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Development of an Emergency Call System using a Brain Computer Interface (BCI)

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***Abstract*—A brain computer interface (BCI) can be used by persons with severe neuromuscular disorders to control external devices such as computers or neuro-prosthesis. To improve accuracy, however, most of BCIs need multi-channels, wet sensors, big and complex systems. It makes most use of BCIs restricted to laboratory and medical area. In this paper, to solve the limitation, mindset (neurosky headset) that is a commercially available BCI is adopted and the emergency call system for severely disabled persons using attention/meditation signal is developed. In addition, to operate on a wide range of disabilities under a wide range of environmental conditions, algorithms of determining trigger method and threshold level are proposed. The usefulness of the system and the proposed algorithms is verified by experiment result.**

I. INTRODUCTION

VARIOUS research groups have developed interface technologies to meet needs of elderly and/or disabled persons with the aim of increasing their quality of life and allowing them a more independent lifestyle. In conventional systems, mechanical linkages such as keyboard, mouse and joystick have widely used for device control [1]. Those mechanical linkages have many advantages such as wide-spread availability, robustness and operational simplicity. In case of severe motor impairments such as amyotrophic lateral sclerosis (ALS), brain or spinal cord injury, and cerebral palsy, however, usage of the mechanical linkages is very difficult. With a high level impairment, the amount of function is substantial and the number of voluntary muscle control is markedly limited. Many people with severe motor disabilities require alternative methods for communication and control.

Recently, many advances have been made in interface technologies, by means of bio-signals [2]: infrared sensing, electromyography, oculography, computer vision, and brain wave. Brain wave among them, especially, can provide a new, common, non-muscular communication and control channel, a brain computer interface (BCI) to disabled persons with variety of impairments, even those who are locked-in [3, 4].

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BCIs can be served by using various technologies such as electro/magnetoencephalography (EEG/MEG), positron emission tomography (PET), functional magnetic resonance imaging (fMRI), and optical imaging. However, MEG, PET, fMRI, and optical imaging are still technically demanding and expensive. Furthermore, PET, fMRI, and optical imaging, which depend on blood flow, have long time constants and thus are not suitable for rapid communication. For now, therefore, scalp-recorded EEG which has relatively short time constants, can function in most environments and offer the possibility of a BCI [5].

EEG-based BCI measures specific features of brain activities and use the results as a control signal. Some systems use potentials evoked by external stimuli [6, 7]. In these cases, users require little or no training. However the mental task must be performed in predefined time window. It may make daily use of BCI under real-world conditions difficult and time consuming. Other systems use EEG components that are spontaneous mental activities in the sense that they are not dependent on specific sensory events [8, 9]. Those systems have merit that users can perform at their own pace, whenever they wish. However training may be essential and it is a most important factor determining the BCI capabilities.

Besides, EEG signals can be affected by various artifacts: eye blinking, facial muscle, head and body movement, static electricity, electromagnetic fields, and so on. To improve accuracy, therefore, most of BCIs require multi-channels, wet sensors, big and complex systems. It makes most use of BCIs restricted to laboratory and medical use.

In this paper, to solve the limitations, mindset (neurosky headset) that is a commercially available BCI is adopted and the emergency call system for severely disabled persons is developed. In addition, to operate on a wide range of disabilities under a wide range of environmental conditions, the proposed system uses some techniques as follows: 1) to obtain system available for daily use by disabled persons and make a training process easily, attention/meditation signal is selected, 2) to stabilize the utilization of system, trigger algorithm is added, 3) to improve the performance of system, adaptation algorithms (initial adaptation to the individual user; continuing adaptation to spontaneous changes in the user's performance such as fatigue or level of attention/ meditation) are used. From the experiment result obtained with completely paralyzed patient, the usefulness of the system and the proposed algorithms is verified.

In section 2, we will mention some commercial BCI

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systems. The configuration of system and methods will be presented in section 3 and section 4, respectively. Section 5 shows the results from experiment. Finally, we will make the conclusion in section 6.

II. BCI Systems

A BCI is a communication pathway between the brain and an external device. It can be divided into two types. One is direct/invasive communication pathway between the brain and an external device. In this case, implanted sensors are used. The other one is indirect/non-invasive communication pathway between the brain and an external device through interpreter. Interpreter may be hardware and/or software which transform brain wave to control signals using signal processing algorithms. Indirect BCI of the two is more flexible and easy to use.

