Thesis for Master's Degree

Secret Brain to Brain Communication via Wireless Brain-Computer Interface System

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2014

석 사 학 위 논 문

무선 BCI 시스템을 통하여 비밀을 보장하는 인간 두뇌 간 의사소통

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정 보 통 신 공 학 부

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Secret Brain to Brain Communication via Wireless Brain-Computer Interface System

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A thesis submitted to the faculty of the Gwangju Institute of Science and Technology in partial fulfillment of the requirements for the degree of Master of Science in the School Information and Communications

Gwangju, Republic of Korea

2013. 12. 17.

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Accepted in partial fulfillment of the requirements for the degree of Master of Science

December 17th, 2013

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MS/IC Soogil Woo(우수길). Secret Brain to Brain Communication via Wireless Brain

20121142 Computer Interface System (무선 BCI 시스템을 통하여 비밀을 보장하는 인간 두뇌 간 의사소통).

School of Information and Communication. 2014. 36p. Advisor: Prof. Heung-No Lee.

Abstract

A Brain Computer Interface (BCI) is a new communication technique where messages or commands that a human sends to the external world using brain signals such as electroencephalography (EEG). BCI systems provide a communication and control channel between the user's brain and an external device, such as a computer or prosthetic hands. EEG signals are recordings of the brain waves generated by electrical activity along the scalp. BCI does not rely on the brain's normal state of nerves and muscles. These signals can be mapped to create different commands using a series of refined signal processing procedures.

This paper focuses primarily on the applications of wireless BCI systems, and introduces existing wireless BCI systems for entertainments, and daily life applications. In the past, researchers proposed wired BCI system applications to diagnose disease. However, they currently make wireless BCI applications that help people live more convenient lives. These applications are able to offer improvements in entertainments, games, medical engineering, rehabilitation, and daily life, because

such systems have obvious advantages over existing ones. They are simpler, more convenient, more mobile, and more flexible than wired BCI systems.

In this thesis, we proposed an application of wireless Brain-Computer Interface system for communication with people using the smart phone. We use the Mindwave of Neurosky company. This application system was made by the eclipse edit tool to operate application in Android smart phone.

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1 Introduction

The BCI transmitter sends command signals to the receiver of a target application. The application then converts these signals into commands that cause movements. The BCI has been used for a widening variety of such applications. The initial applications have been aimed at helping disabled people utilize machines. These days, many researchers consider that wireless BCI systems are a very important step towards getting BCI applications out of laboratories.

Many BCI systems are wired BCI systems as shown in figure 1. The acquisition part of wired BCI systems generally comes with bulky and heavy amplifiers and preprocessing units. Connection wiring is complicated with a number of cables between electrodes and acquisition part. For these reasons, user's movement is limited and application of BCI is difficult to escape from laboratory scale experiments. These restrictions make the types of applications for which these systems can be made useful be severely limited.

Figure 1 shows the conventional EEG based BCI system. Using EEG signals as an input to the system, the BCI system extracts feature signals from the EEG signals. Feature signals are the components of EEG signals which reflect subject's intention. Because these feature signals are often corrupted by noise or contaminated by an interfering signal, the informative signal features are hidden. To extract these feature signals and translate the command for external device, signal processing methods are applied such as feature extraction and classification.

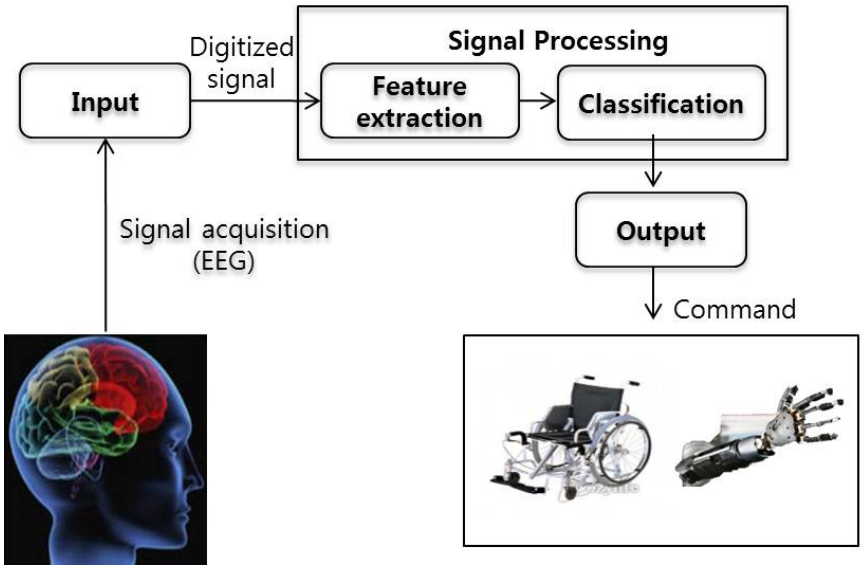

Figure 1. EEG based wired BCI system

Wireless BCI systems are to eliminate the wire connection between the signal acquisition and the translation part. The connection is replaced with the use of a wireless transmission unit such as Bluetooth and other communication technologies. Removing wired connections, portability of wireless BCI systems is greatly improved. Posture and movement on wearing the acquisition part of wireless BCI systems are also unimpeded. These desirable aspects of wireless BCI systems promote to go beyond a laboratory scale experiment and usher in the development of real-life applications as shown in figure 2.

