Review of Application for wireless Brain Computer Interface (BCI) systems

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ABSTRACT

We would like to contribute a chapter in a book on the applications of wireless Brain-Computer Interface (BCI) systems. In this chapter, we aim to review the trends in research for wireless BCI systems, as well as their current and anticipated applications. Wireless BCI systems have the clear advantages that they are simple, convenient, mobile, and flexible. Recent wireless BCI applications attempt to help people live more conveniently in many areas: entertainment, games, medical engineering, rehabilitation, and daily life. This chapter will be divided into the following eight subchapters: Introduction, Background, Recent research of wireless BCI systems, Applications of wireless BCI systems in daily life, medical engineering, and entertainment, Future research directions, and Conclusion.

I. INTRODUCTION

Over the past couple of decades, the study of brain-computer interfaces (BCI) has grown into a rich and diverse field, the critical goal of which is to allow operation of various devices. The BCI transmitter sends command signals to the receiver of a specific application. The target application then converts these signals into commands that cause movements of a target device. The more BCI has been used for a widening variety of such applications, the more its importance has grown. The initial applications have mostly been aimed at helping disabled people utilize machines, including robots, wheelchairs, smart TVs, computers, and home appliances. These days, many researchers think that wireless BCI systems are a very important step toward getting BCI applications out of laboratories.

This chapter focuses primarily on applications of wireless BCI systems, and introduces existing BCI wireless systems for applications in areas including entertainment, biomedical engineering, and daily life. Past researchers created wired BCI system applications to diagnose disease (Boyd et al., 1988). Researchers currently make wireless BCI applications that help people live more convenient lives. These applications are able to offer improvements in entertainment, 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. Finally, we will discuss future applications of, and anticipate the limitations of, such wireless BCI systems.

II. Background

BCI systems provide a communication and control channel between the user's brain and an external device, such as a computer or prosthetic device. Electroencephalogram (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 sophisticated signal processing procedures. Hundreds of research laboratories and companies around the world are currently focused on BCI research and performance. Some examples of EEG-based applications include the control of cursors (Wolpaw et al., 1991; 2003; Kostov et al., 2000), wheelchairs (Vanacker et al., 2007; Luth et al., 2007; Rebsamen et al., 2007; Iturrate et al., 2009), robots (Tonin 2009; 2010), typing skills for communication (Cass and Polich, 1997; Covington and Polich, 1996; Sugg and Polich, 1995; Vesco and Bone, 1993), and diagnosis of disease (Gotlib et al., 1998; Pfurtscheller et al., 2003; Hebert et al., 2004; Dauwels et al., 2010; Elgendi et al., 2011; D'Arcy et al., 2011).

However, many of these conventional BCI systems have disadvantages related to using wired BCI systems. These BCI systems have data acquisition parts composed of huge, weighty amplifiers and preprocessing units. These systems consist of the wet electrodes with conductive gels or glues. The use of wet electrodes makes users feel drowsy and tired and require a long time to prepare.

Recent research has also focused on wireless BCI systems and applications using dry electrodes. Dry electrodes are able to replace electrodes that must be covered with conductive gel, another change allowing EEG-based applications to escape laboratories. Given these and other benefits, many researchers are making useful and diverse applications for people using wireless

BCI systems. Some examples include cellphone-based BCI for communication (Wang et al., 2011), control of smart homes (Lin et al., 2012), control of robots (Lin et al., 2012), control of wheelchairs (Lamti et al., 2012; Carrino et al., 2012; Gentiletti et al., 2009), and interesting games (Emotiv Corporation; Neurosky Company; Matthews et al., 2012; Liao et al., 2012).

Future applications of wireless BCI systems could provide more convenient lives for all people, as well as medical diagnostic instruments for the handicapped. This chapter is focused on recent research about wireless BCI systems, and about current and future applications of wireless BCI system in daily life, medical engineering, and entertainment.

III. RECENT RESEARCH OF WIRELESS BCI SYSTEMS

Unlike wired BCI systems, the wireless systems are designed to provide convenience in monitoring the neurophysiological signals of users. Wireless BCI systems provide enhanced portability and wearability. Wireless BCI systems eliminate the wires connecting the wearable acquisition unit and the translation unit. The translation unit is usually housed in a portable device such as a notepad or smart phone. This improvement provides ease of installation and postural freedom for users. Furthermore, owing to advanced integrated circuit designs, the components of wireless BCI systems are small and efficient in power consumption. These advantages allow wireless BCI systems to be shaped into user friendly interface devices such as baseball caps (Lin et al., 2008; Sullivan et al., 2008), headsets (Liao et al. 2012; Brown et al., 2010; Xu et al., 2011; Zander et al., 2011), and headbands (Lin et al., 2008 and 2010; Wang et al., 2011; Liao et al., 2010). People can easy wearing the wireless BCI systems of these styles.

