (drowsiness, emergency, concentration) for realizing BCI are introduced and discussed.

2 BCI for Detecting User's Intention

On BCI system, subjects are requested to execute pre-defined tasks, and signals which are related to the user's task were extracted from the data measured by EEG (electroencephalogram), fNIRS (functional near-infrared spectroscopy) or other measurement methods.

The research activities on BCI for detecting user's intention are introduced in this section.

2.1 BCI Based on Motor Imagery (MI)

If user imagines the movement (MI) of their own limbs, the area of the primary motor cortex is activated, and the power increase or decrease of the EEG of mu (around 10 Hz) and beta (12.5 to 30 Hz) bands (event-related (de)synchronization: ERS, ERD) were observed (Fig.2). As the area activated by the MI corresponds to the limbs of the MI (e.g., right hand, left hand), the spatial distribution

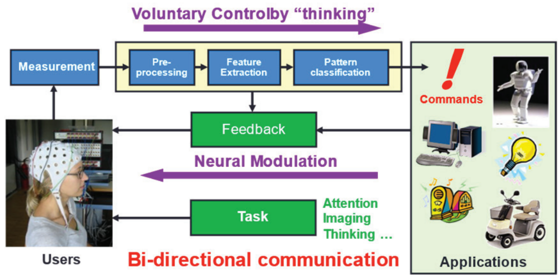

Fig. 1 Brain-Computer Interface

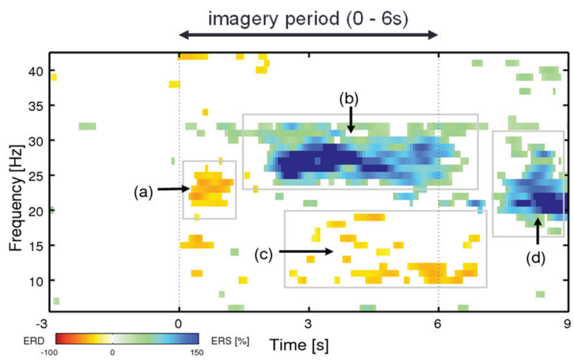

Fig. 2 EEG Frequency Responses to the Imagery of Feet Movement [1]

of such a power change of EEG on the surface of the scalp can be used to determine the object of MI ("motor homunculus").

This system can be applied to the control of electric wheelchairs, switch on/off the electric devices [1]. The EEG power on specific bands could be used as a neuro-feedback signal to modulate the activities of motor cortex during MI, and the target EEG frequency band activities were enhanced after continuous neurofeedback [2].

2.2 Auditory BCI

Stimulus-driven BCI is a system to detect user's intention from brain activities elicited by the cognitive action (perception, selective attention) to sensory stimuli. Because it is easy to present large amount of information to users, visual stimuli have been commonly used as sensory stimuli [3, 4].

However, a stimulus-driven BCI using visual stimuli completely occupies user's visual function and it will restrict their activities during operating it. If auditory stimuli are used for stimulus-driven BCI instead, users can do anything with their eyes during operation.

As auditory signal contains less amount of information than visual one, it should be necessary to take care for improving perception in auditory space. To achieve it, auditory VR (virtual reality) technology would be a good tool to enable users to segregate simultaneously presented multiple sound sources contained in biaural stereo sounds. Segregation to multiple sources can be realized by (1) sound source location in auditory sound space, (2) attributes of sound (e.g., pitch, frequency, intensity, duration, timbre), and (3) their time course (melody, stream). In human central auditory system, auditory illusion has an import role to realize the segregation of multiple sounds [5, 6, 7].

We have been developed the auditory BCI based on stream segregation, one of the auditory illusions. If the sound with high and low frequency bands are presented to subject alternately (*HLHLHL*…), subject tends to recognize one alternate tone sequences as two tone-streams at high (*HHHHH*…) and low (*LLLLL*…) frequency bands.

We showed that, with a stream segregation capability, subjects could perceive one tone sequence, consisted of tones with multiple (two or four) frequencies which were presented in turn, as the same number of tone streams at corresponding frequencies. It was also shown that, when subjects pay selective attention to one of the streams, the P300, one of the event-related potential components of EEG, was elicited only by that stream.