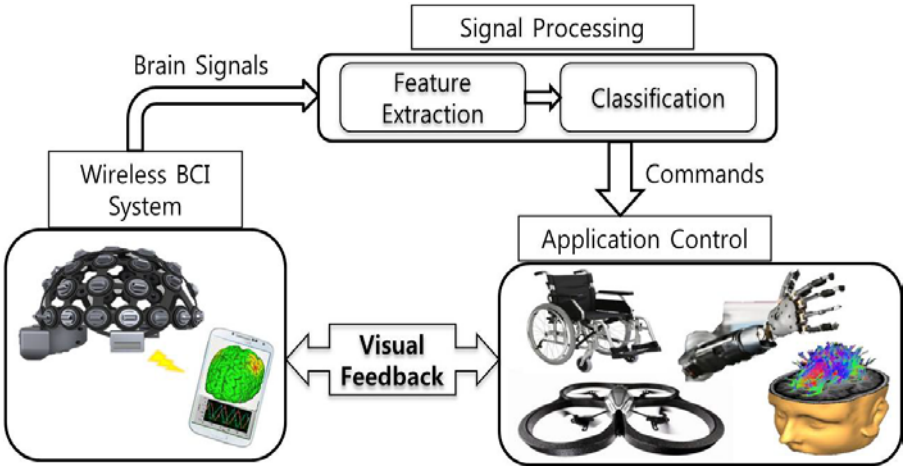

Figure 2. EEG based wireless BCI system

With wireless BCI systems, various applications are under development now. In the early days, cursor control and speller applications were developed targeted for helping the disabled people. Wireless BCI systems are applied in entertainments as well. Moreover, researchers have applied wireless BCI systems to exciting new applications such as home automation system based on monitoring human physiological states, cellular phone dialing, and drowsiness detection for drivers.

In this paper, we focus on applications of wireless BCI systems and introduce wireless BCI systems for applications in areas including entertainments, and daily life. Initial researchers proposed BCI system applications to diagnose disease [1]. Currently, they make wireless BCI applications that help people live more convenient lives. These applications are able to offer improvements in entertainments, games, medical engineering, rehabilitation, and daily life, because such systems have obvious advantages. They are simpler, convenient, and flexible.

In this thesis, we proposed an application of wireless Brain-Computer Interface system for communication with people using the smart phone. We use the commercial wireless BCI system. This application system was made by the eclipse edit tool to operate application in Android smart phone.

This paper will be divided into the following nine subchapters: Introduction, Background, Recent research of wireless BCI systems, Applications of wireless BCI systems, Proposed wireless BCI system and application for communication with people, Methods, Results, Conclude and Discussion.

2 Background

In 1924, Hans Berger found that electrical signals can be measured from the scalp of the human brain and published his first paper which has ever since established Electroencephalography (EEG) as a basic tool for clinical diagnosis and brain research [2].

Many research laboratories around the world currently focus on BCI research and performance. Some examples of EEG-based applications include the control of cursors [3-5], wheelchairs [6-9], robots [10-11], typing skills [12-14], and diagnosis of disease [15-20].

BCI systems can be categorized as invasive and non-invasive. Electrodes are implanted into the brain by a surgery in invasive BCI systems. Invasive devices are able of measuring high quality EEG signals. However, accompany great risk due to surgery at all time. Electrical signals produced by brain activities are recorded as EEG signals at the scalp of the human brain in non-invasive BCI systems. In EEG-based BCI systems, there are two kinds of features of EEG signals that are most popular to date: steady state visual evoke potentials (SSVEP) [21-23], motor imagery [24]. SSVEPs are elicited by visual stimulus. The stimulus is usually given the fresh light in the foam. In this case, the stimulus changes at a frequency higher than 6 Hz. If the stimulus is a flash, SSVEP shows a sinusoidal-like waveform whose fundamental frequency is the same as the blinking frequency of the stimulus. Many studies have been performed to implement applications including chatting system [22], controlling home appliances such as adjusting TV volume and turning on/off the light lamp [26-27]. MI-based BCI systems utilize sensorimotor rhythms (SMRs), such as the Mu (7-13 Hz) and Beta (13-30 Hz) rhythms; these rhythms can be recorded on the scalp over the sensorimotor cortex area. MI-

based BCI systems have been applied for computer games [28]. They have been also applied to improve mental concentration ability of average people [29-30].

Current research has also aimed to wireless BCI systems and applications using dry electrodes. Dry electrodes can be used to replace electrodes that must be covered with conductive gel, another innovative change allowing EEG-based applications to escape from laboratories. Some examples include cellphone-based BCI for communication [22], control of smart homes [31], control of robots [31], control of wheelchairs [27,32,33], and games [30,34,35,36].

3 Recent research of wireless BCI systems

Wireless BCI systems eliminate the wire connections between the wearable acquisition unit and the translation unit. The translation unit is usually housed in portable devices such as notepads and smart phones. This improvement provides easy installation process and freedom of postures for users. Owing to advanced integrated circuit designs, the components of the wireless BCI systems are small in sizes and efficient in power consumption. These advantages allow wireless BCI systems to be shaped in user friendly styles such as baseball caps [29,37], headsets [30,38,39], and headbands [22,29,40,41]. Wireless BCI systems still have restrictions. The quality of the measured EEG signals has to be improved for more precise classification of signals. This uncleanness interferes with signal measurements.

3.1 Electrodes of wireless BCI systems

The development of improved EEG electrodes which measure brain signals precisely with low noise is the most important challenge. Practically, the signal acquisition part of general wireless BCI systems only contains a signal acquisition module. To provide clear EEG signal acquisition at the electrode-skin interface, development of outstanding electrodes becomes a critical issue. Many research groups have recently been interested in developing advanced electrodes which can achieve low-noise recording with comfort.

Passive electrodes are widely used to measure EEG signals in wired BCI system. Treatments are needed, including a hair preparation step and the use of conductive gels or glues for better attachment and higher conductivity. These preparations induce discomfort and require long preparation time. Therefore, the long-term monitoring of EEG signals using passive electrodes is not feasible [25].