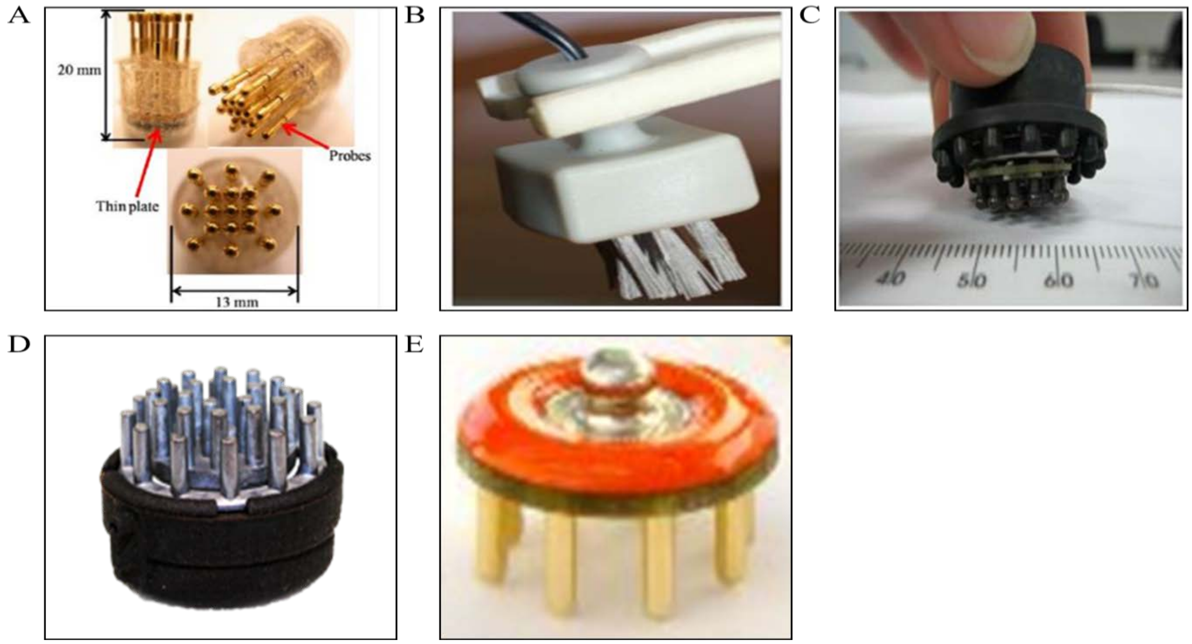

Figure 1 (A) a spring-loaded dry electrode (Liao et al., 2011) (B) a bristle-type dry electrode (Grozea1 et al., 2011) (C) the QUASAR hybrid EEG biosensor (Matthews et al., 2007) (D) the QUASAR's dry electrode (QUASR Company) (E) Gtec's dry electrode (Guger Technologies).

A. *Issues of wireless BCI systems*

Wireless BCI systems still have issues that need to be resolved, including better signal quality, and more comfortable designs. The quality of the measured EEG signals has to be improved for more precise classification of signals. As EEG signals are measured, they can easily be contaminated by various noise sources (e.g., other physiological signals, power line noise). This contamination interferes with signal measurements by causing strong leakage currents and contact impedances.

B. *Electrodes of wireless BCI systems*

The most important current challenge regarding EEG electrodes is measuring brain signals precisely with low noise. Generally, the signal acquisition part of wireless BCI system, contains only a signal acquisition module and a simple embedded system for transmission of the measured signals. To provide acquisition of clear EEG signals at the interface between electrode and skin, advances in electrodes has become a critical issue. For this reason, many research groups have recently worked at developing advanced electrodes that are both comfortable and able to achieve low-noise recording of the EEG.

In conventional wired BCI systems, passive electrodes are widely used to measure EEG signals. However, extra treatments are essential to record reliable EEG signals because scalp potentials are only on the order of several micro-volts, and thus very noise-sensitive. These treatments include a hair preparation step, and the use of conductive gels or glues for better attachment and higher conductivity. These preparations cause discomfort and require a long time to prepare. Therefore, long-term monitoring of EEG signals using passive electrodes is not feasible. Recently, researchers have used more advanced electrodes called "dry electrodes" to overcome these issues.

Dry electrodes are defined as those that do not require the use of conductive gels or glues for installation. Users can conveniently attach the electrodes to their scalp without any hair preparation. Special materials and shapes are employed in the design of dry electrodes to make effective, dry contact at the electrode-skin interface. Research has produced a huge variety of electrode materials and structures, including micro-machined structures (Sullivan et al., 2008; Chiou et al., 2006; Lin et al., 2010), non-contact types (Sullivan et al., 2007; Chi et al., 2012), spring-loaded fingers (Liao et al., 2011; Matthews et al., 2008), bristle structures (Grozea1 et al., 2011), and conductive foams (Liao et al., 2012) as shown in Figure 1.