Over the past 15 years, BCI research programs have been extensive and rapidly growing by the advent of powerful low-cost computer equipment, by growing recognition of the needs and potentials of people with disabilities, and by growth in the interface between multiple key scientific areas. Especially, BCIs are rapidly approaching home use of non-invasive EEG-based BCIs over first-generation medical practice (clinical trials of invasive BCI technologies). There are many prospects that BCI research will rapidly accelerate in non-medical area of commerce, particularly in the gaming, PC applications, automotive, and robotics industries.

Based on these prospects, in addition, many companies have developed revolutionary new personal interfaces such as EPOC, mindball, neural impulse actuator, and mindset for human computer interaction. The detailed description of each system is as follows.

A. EPOC

Emotiv EPOC is the peripheral for gaming on windows PCs. The EPOC has 14 electrodes and a two-axis gyro sensor for measuring head rotation. It can measure four categories of inputs: conscious thoughts (imaging 12 kinds of movements), emotions (excitement, engagement/boredom, meditation and frustration), facial expressions and head rotation. Emotiv system will make it possible for games to be controlled and influenced by the player's mind, and facial expressions. It connects wirelessly with the PC.

B. Mindball

Mindball is a two person game controlled by players' brain waves in which players compete to control a ball's movement across a table by becoming more relaxed and focused. The brain waves are detected by BCI sensors attached to the headbands. The brain waves increasing the chance to win Mindball are alpha and theta waves. They occur when players are calm and relaxed. The player being most relaxed makes the ball roll over the opponent's goal, with his brain waves as only aid, and thereby wins the game.

C. Neural Impulse Actuator

The Neural Impulse Actuator (NIA) is a device developed the OCZ technology. It attempts to move away from the classic input devices like keyboard and mouse and instead read electrical activity from the head. The NIA detects the natural biopotentials (upper facial muscle movement, eye movement, and alpha/beta brain rhythmic activities) in the body using a set of three sensors attached to the front of the headband and principles of signal analysis are used to simplify these inputs into different frequency components which can then be assigned to individual computer commands.

The characteristic of the NIA is that different users will have different results. Some users, due to any number of reasons, will simply take to the NIA quicker than others. On the other hand, other users will not be able use it to anywhere near its full potential after practice.

D. Mindset

Neurosky's hardware, the think-gear module, uses their patented dry active sensor technology to read the brain signals. The electrodes of standard medical electroencephalography use a conductive gel to facilitate the reading of the signals. Dry active sensor technology does not need such a gel and unlike medical EEG, which uses many electrodes, Neurosky only uses one. This makes headsets based on Neurosky technology very low cost, and easy to put on. The Neurosky mindset is first manifestation available for the consumer market. As acquisition tool, it measures electrical impulses generated by mental activity, and uses proprietary algorithms to calculate the observed types of brain behavior. For consumer games and education, the mindset makes calculated brainwave levels and interpreted mental states available as digital input for computers, software, and devices. There are currently over a dozen games and educational application available. Data is fed to the computer via wireless bluetooth.

Table I shows the comparison of consumer brain computer interface devices. Among them, we use the mindset as BCI because it is robust in a noise environment, and easy to put on in real conditions.

TABLE I
Comparison of Consumer Brain Computer Interface Devices

	EPOC	Mindball	NIA	Mindset
productor	Emotiv Systems	Interactive Productline	OCZ Technology	Neurosky
Electrodes	16	1	3	1
Input signal	Pure neural signal	Pure neural signal	Biopotential from forehead	Pure neural signal
movement	Head rotation through two-axis gyros	-	Multiple mapped profiles	-
SDK	yes	-	-	yes
Cost	299 $	-	100 $	199 $

III. Configuration of System

Like any communication or control system, in general, a BCI has input, output, and components that translate input into output. Fig. 1 shows these elements and their principle interactions.