Researchers have studied advanced electrodes called dry electrodes to overcome the weaknesses of passive electrodes. Dry electrodes are defined as those that do not require the use of conductive gels or glues for installation process. The users can conveniently attach the electrodes to the user's scalp without any hair arrangement [25]. They employ special materials or shapes in the design of dry electrodes to make dry contact at the electrode-skin interface. The research has produced a huge variety of electrode materials and structures, including micro-machined structures [37,42], non-contact types [43,44], spring-loaded fingers [45], and bristle structures [46].

4 Applications of wireless BCI system

4.1 Wired BCI applications for communication

Spelling applications are communication tool that allow subjects to show other people by selecting words or other symbols. People who are amyotrophic lateral sclerosis (ALS) have learned to use MI-based BCI to control a spelling application [47]. One MI-based BCI spelling application divided the symbol. A research group invented a spelling system called “Hex-O-Spell” in which the BCI differentiated among six choices. Two selections were used to arrive at the letter or symbol as shown in figure 3 [48].

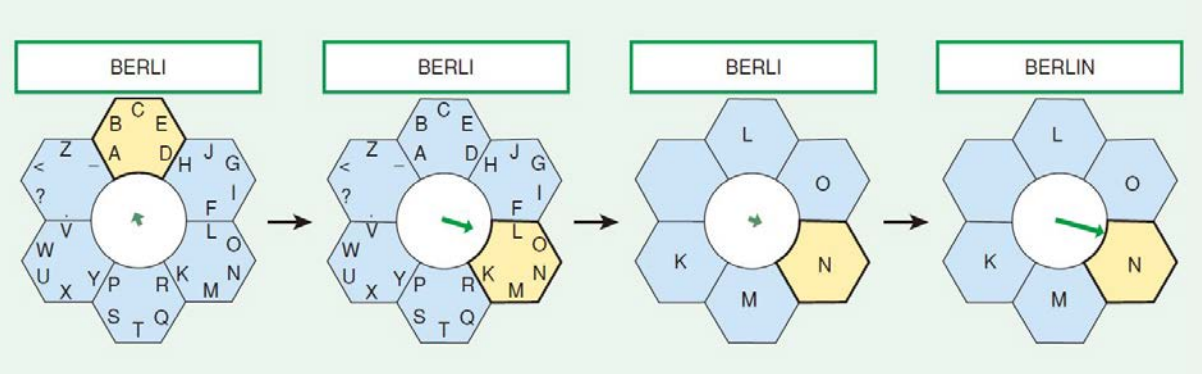

Figure 3. The Hex-o-Spell [48]

Their application show that information extracted from one brain using EEG can be transmitted to another brain using TMS to allow two persons to solve a task via direct brain-to-brain transfer of information as shown in figure 4 [49]. This application was intended that the two users could solve a task by transmitting a signal from one brain to the other.

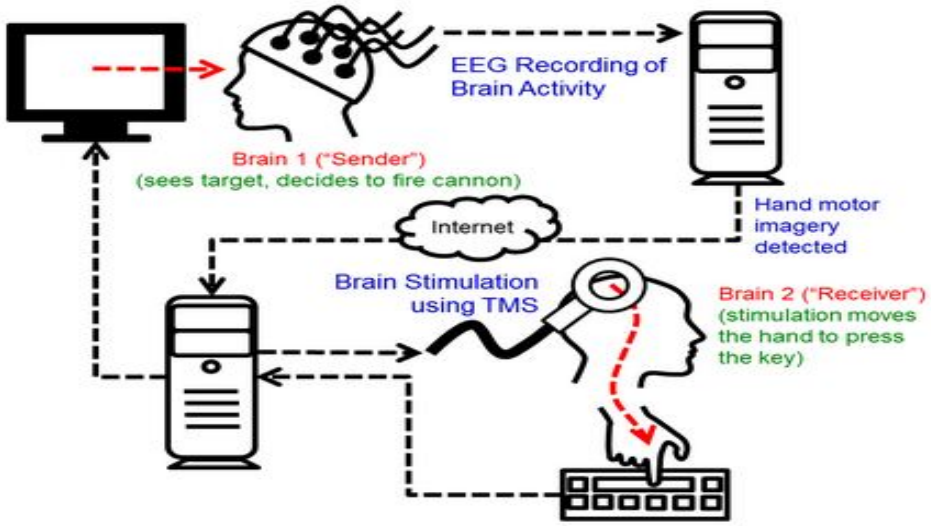

Figure 4. The Experimental Set-Up to communicate [49]

4.2 Applications of wireless BCI systems in daily life

The lives of human have changed since the rise of science technology. They have changed human life styles. Thanks this advancement, many people now live better lives. They did accustom them to their surroundings and pursue convenient lives. BCI systems provide users with communication and control using only brain activity so that they do not need to use their hands. Traditional wired BCI systems have disadvantages. The acquisition part of wired BCI systems generally comes with bulky, heavy amplifiers and preprocessing units. These limit user movement. These restrictions have severely limited the types of applications for which these systems can be made useful. Portability is thus much improved. Researchers have been able to make real-time applications with portable wireless BCI systems.