C. Dry Active electrodes

While we can reduce installation time significantly using dry electrodes, the contact impedance between the scalp and the electrodes is higher than with gel-based passive electrodes due to the absence of conductive gels. Thus, the signal quality of dry electrodes is worse than that of the gel-based passive electrodes because of this problem with increased impedance.

To solve the problem, some research groups have focused on active electrodes to overcome this drawback. Active dry electrodes contain amplifiers or buffer circuits integrated into the electrodes themselves (Ruffini et al., 2004; Sullivan et al., 2007; Chi et al., 2012; Ruffini et al., 2007; Matthews et al., 2007, 2008). These amplifiers or buffer circuits are located between the electrodes and the signal acquisition front-end. They are aimed at impedance conversion. By providing high input impedance on the electrode-amplifier interface, active circuits reduce the distortion of the measured signals. This is desirable for active dry electrodes which do not use conductive fluids. Also, the low output impedance of the amplifier eliminates artifacts caused by posture changes in mobile environments. Therefore, the use of active electrodes allows optimal quality of the physiological signals measured. Recent wireless BCI systems are equipped with active dry electrodes to combine the advantages of active and dry electrodes. Since these electrodes provide more robust and stable signal quality in mobile environments, they are suitable for wireless BCI systems.

D. Wireless BCI systems Design

Regarding the appearance of the systems designed, a variety of designs has been adopted depending on the purpose of the applications and the users targeted. Widely used devices for the acquisition part of wireless BCI systems include headsets, head bands, and baseball caps. In designing the appearance of wireless BCI systems, we need to consider factors such as materials, stability, and convenience of installation. To provide long-term monitoring capability, the wearable parts of wireless BCI systems have to be light and comfortable. Also, convenient installation is necessary to save time in the set up process. Appropriate pressures holding the electrodes to the skin surface, are also needed to maintain stable electrode positions and low impedance at the sensor-skin interfaces. Additionally, to allow for the diversity of users' head sizes, the materials used in wireless BCI systems should be flexible, or size adjusters must be added.

IV. APPLICATION OF WIRELESS BCI SYSTEMS IN DAILY LIFE

The lives of people have completely changed since the rise of modern science and technology. They have changed human life styles, physical appearance, workspaces, and homes, among other things. 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. Wired BCI systems come with bulky, heavy amplifiers and preprocessing units. These limit user movement, so that it is difficult to apply wired BCI technology outside the laboratory. These restrictions have severely limited the types of applications for which these systems can be made useful. This makes clear the advantages of the newer, wireless BCI systems that replace wires and connections with wireless transmission modules (e.g., Bluetooth or zigbee). Portability is thus much improved. With portable wireless BCI systems, researchers have been able to make real-time applications. In the past, the focus of wired BCI applications has been on medical engineering. Recently, applications have been developed to make daily life more convenient. For example, subjects can control home appliances and devices using a wireless BCI system. There have been a number of specific applications of wireless BCI for daily life, including cell-phone based BCI for communication (Wang et al., 2011), a smart living environmental auto-adjustment control system (Lin et al., 2012), robot control (Lin et al., 2012), real-time speech synthesis (Bryan et al., 2012), and recording brain waves at the market (Sands and Sands, 2012).