3 Mental State Detection from Multiple Biosignals

The BCI system can be designed for detecting user's mental states. By analyzing biosignals, e.g., EEG, ECG (electrocardiogram), EOG (electrooculogram) and EMG (electromyogram), user's mental states (drowsiness, emergency, concentration) as well as emotions can be detected and evaluated.

3.1 Drowsiness Detection during Driving

For avoiding traffic accidents due to driver's falling asleep during driving cars, it is effective to detect driver's drowsiness during driving. We have been investigating the method to detect drowsiness from multiple biosignals during performance of driving simulator.

It was shown that the driver's drowsiness can be detected by analyzing the multiple biosignals using multivariate statistical process control (MSPC) method (Fig. 3).

We also developed the eyewear to detect user's mental and physical states by measuring and analyzing EOG and 6-axis motion sensors (commercially available) [8]. It is also possible to detect mental states only by using peripheral biosignals for practical applications.

3.2 Emergency Detection during Driving

If the obstacle on road (e.g., walker, car, bicycle) suddenly appears during car driving, driver should take action to avoid clashing. If there is no time enough to avoid, driver tends to be panicked and no action can be taken. If such emergency states can be detected from biosignals, it can be used to control the car instead of the panicked car driver.

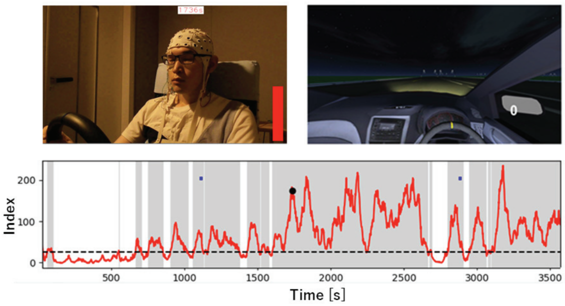

Fig. 3 Drowsiness Detection

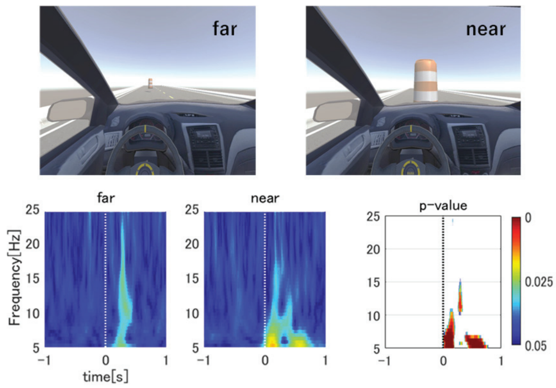

Fig. 4 Detection of Obstacles on Road During Car driving Environment [9]

VR environment of this situation was designed with HMD and EEG signal was measured during the crash avoidance trials. From this experiment, index of the inter-trial phase synchrony (phase-locking index: PLI) of EEG significantly increased within 100 or 200 ms only on the emergency states [9]. This result indicates the possibility to detect user's emergency detection and can be used to avoid car accidents with road obstacles.

3.3 Contribution of VR to BCI Research

To execute such experiments, the in-house VR applications working on Oculus Quest series are designed and used. Especially on experiments to test to detect mental states, it is required that detailed and realistic artificial stimuli should be provided to subjects for reproducing same situations or scenarios in their minds many times during experiments. VR applications are quite suitable for such experiments.

Moreover, reality of the environment is required for BCI system itself. As BCI system is for the support for human in a daily life, better performance is expected to be obtained when users perform in the realistic world. VR technologies will be a key for immersion of users into the BCI environments.

4 Conclusions

Some of our research activities on BCI and mental state detection were introduced.

Reality of sensory stimulation to subjects used in the experiments is one of the important keys to find experimental neurophysiological evidence of the human mental activities. Current VR technology should be applied to the research to approach the nature of the brain and nervous system, and to develop the BCI system to detect mental states.

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