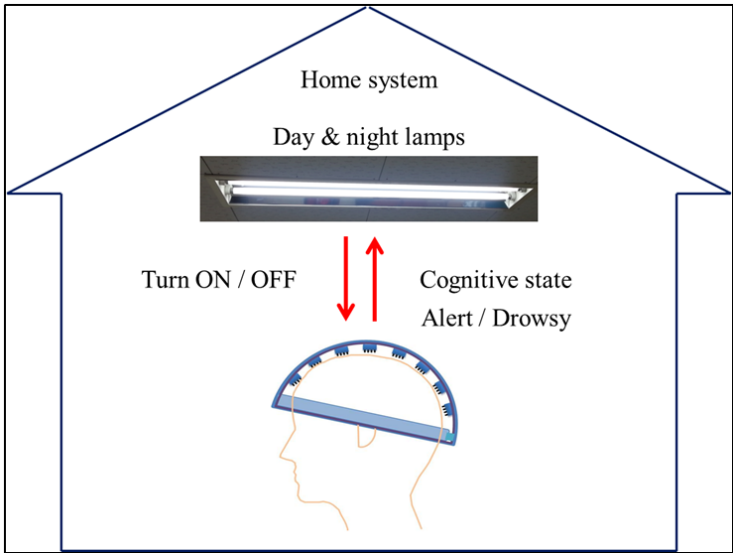

Figure 5. Wireless BCI based- smart living environmental auto-adjustment control system.

4.2.1 Home Appliances Control System

Many environmental control systems have been proposed to improve human quality of life. They integrated the BCI technique with universal plug and play (UPnP) home networking for smart house

applications. The result was a BCI-based, smart living, environmental auto-adjustment control system (BSLEACS) as shown in Figure 5. This system has the advantages of low power consumption and that the modules occupy a small volume. These advantages are suitable for smart house applications in daily life. Most of the current BCI-based environmental control systems, require many EEG channels to extract sufficient features and are inconvenient because a bulky and expensive EEG device, and computers, are required for acquisition of the physiological signals and backend analysis. This will, therefore, limit the flexibility, portability, and practicality of these systems. In contrast, the BSLEACS needs only a single EEG channel to recognize the subject's cognitive state. Then they can control electric home system based on changes in this state. This system helps ordinary people have more convenient lives.

4.3 Applications of wireless BCI systems in entertainments

Nowadays, many people think hobbies are very important. Hobbies may allow people to improve their personalities, step away from their work worlds, and to express their creative talents. For this reason, most people have hobbies, though tastes differ. The growth of the digital game industry attests to the fact that many people play games in their free time. People are conscious of the importance of the game industry. For this reason, BCI researchers and BCI companies have developed applications for entertainment. They have made game applications based on wireless BCI systems. The new wireless systems have features such as freedom in the user's posture and simple installation. These features make the games easier to enjoy. We found that several research groups have made wireless BCI applications for entertainment including: archery games [30] and video games [36]. There are also commercial companies. The three most famous of these systems are EPOC of the Emotiv Corporation, Mindset of the Neurosky Company, and DSI 10/20 of the Quasar Company.

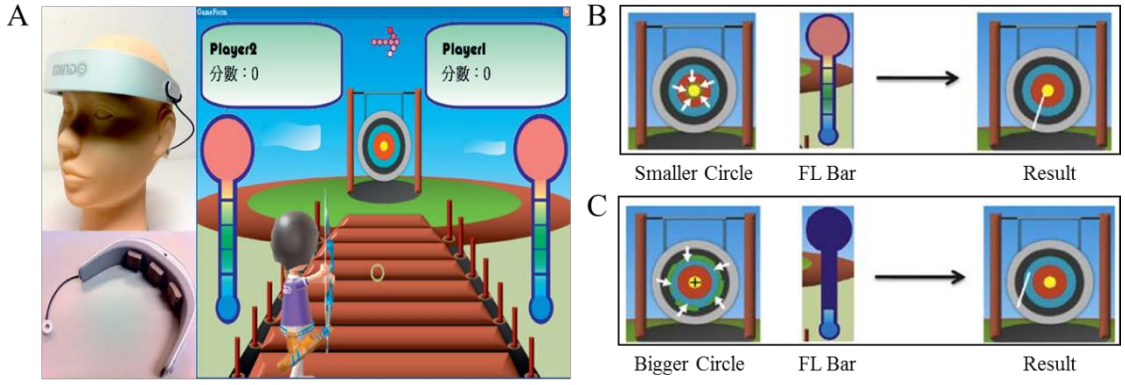

Figure 6. (A) The interface for the EEG-based BCI archery game. The visualized gaming results (Focusing level (FL) values) for lower and higher FL values are shown in (B) and (C), respectively [30].

4.3.1 Archery Game of Wireless BCI Systems

The proposed game is controlled by users via a mental focusing. The feature uses the EEG signal to demonstrate the performance of a wireless BCI entertainment device with dry sensors. Furthermore, as shown in Figure 6 (A), the FL bar on the right side of the screen indicates the level of mental focus of the user. If the FL is high, then the arrow hits near the center of the mark, and the player gets a high score. When the FL is low, then the arrow fails to hit the center of the mark, and the player gets a low score. The FL score really does depend on mental concentration; the game is based on cognitive state. In addition to the game of archery, users can be trained to improve their mental concentration using this game.

4.3.2 Wireless BCIs of Commercial Companies

Over the past years, achievements in research of both BCI and neurosciences generally, have been made. These achievements have helped stimulate the interest of the general population. Due to improvements in wireless BCI systems, bulky wired BCI systems have been replaced with portable, wearable devices. Because of these circumstances, commercial companies have advanced system devices and pioneered important new markets for wireless BCI systems. They have released portable and wearable wireless EEG acquisition systems with interesting new entertainment applications. We now aim to compare the aforementioned three commercial wireless systems, the EPOC, the Mindset, and the DSI 10/20, the pictures of the three systems shown in Figure 7. Table 1 indicates characteristics of them.

Emotiv Corporation is selling a wireless BCI system: the EPOC, EEG neuroheadset shown in Figure 7 (A). The EPOC, EEG headsets are a multi-channel wireless BCI system for consumer use. This headset is equipped with 14 saline-based wet-contact resistive electrodes for measuring EEG, EOG, and facial EMG. The users also can access BCI systems using PC, and smart phone. Emotiv has provided users with a variety of applications such as games, and research and development tools, for detecting emotions and monitoring EEG signals, either free or charged for.