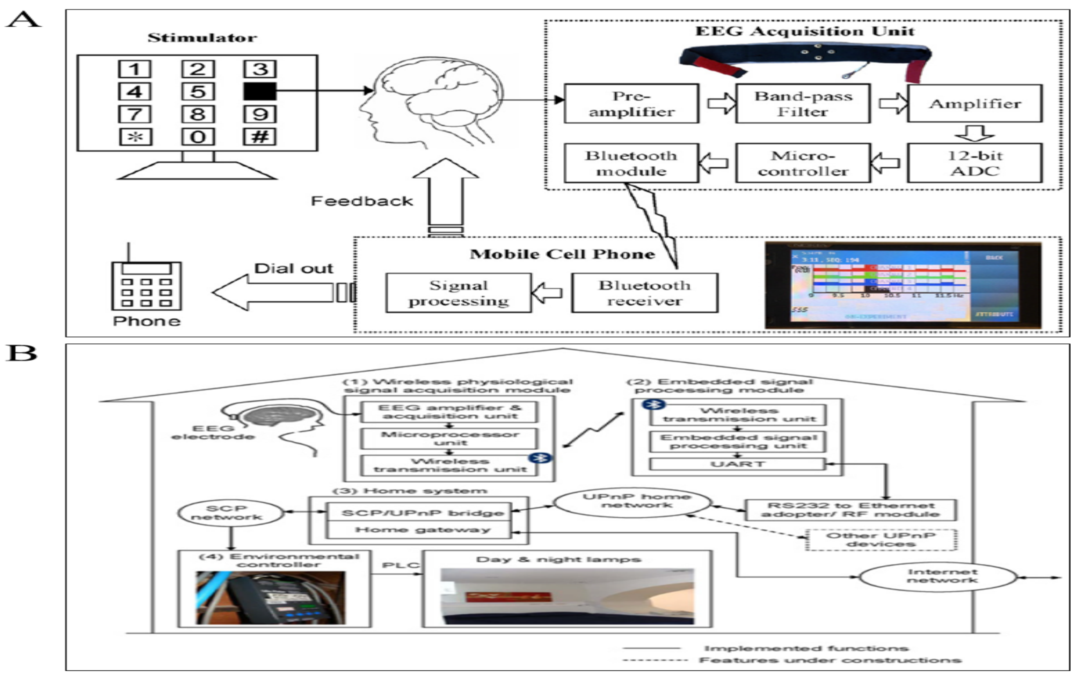

Figure 2 (A) Diagram of the cell phone based, BCI for communication (Wang et al., 2011), (B) System architecture of wireless BCI based- smart living environmental auto-adjustment control system (Lin et al., 2012).

A. *Cellphone Application Based on wireless BCI*

Although EEG based BCI systems have already been studied for several decades, moving a BCI system from a laboratory demonstration to real-life applications still poses severe challenges to the BCI community (Wang et al., 2009). In this paper, the cellphone-based BCI application shown in Figure 2 (A) was created to demonstrate performance in real-life. Many current wireless BCI demonstrations can be realized on cell phones now, and numerous new applications could emerge using this cell phone approach. This concept was incorporated into a system that consists of a four-channel bio-signal acquisition/amplification module, a wireless transmission module and a Bluetooth-enabled cell phone. To operate the system, a steady-state visual evoked potential (SSVEP) based BCI, recognized for ease of use, little need for training and high information transfer rate (ITR), was employed in the test paradigm. The acquired EEG data were sent by Bluetooth transmitter to a regular cell phone. Advances in mobile phone technology allow newer phones to become convenient platforms for real-time processing data such as EEGs.

B. Smart living Environmental Control system

Recently, many environmental control systems have been proposed to improve human quality of life. Research has focused on direct environmental control using the human neurophysiological state. 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 2 (B). The BSLEACS mainly consists of a wireless physiological signal acquisition module, an embedded signal processing module, a simple control protocol and power line communication environmental controller, and a host system. 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, and can then control electric home appliances based on changes in this state. This system helps ordinary people have more convenient lives.

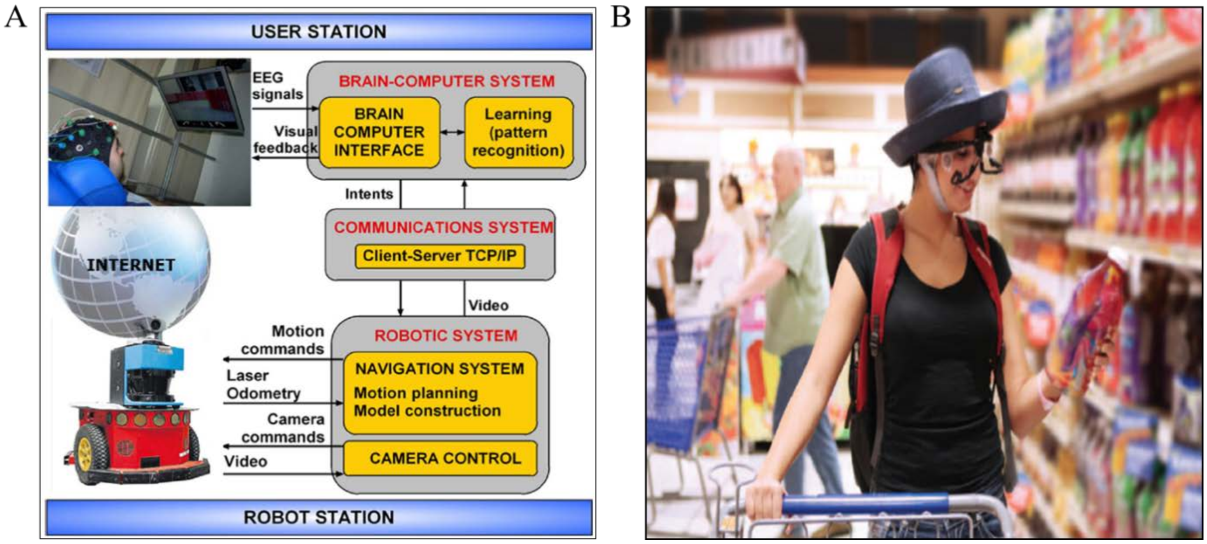

Figure 3 (A) Design of the robotic telepresence system actuated by a noninvasive BCI with main modules and information flow (Lin et al., 2012), (B) The participant shops while wearing an EEG cap, with EEG amplifiers in the subject's backpack (Sands and Sands, 2012). The participant is free to move about the store unimpeded. (Photo courtesy of Sands Research, Inc.)