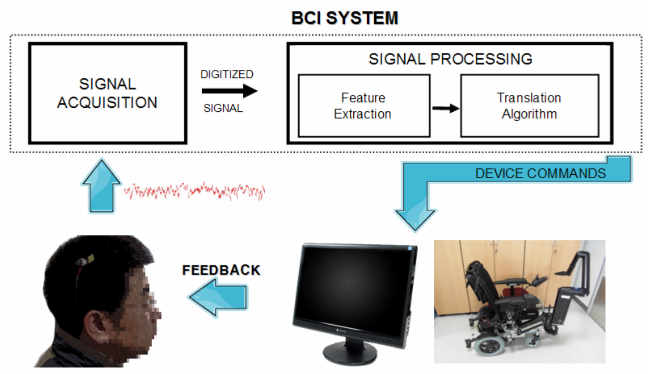


Fig. 1. The general configuration of BCI system

A. Signal acquisition

As stated above, neuronal activities within the brain are recorded by using mindset. Mindset consists of one forehead sensor, and ear contacts like Fig. 2. To maintain accuracy of brainwave reading, the forehead sensor must touch the left side of forehead, and ear contacts and reference points located on ear pads must touch the skin of the ear.

Fig. 2. Overview of the Mindset

B. Signal processing: feature extraction

The ThinkGear chip in mindset processes all acquisition data from a sensor, and calculates the data. The calculated values are output by the ThinkGear chip, through the headset, to a PC via wireless bluetooth.

Data output from ThinkGear chip are raw sampled wave values, signal poor quality metrics, eSense attention and meditation meter values, EEG band power values for delta, theta, alpha, beta, and gamma. Among them, in this paper, signal poor quality metrics and eSense meter values are used.

1) POOR_SIGNAL Quality: this value describes how poor the signal measured by the ThinkGear is. It ranges in value from 0 to 200. Any non-zero value indicates that some sort of noise contamination is detected. The higher the number, the more noise is detected. A value of 200 has a special meaning that the ThinkGear contacts are not touching the user's skin.

Poor signal may be caused by a number of different things: a)Sensor, ground, or reference contacts not being on a person's head, b)Poor contact of the sensor, ground, or reference contacts to a person's skin, c)Excessive motion of the wearer, d)Excessive environmental electrostatic noise, e)Excessive non-EEG biometric noise.

2) eSense Meters: the meter values are reported on a relative eSense scale of 1 to 100. On this scale, a value between 40 to 60 at any given moment in time is considered "neutral", and is similar in notion to "baselines" that are established in conventional EEG measurement techniques. A value from 60 to 80 is considered "slightly elevated" and may be interpreted as levels being possibly higher than normal. Values from 80 to 100 are considered "elevated", meaning they are strongly indicative of heightened levels of that eSense. Similarly, on the other end of the scale, a value between 20 to 40 indicates "reduced" levels of the eSense, while a value between 1 to 20 indicates "strongly lowered" levels of the eSense.

The eSense meters are a way how effectively the user is engaging attention (similar to concentration) or meditation (similar to relaxation). Generally, attention meter indicates the intensity of a user's level of mental "focus" or "attention" such as that which occurs during intense concentration and directed (but stable) mental activity. Distractions, wandering thoughts, lack of focus, or anxiety may lower the attention meter level. The meditation meter indicates the level of a user's mental "calmness" or "relaxation". Meditation is a measure of a person's mental states, not physical levels, so simply relaxing all the muscles of the body may not immediately result in a heightened meditation level. However, for most people in most normal circumstances, relaxing the body often helps the mind to relax as well. Meditation is related to reduced activity by the active mental processes in the brain. It has long been an observed effect that closing one's eyes is often an effective method for increasing the meditation level.

C. Signal processing: the translation algorithm

The first part of signal processing simply extracts specific signal features, eSense meter values. The next stage, the translation algorithm, translates these signal features into device commands that carry out the user's intent.

There are many algorithms that can be divided into linear and nonlinear methods [10, 11]. In case of emergency call system, the number of commands is small, we use the threshold method. Therefore, (attention meter value > threshold1) and (meditation meter value > threshold2) translate command1 (led1 on and buzzer1 on) and command2 (led2 on and buzzer2 on), respectively. At the beginning time, the values of threshold1 and threshold2 are selected according to training results of the user, and then adaptively change by user's performance.

D. *The output device*

The emergency call system can provide severely disabled person who may be completely paralyzed, or "locked in", with basic and effective communication capabilities so that they can express their wishes to caregivers/medical team, especially, when they require assistance. The emergency call device used in paper is like as Fig. 3. In the future, the system will include the control of external devices such as a lamp and a television, beside the emergency call function.