The Neurosky Company is another manufacturer of wireless BCI technologies for consumer products. It develops some products independently, such as the Mindset and the Mindwave in Figure 7 (B). The Mindset is a wireless BCI headset with an EEG signal acquisition unit. It is equipped with earphones and a microphone, and measures the EEG signal of the user using a dry electrode on the

user's forehead. We found that they used only a single dry electrode on the forehead in creating their products, and this generally allows only the alpha and beta waves to be seen. Different brain states are the result of different patterns of neural interaction. These patterns lead to waves characterized by different amplitudes and frequencies. For example, waves between 12 and 30 hertz (Beta Waves), are associated with concentration, while waves between 8 and 12 hertz (Alpha Waves), are associated with relaxation and a state of mental calm. In the current environment, Neurosky Company focuses on products to train the mind and improve concentration.

The Quasar Company commercialized its wireless BCI system using dry electrodes. These are defined as those that do not require the use of conductive gels or glues for installation. The company also has technologies for non-invasive dry bioelectric measurement and monitoring. Figure 7 (C), DSI 10/20, is the most representative wireless BCI system of Quasar. It has some applications: detection of neurotoxic effects, integrated adaptive assistance for Unmanned Aerial Vehicle (UAV) control and related applications, and real-time bio-sensors. Quasar applications are currently used in adapting technical skills rather than for general life. Integrated adaptive assistance system improves UAV mission performance by reducing the cognitive workload of operators. This technology could be applied to various entertainment applications. The company expects to create more entertainment applications in the near future.

Figure 7. (A) EPOC system [34], (B) Mindset [35], and (C) DSI 10/20 [50].

Company	Emotiv	Neurosky	Quasar
Product	EPOC fig 7 (A)	Mindset fig 7 (B)	DSI 10/20 fig 7 (C)
Electrode type	Wet	Dry	Dry
Style	Headset	Headset	Brain cap
Channel number	14 channel	1 channel	21 channel
Processing unit	PC, Smart phone	PC, laptop	PC, laptop
Transmission protocol	RF	Bluetooth	Bluetooth
Game app	O	O	X
EEG monitoring app	O	O	O
Mind control app	O	O	X
EEG & Eye-Tracking app	X	X	O

Table 1. Comparison of Wireless BCI systems in commercial companies.

5 Proposed wireless BCI system

Our dry electrodes consist of six probes of spring loaded type. This structure provides flexibility between the sensor and the irregular scalp surface. The probes are easy to touch with the user's scalp through the hairs. For these reasons, preparation is not needed in their installation process. The proposed electrodes provide both a convenience of installation and an appropriate adhesion to acquire higher EEG signals. Figure 8 is the proposed electrode.

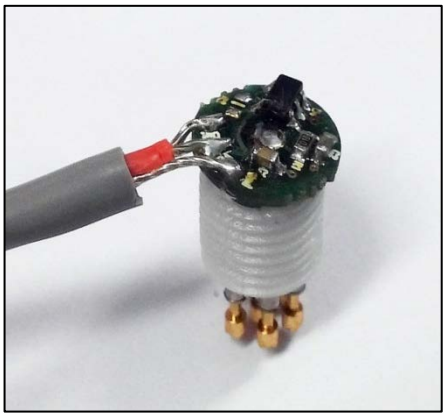

Figure 8. Proposed electrode for wireless BCI system

6 Methods

We explain the application for wireless BCI system to communicate with people. Many researchers think importance of BCI applications. They are used in certain patients or general people of diverse fields such as medical engineering, entertainment and daily life. We are making wireless BCI systems. Therefore, we develop the application to communication with people using the Mindwave (wireless BCI system) of Neurosky company. The Mindwave consists of the one dry electrode so this system has restricted to measure brain signal. However, we can communicate with people using the attention and meditation level of the Mindwave.

6.1 MindWave of Neurosky

The Neurosky Mind Set is a wireless headset added with an EEG signal acquisition unit. This headset is equipped with earphones and a microphone. They measure the EEG signals of user using a single dry-contact electrode on their forehead. Along with the capability of raw EEG recording, the Mind Set has the patented algorithm, named as eSense. This algorithm interprets the user's mental states such as attention and meditation. These translations are estimated by monitoring the power levels in specific frequency bands such as alpha, beta and theta rhythms. The monitoring values of the brain state are used to make a control signal in applications.

MyndPlay Brainband and PLX devices XWave headset utilizes the ThinkGear Application-Specific Integrated Circuit (ASIC) module. This module of Neurosky is a system-on-chip integrated circuit equipped with signal acquisition components. These devices come in a headset style. They have

supported the control of various applications such as media player and cognitive state visualization for smart phone. [35]