C. *Mobile Robot control system*

In the future people will be able to control robots using a wireless BCI system. One researcher has already made a telepresent mobile robot, controlled with a noninvasive BCI as shown in Figure 3 (A). They suggested an EEG-based brain-actuated telepresent system to provide users connected to the internet, with presence in remote environments through a mobile robot also linked to the internet. They utilized synchronous, P300-based BCI, and a mobile robot with autonomous navigation and camera orientation capabilities (Wolpaw et al., 2002; Minguez et al., 2008). The computer screen of this system displays live video sent by the robot, with information related to robot motion and camera orientation tasks. The user concentrates on the desired option on a computer screen to control the robot. This BCI system collects EEG brain activity and decodes the user's intentions using traditional P300. User's intentions are transferred to the robot via the internet. The robot independently responds to commands using a navigation system or the camera orientation system. Application of this system has disadvantages because it utilized a wired BCI system. If researchers re-created the application using wireless-BCI, people could control the robot anytime, anywhere. This could improve lives.

D. *Application for Effective Purchase*

Neuroscience, in forms such as brain waves and eye tracking, is employed in a number of scientific fields, and plays an important role in measuring the effects of communication, particularly in marketing campaigns. Traditional methods of measurement such as surveys and interviews, depend on the verbal ability of the consumer to articulate their motivations for purchasing a product. Researchers have been able to directly record brain responses in the supermarket as shown in Figure 3 (B). The EEG signal of participants was recorded during their shopping experience. Researchers used a miniaturized video recorder, EEG amplifiers, and eye tracking systems. They anticipate that this application will be useful in determining the effectiveness of marketing displays. One large advantage is that these results are occurring in actual point-of-purchase scenarios, where participants are making real monetary decisions.

E. *Speech synthesis Based on wireless BMI*

Many patients have lost the ability to speak due to accident, stroke or disease. The loss of speech not only makes communication of needs to caregivers very difficult, but also leads to profound social isolation. Several BCI systems have been proposed, using SSVEP or P300 based online communication systems (Krusienski et al., 2008; Allison et al., 2008; Wang et al., 2011). However, because they provide only slow verbal or textual output, subjects cannot have normal conversations or social interactions. One researcher took a novel approach to speech prosthesis by addressing speech motor control. The researcher can apply wireless BCI system using this application of speech synthesis.

V. APPLICATION OF WIRELESS BCI SYSTEMS IN MEDICAL ENGINEERING

Medical engineering is the application of engineering principles and design concepts to medicine and biology. In many industrialized countries, the proportion of people over 65 years of age is growing faster than any other age group because of longer life expectancy. In response to the sharply increasing number of the elderly, the medical engineering industry is growing rapidly, and furthermore, is one of the most important growth areas in the engineering sector. Among the many applications related to biomedical engineering, BCI technology starts with Hans Berger's discovery of the electrical activity of the human brain, and the subsequent development of the EEG. Since then, the study of BCI has grown dramatically. BCI systems are now used to detect cerebropathia and depression, analyze brain signals, and assist rehabilitation. There are many applications using traditional BCI systems in medical engineering. However, traditional BCI systems often cannot detect EEG signals of the patients because these systems do not have portability and mobility. These types of systems are limited to assisting rehabilitation and detecting brain disease. More recently, some researchers have been studying ways to use wireless BCI systems to reinforce the earlier wired systems. Using wireless BCI systems, devices can be controlled and data collected easily. Several research groups have made applications to control wheelchairs (Lamti et al., 2012; Carrino et al., 2012; Gentiletti et al., 2009), for drowsiness detection (Lin et al., 2010; Hung et al., 2010), Patient Monitoring System (Whitchurch et al., 2007) and diagnostic devices (Pfurtscheller et al., 2003; D'Arcy et al., 2011).