Fig. 3. Overview of emergency call device

However, peoples with severe motor disabilities are difficult to push the button of call switch. To solve the problem, we reconstruct the call switch by connecting board output to call switch instead of mechanical linkage. Fig. 4 shows the reconstructed call switch.

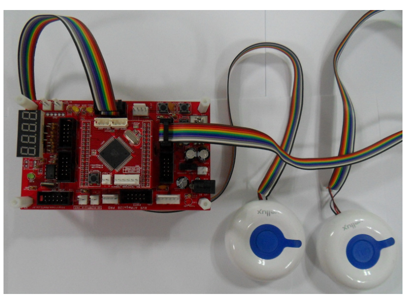


Fig. 4. The reconstructed call switch

The main components of the device are microcontroller, call switch, and buzzer. Through the serial connector, at first, the command from PC is transferred to microcontroller. Then, microcontroller carries the corresponding operation to the command. In case of command1 (for the emergency condition), the call switch1 turns on and a continuous repeating tone is activated during a predefined time window. In case of command2 (for general purpose: control of external devices), the call switch2 turns on and a two toned beep, low frequency beep is activated during a predefined time window.

IV. Methods

A. *Training method*

The eSense meters, which show how effectively the user is engaging attention or meditation, are widely used as control signal in many studies such as neuro-feedback, and monitoring a sportsman performance, etc [12-14].

Like exercising an unfamiliar muscle, however, it may take some time to gain full proficiency with each of the eSense meters. In many cases, furthermore, people tend to be better at one eSense than the other.

In this paper, to solve the problems, training session is performed in advance.

1) Check POOR_SIGNAL Quality: obtain the value of POOR_SIGNAL to check how poor the signal measured by a sensor. If the value is enough low, we can obtain the raw brain wave and power spectrum graph like as Fig. 5.

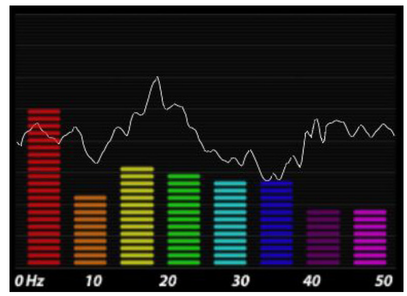


Fig. 5. The raw brain wave and power spectrum graph under the normal condition

2) Attention: Users concentrate and focus their thought towards pushing up the meter of attention for predefined time window. Then, we obtain the maximum value of attention meter like as Fig. 6 (a).

3) Meditation: Users try to relax for predefined time window. Then, we obtain the maximum value of meditation meter like as Fig. 6 (b). After some trials of training session, we finally obtain the maximum and average values of eSense meters. From these results, we can determine the initial threshold and user's trend.

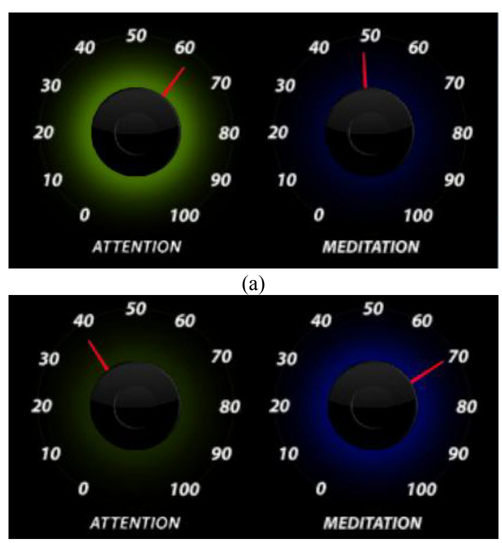


Fig. 6. (a) Attention and (b) meditation meters during training session

B. Triggering method

User can determine whether eSense data have meaning or not, by using triggering method. Most BCIs for people with no impairments do not require the triggering method. They can wear the BCI system, when they need to measure eSense data. However, disabled person have to wear the BCI system all the time. Therefore, to stabilize the utilization of system and prevent malfunctions of system, trigger algorithm is essential.