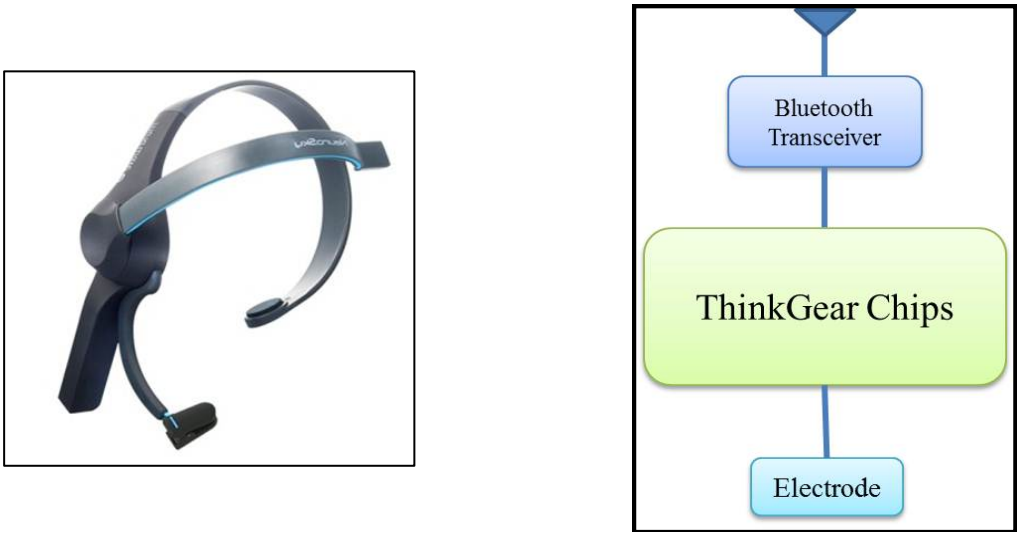

Figure 9. NeuroSky and their system block diagram

6.2 Motivation

A BCI transforms brain activity into computer commands. This type of system allows people to communicate through direct measurements of brain activity. The modulation of brain signals can be recorded from the scalp using EEG.

In this thesis, we focus on the non-invasive BCI systems allowing communication through vibration. There are spelling applications to communicate in BCI system field. Also, the spelling is the main application in interfaces. Spelling can indeed enable the physically face up to make many activities.

However, communication application using the smartphone vibration is not existed in BCI technology. We proposed wireless BCI application to communicate with people. Therefore, it can improve their quality of life and can allow them more independence. This independence can be translated into social cost reduction. Besides, disabled people who can communicate could work and get a more rewarding place in society.

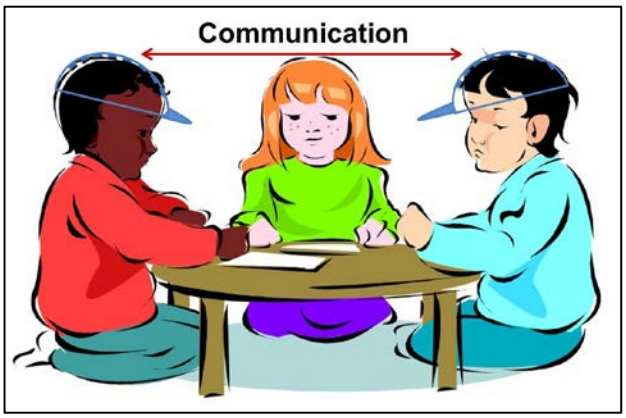

Figure 10. Motive of communication application

This figure is EEG-based communication application for wireless BCI system. Now, we described communication application. In this figure, there are 3 persons. Let is Jacob, Michael, and Emily. They communicate only 2 persons; Jacob and Michael. In this situation, Jacob and Michael wear the wireless BCI system. They can communicate. However, Emily can′t communicate with Jacob and Michael.

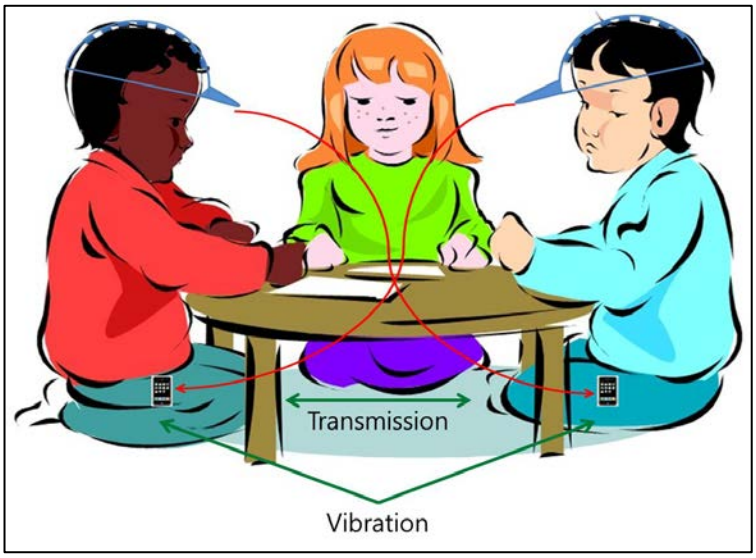

Figure 11. Communication application

6.3 System Block diagram

The system architecture of communication application, as shown in figure, mainly consists of four parts: 1) wireless physiological signal acquisition module; 2) signal processing module in smart phone; 3) phone control system; 4) phone vibration module. Here, the wireless physiological signal acquisition module uses the Mindwave of commercial system. This module is designed to acquire and transmit an EEG signal to the signal processing module in smart phone wirelessly via Bluetooth. Bluetooth provides a short range wireless and secure communication between devices to eliminate the need for messy cables. By using the encryption function in the security procedures of Bluetooth, it will translate the transmitted data into secret code to avoid the contents being eavesdropped. The signal processing module is designed to estimate the user's cognitive state from his or her EEG, and provides the estimated cognitive state to the phone control system. The phone control system is designed for data storage/display, and is also served as control to manage the request from control device as well as the phone vibration control, which is used to control communication, such as yes and no response.