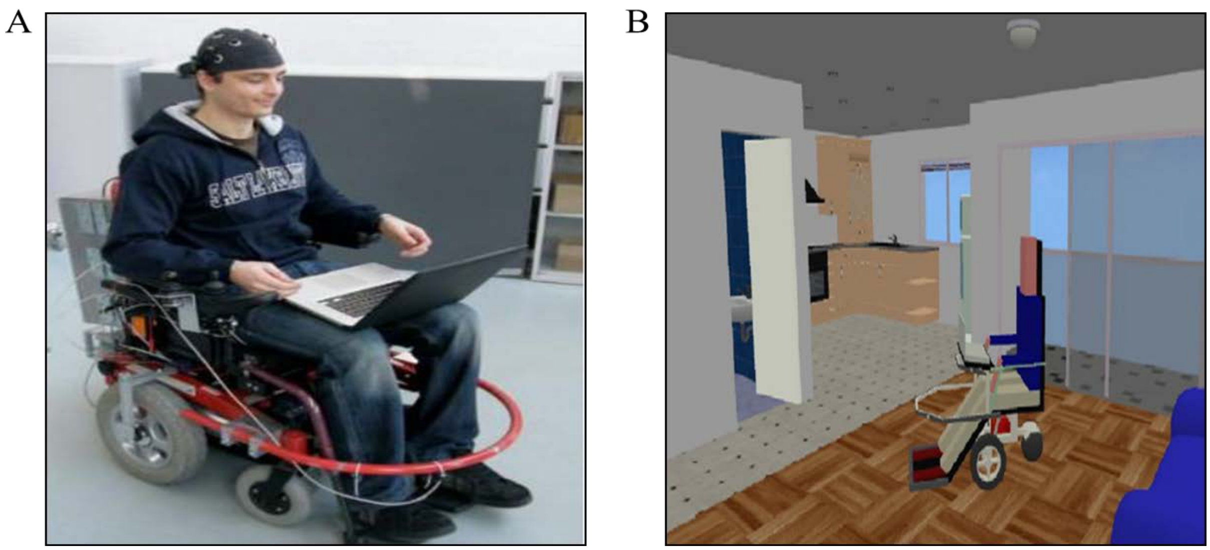

Figure 4 (A) A subject testing the system on the wheelchair (Carrino et al., 2012), (B) A picture of the simulated smart powered wheelchair (Gentiletti et al., 2009).

A. Wheelchair control system

In impressive studies by Lamti et al. (2012), Carrino et al. (2012), and Gentiletti et al. (2009), wheelchairs were controlled by the brain signals of subjects. This application is to enable disabled or elderly persons with heavily reduced physical or mental abilities, to steer powered wheelchairs when use of a conventional joystick is hardly possible. Several past BCI investigations were directed towards applications that went beyond an interface with computers (Darmanjian et al., 2003; Müller-Putz et al., 2005). However, these new BCI applications have made apparent new challenges and problems (Philips et al., 2007; Graimann et al., 2008). These groups are working to develop wireless BCI commanded wheelchair systems, using non-invasive EEG and P300 models that use an event-related-potential (ERP) component, elicited in the process of decision making or thinking. This is part of a brain-eyes based interface that can help patients with Looked-In Syndrome, and assist them by measuring their physiological status and provide brainwave profiles that indicate sleeping and waking states. They have been to create research platforms based on the well-known BCI2000 (Schalk et al., 2004) or OpenViBE (http://openvibe.inria.fr/) software. These platforms manage signal acquisition. The detected brainwaves signals then follow a preprocessing treatment. According to the user's needs, the system selects the channels of software to enable and initiate. Subjects can control the wheelchair through this process, shown in Figure 4.

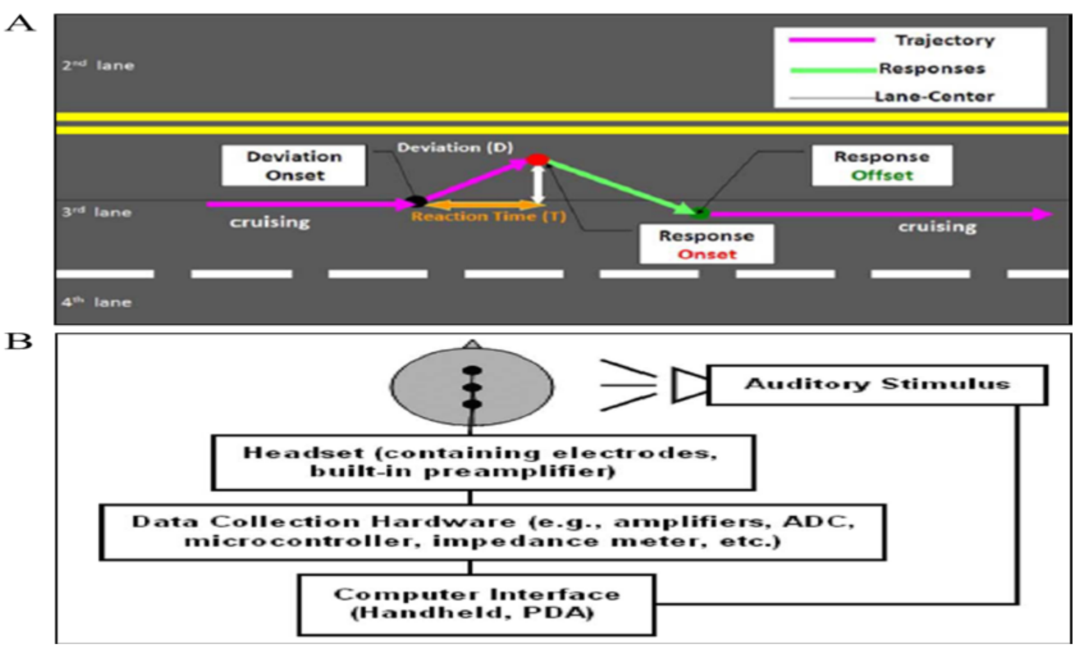

Figure 5 (A) Illustration of the driving task (Lin et al, 2010). (B) Schematic overview of the HCS. The headset contains recording electrodes and built-in preamplifier (D'Arcy et al., 2011). The data collection hardware amplifies and processes the signals before sending them to the computer. Auditory stimuli are presented via earphones and are also controlled by the computer.