In this paper, triggering is on when the number of (attention /meditation meter > threshold) is greater than 3 during the preset triggering time window like as Fig. 7. In future, the triggering method will include the detection of various signals such as EOG, glance, and muscle activities. Then, the system will safely handle disabled persons with variety of impairments.

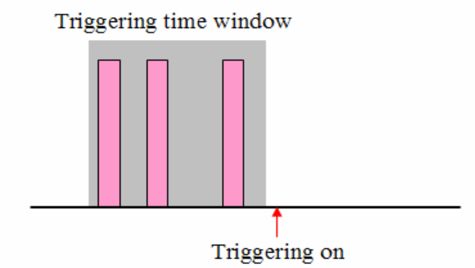


Fig. 7. The concept of triggering method

C. Adaptation method

To improve the performance of system, adaptation algorithm is used. First, when a new user first accesses the BCI the algorithm adapts to that user's signal features. From training results, in this paper, we determine the initial threshold values ((maximum eSense values-average eSense value) * predetermined value).

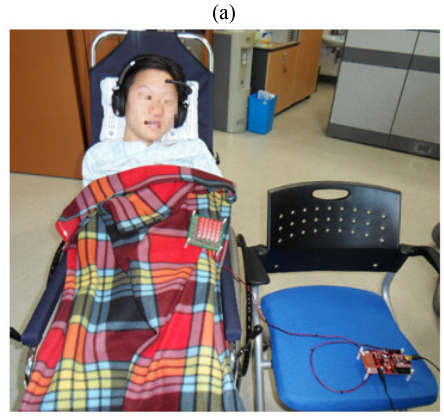
A BCI that possesses only the first level of adaptation, i.e. that adjusts to the user initially and never again, will continue to be effective only if the user's performance is very stable. However, EEG signals typically display short- and long-term variations linked to time of day, hormonal levels, immediate environment, recent events, fatigue, illness, and other factors. Thus, effective BCIs need a second level of adaptation: continuous adjustments of threshold values to reduce the impact of such spontaneous variations. A good translation algorithm will adjust to these variations so as to match as closely as possible the user's current range of signal features to the available range of device command values. In this paper, the levels of thresholds are continuously adjusted based on the average values the time of success after sensing the triggering on.

V. Results

A patient (a boy age 15) is the BCI user in this study. He is completely paralyzed. He had no arm and leg function, and used a wheelchair. He had no previous experience of BCI use.

During BCI operation, the user sat facing a monitor of a laptop computer. EEG activity was recorded from mindset. At the early stage of experiment, the user tended to be better at meditation meter than attention. So, the initial threshold value of attention is 50, while the initial threshold value of meditation is 80. During experiment, we recommend trying different tactics until he was successful with attention. When he saw a reaction on the monitor from his efforts, he could duplicate the action more easily with additional practice. In addition, the threshold value of attention at the final stage of experiment is changed up to the similar threshold value of meditation. Fig. 8 shows the experiment situation that uses the initial version of emergency call device which consists of led circuit and a buzzer.

(a)



(b)

Fig. 8. The experiment result: (a) led1 off and buzzer1 off, (b) led1 on and buzzer1 on

Then, we obtained experiment results from normal subjects. The results were very similar to patient results. The level of threshold and the number of times of success were improved as subjects performed more trials. From these results, we know that the usefulness of the system and the proposed algorithms is verified.

However, there was a problem. In case of peoples with severe motor disabilities, the poor contacts of sensor or reference points were often occurred. To solve the problem, in the future, we will develop the headband type system.

VI. CONCLUSIONS

The emergency call system using mindset that is a commercially available BCI for severely disabled persons is proposed in order to solve the conventional problems such as multi-channels, wet sensors, big and complex structure. In addition, to operate on a wide range of disabilities under a wide range of environmental conditions, the proposed system uses some techniques as follows: 1) to obtain system available for daily use by disabled persons and make a training process easily, attention/meditation signal is selected, 2) to stabilize the utilization of system, training and trigger algorithm are added, 3) to improve the performance of system, adaptation algorithms are used. From experiment results, finally, the usefulness of the system and the proposed algorithms is verified.

In the future, the system will include the control of external devices such as a lamp and a television, beside the emergency call system. In addition, we will improve the overall system and algorithms for general-purpose use in accordance with usability test.

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