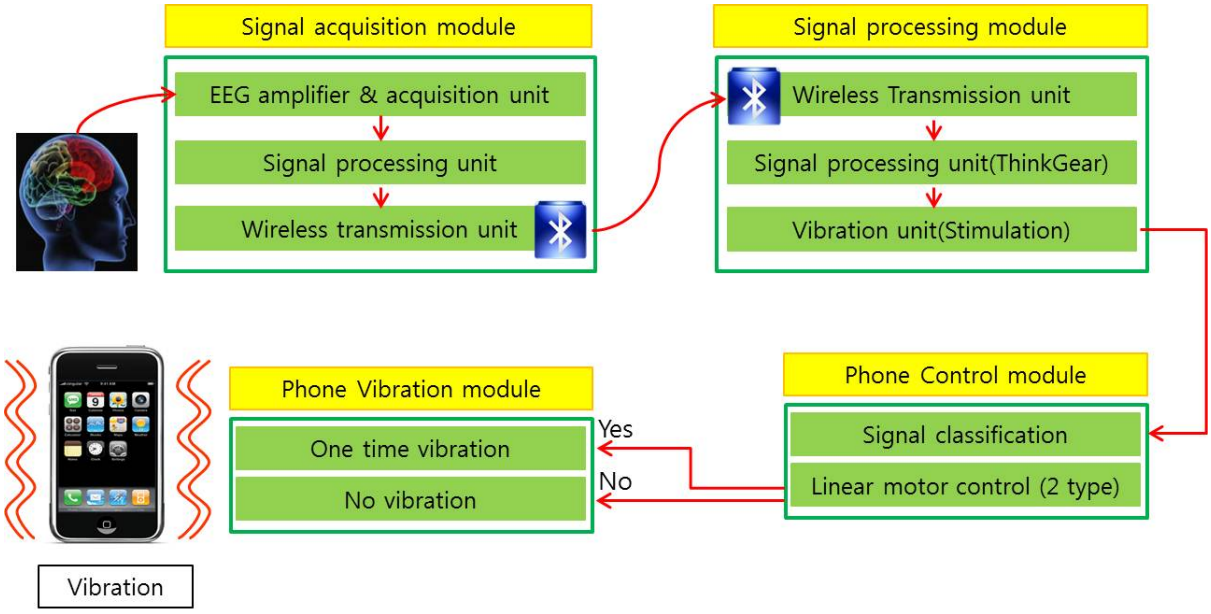

Figure 12. System Block diagram of communication application

7 Results

This is phone screens of wireless BCI system based communication application shown in the figure 13 and 14. This is the screen of application. We can show the attention level in the first bar, meditation level in the second bar, signal level in the third bar, and power level in the fourth bar. User push the connect button then, generated signal level. When the signal level of this application is full, then wireless BCI system is connected to the smartphone via Bluetooth. After wireless BCI system connects to the smartphone, attention change following the mental states of human. The Attention level depends on concentration state of people. Therefore, we set up the attention level at every time. When the attention level becomes over the threshold level, the system generates the power signal. We set up the threshold power level seventy. When power level is bigger than seventy, smartphone vibrate one time. Power is important to operate the vibration. The power is defined as shown in equations:

$$\text{Power\_}Percent = \frac{((100-Setting\_Attention)-(100-Attention\_Level))}{(100-Setting\_Attention)} \quad (1)$$

$$\text{Power\_}level = Minpower + (Maxpower - Minpower) \times Power\_Percent \quad (2)$$

We set up the minimum power, maximum power, and setting_attention value. We set the parameter such as Minpower=0, Maxpower=100, Setting_Attention= Value (0~100), and Power level > 70.