B. Prevent accidents of Drivers' Drowsiness

Drowsy drivers have been implicated as a causal factor in many accidents because of the marked decline in their perception of risk and recognition of danger, as well as their diminished ability to handle their vehicles (Horne et al., 1995; Maycock, 1996, 1997; Connor et al., 2002; Brookhuis et al., 2003). Therefore, the ability to monitor drowsiness in real-time, is very important in avoidance of traffic accidents. Figure 5 (A) shows a real-time wireless BCI to detect drowsy drivers and thus prevent car accidents. The design includes wireless signal acquisition and processing modules. The acquisition module is small enough to be embedded in a wearable headband. The two modules are linked by a Bluetooth connection. This provides the advantages of mobility and long-term monitoring. These researchers have developed a real-time drowsiness detection algorithm, that functions using just three electrodes positioned over the occipital lobe. The algorithm detects the user's drowsiness by analyzing EEG signals reflecting the theta (4-7Hz) and alpha (8-11Hz) brain waves, indicating cognitive state and memory performance (Klimesch, 1999; Makeig et al., 2000; Schier, 2000). Their novel BCI system contains the advantages of small volume and low-power consumption, and is suitable for practical driving applications.

C. Diagnostic Device for conscious Awareness

According to a number of recent studies (Wimo et al., 2003; Dauwels et al., 2010; Gotlib et al., 1998; Hebert et al., 2004), the number of elderly patients suffering from brain disorders such as dementia and depression is growing rapidly. Scientists studied to diagnose brain illness. A way was found to diagnose Alzheimer's disease or depression using EEG signals. However, the main problem was that most studies used just one, or very few measures, and many of those studies analyzed different data sets. Consequently, it was difficult to rigorously compare the various measures. When an individual's brain is damaged, evaluating the level of awareness can be a major diagnostic challenge. One researcher presented a diagnostic device that addresses this problem (D'Arcy et al., 2011). Unlike traditional EEGs, the device was designed for point-of-care use by incorporating a portable, user-friendly, and stable design. Users can always monitor their own EEG signals using a smart phone anywhere, anytime. Auditory stimuli are presented to users by earphone. Quantitative data are provided for the evaluation of five identifiable levels of neural processing: attention, memory, sensation, perception, and language. The device can be applied to a wide variety of patients across a host of different environments. The technology is designed to be wireless enabled for remote monitoring and assessment capabilities.

VI. APPLICATION OF WIRELESS BCI SYSTEMS IN ENTERTAINMENT

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. The worldwide game industry is poised to reach $70.1 billion by 2015, thanks to the combined growth of console, portable, PC, and online video games, according to market researcher DFC Intelligence. 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. Unlike traditional wired BCI game 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 (Liao et al., 2012) and video games (Matthews et al., 2012). There are also commercial companies that have developed BCI systems in the form of caps and headsets using wireless technology, in a variety of applications. The three most famous of these systems are EPOC system of the Emotiv Corporation, Mindset of the Neurosky Company, and DSI 10/20 of the Quasar Company.

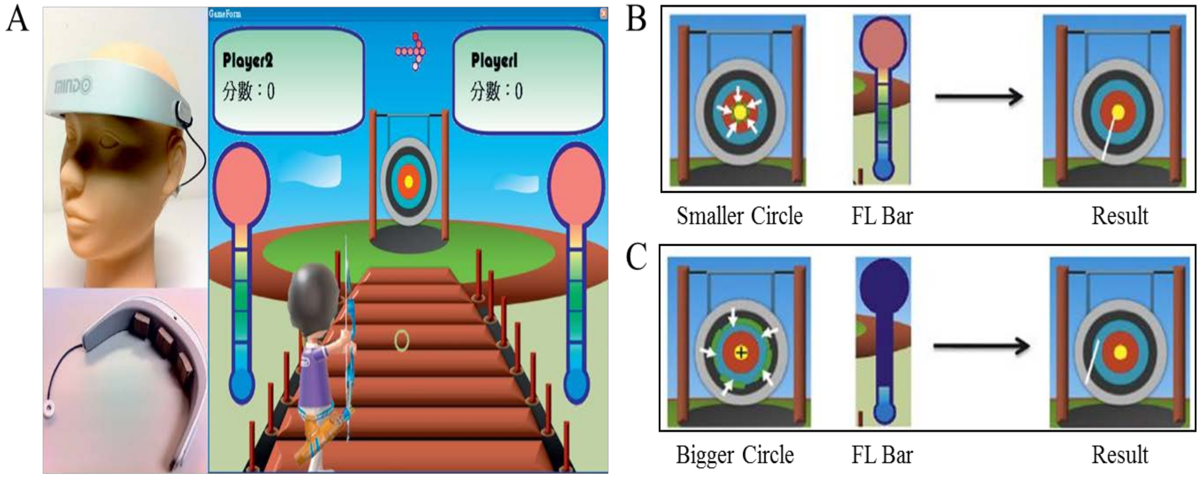

Figure 6 (A) The interface for the EEG-based BCI archery game. The visualized gaming results (Focusing level (FL) values) for lower and higher FL values are shown in (B) and (C), respectively (Liao et al., 2012).