Figure 13. Communication application screen

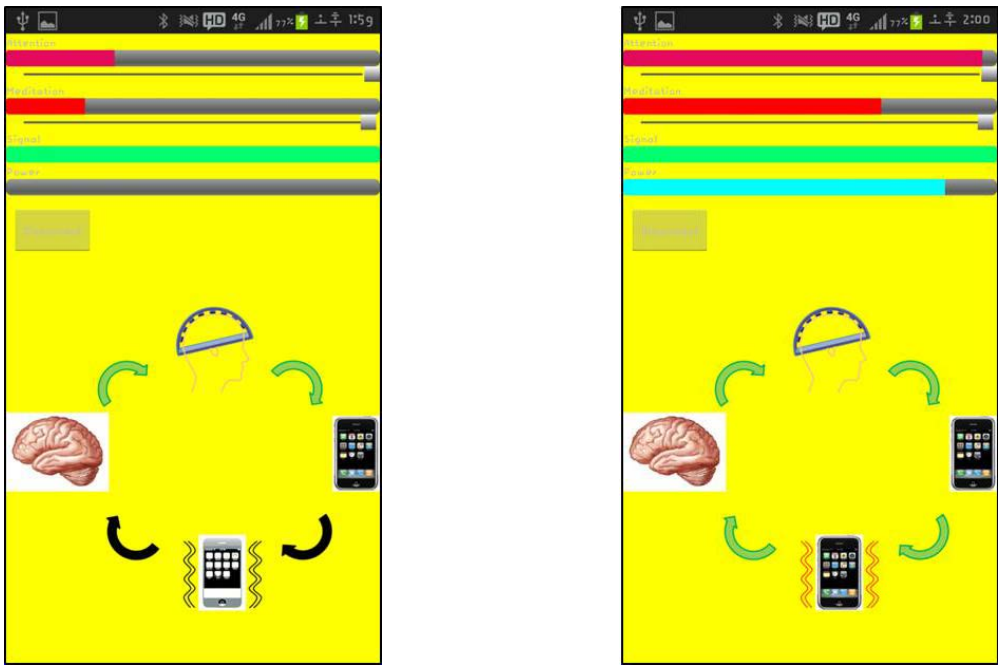

Figure 14. Communication application screen

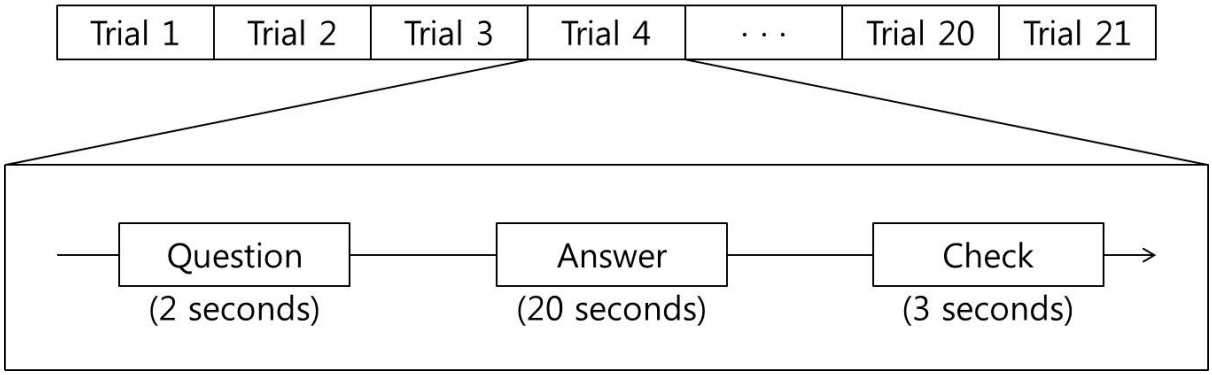

Figure 15. Schematic representation of survey experiment

We experiment Yes or No test to evaluate performance of our application. Five users participated in psychological test experiment as shown in figure 15. Psychological test consists of 21 questions. For example, question is “do you like black”, “do you smoke”, and so on. Each of tests takes 20 seconds. The Electrode located on the user′s forehead. Subjects responded Yes or No. When subjects tell the yes, smartphone vibrate one time. This is accuracy of communication application. Total accuracy is 68.6% accuracy is low as shown in table 2. However, we can see potential in the experiment for developing the communication application.

	Gender	Age(yrs.)	Total	Correct	False	Accuracy
Subject 1	Male	23	21	12	9	57.1%
Subject 2	Male	27	21	15	6	71.4%
Subject 3	Male	25	21	19	1	90.4%
Subject 4	Male	25	21	14	7	66.7%
Subject 5	Male	25	21	12	9	57.1%
Total		25	105	72	33	68.6%

Table 2. Result of Psychological test.

8 Conclude

We proposed the application of wireless BCI system for communication with people. However, our application has limitations. 68.6% accuracy of this application is low. Communication types are simple (Yes or No). This application has limitation caused by accuracy and signal quality. We will apply classification algorithm such as LDA and SVM. We will expand the communication types.

New applications are being created to utilize them. These new applications have the potential to improving quality of human life, and will likely come to serve people for a wide variety of purposes. Currently wireless BCI systems have limitations: 1) It is difficult to guarantee high EEG signals because of noise sources such as power line noise and other physiological signals, 2) It is difficult to increase information transfer rate of BCI.

Users will be able to wear BCI systems and use these applications to control medical devices and many other machines with these problems solved. Wireless BCI systems still have many limitations as noted previous paragraph. However the quality of wireless BCI systems is improved continuously via innovative research.

9 Discussion

We have explained applications of wireless BCI systems which have been advanced for consumers and research. They have been applied for medical and entertainment applications. Many research groups are making continuous efforts to improve newer wireless BCI systems that are easy to wear and more accurate in reading thoughts. Researchers are aiming to make new applications. Some applications will be continuously designed for the handicapped and disabled people in rehabilitation medicine and medical engineering.

We aim to discuss the limitations of wireless BCI systems. Wireless BCI systems have some problems, including 1) insufficiency in features controllable by EEG signals, and 2) deficiency in accuracy of EEG signal interpretation.

The potential of BCI systems utilizing EEG signals for controlling applications is limited. The limited dimension of EEG signals does not offer much expansion in control. Many BCI systems have utilized EEG signals to determine the user's cognitive states. The users can control an application utilizing the measured cognitive states generated by the intentions of the user. This simplicity in control comes with a short learning curve for adapting to the program. However, the applications to which BCI systems can be used are restricted as well due to low degree in control. Some groups are aimed at the progress of other feature types.

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11 Acknowledgement

어떤 사람에게는 2년이란 시간은 길다고 합니다. 그들은 2년이란 시간 동안에 못할 것이 없다고들 합니다. 하지만 내게 2년이란 시간은 결코 긴 시간이 아니었습니다. 지금 생각해보면 처음 학교에 왔을 때부터 지금까지 주마등처럼 지나갑니다. 그 시간 동안 연구실사람들과의 추억, 새로운 깨달음, 새로운 만남도 있었습니다.

대학원에 와서 연구를 하면서 새로운 사실도 알게 되었고 뜻있는 일들이 많았습니다. 돌이켜 보면 석사과정 동안에 참으로 많은 일들이 있었습니다. 나에게 있어서 힘든 일도 있었지만 기분 좋은 일들이 더 많았던 것 같습니다.

연구를 하면서 많은 사람들이 도움과 격려를 받았습니다. 책 작업을 하면서 정말 고생을 많이 하시고 부족한 저를 열정으로 가르쳐주신 이흥노 교수님께 감사 드립니다. 또한 논문 심사위원으로 도와주신 전성찬 교수님과 이보름 교수님께도 감사드립니다.

그 밖에도 INFONET 연구실의 구성원에게 너무 감사합니다. 연구실 맏형인 진택이형, 환철이형, 힘들 때 많은 위로를 해준 웅비형, 같은 BCI연구를 했던 영학이형, 승찬이형, 내 동기인 형호형, 주성이, 종목이, 해웅이 등 너무 감사한 마음을 드립니다. 이 밖에도 많은 사람들께 감사의 인사를 드립니다.