A. *Archery Game of wireless BCI systems*

Figure 6 shows a recently published interface for an EEG-based wireless BCI archery game. The proposed computer archery game is controlled by users via a mental focusing feature. 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.

B. *Wireless BCI of Commercial Company*

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.

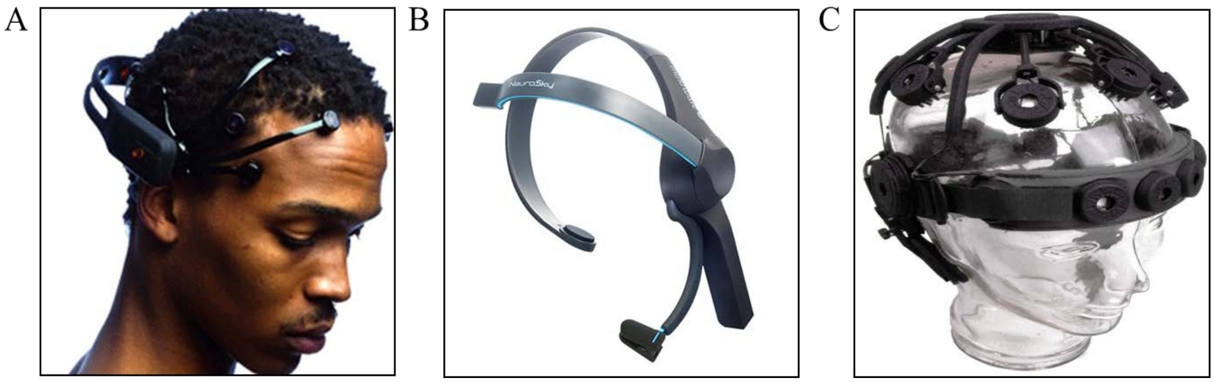

Figure 7 (A) EPOC system (Emotiv Corporation), (B) Mindset (Neurosky company), and (C) DSI 10/20 (Quasar Company).

C. *Applications of Emotiv*

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. Also, users can access BCI systems using PC, laptop, tablet, 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. In the research and development tools, there are many applications. The Control Panel provides signal processing by EEG signal algorithms, included with a tool to display EEG, FFT, Gyro, and data packets. The Brain Activity Map displays a real-time map of mental activity of users in four significant brainwave frequency bands. Emotiv offers interesting game applications that require users to use their minds or mental power. In photo applications for detecting emotions, the EmoLens leverages the power of the Emotiv EPOC headset's ability to detect emotions via facial expressions and subtle monitoring of operators mental state, to automatically index photos as operators browse them on Flickr. These various applications in entertainment help consumers to enjoy the special games.

D. Application of Neurosky

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.

E. Application of Quasar

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.

VII. Future Research Directions

Wireless BCI systems have already been developed for consumer and research uses, and they are attracting public attention. However, these advantages of these systems have only been applied for such as medical and entertainment applications, so far. Wireless BCI systems have not yet fully made their way into our lives. Many research groups are making efforts to develop convenient wireless BCI systems that are easy to wear and accurate in reading thoughts. Researchers will make new applications to help people enjoy a better quality of life. Many applications will be designed with everyone in mind, to be used in entertainment and daily life. Some applications will be designed for the handicapped in rehabilitation medicine or medical engineering. We could use many new BCI applications in the future, and new ones in the fields of entertainment, rehabilitation, and communication are already envisioned. Again, these devices are not only intended to be helpful for people with severe movement disorders, but also for average people.

In the next section, we aim to discuss future applications of, and anticipate the limitations of, wireless BCI systems. Wireless BCI systems currently have problems of insufficiency in features controllable by EEG signals, deficiency in accuracy of EEG signal interpretation, and absence of killer applications.

The available potential of EEG signals for controlling applications are limited. The limited dimension of EEG signals does not offer much expansion in control. Among the wireless BCI systems discussed in scientific articles, and commercial products, many have utilized EEG signals to determine the user's cognitive states (e.g., attention and relaxation). The users can control an application utilizing the measured cognitive states generated by the user's intentions. For example, the users can control the direction of arrows in an archery game using a wireless BCI system (Liao et al., 2012). This simplicity in control comes with a short learning curve for adapting to the program; however, it is limiting as well. The applications to which BCI systems can be applied are limited as well due to lack of high degrees of freedom control. Some research groups have focused on the development of other feature types to solve the problem. One example is to use detection of various cognitive states, such as drowsiness and alertness (Lin et al., 2010; 2012). The number of features that can be obtained is very limited. Because of this, wireless BCI systems today can interpret only simple messages from user's intentions.

Current BCI systems are not reliable enough to be used accurately. Improving the accuracy of wireless BCI systems is one of most important issues for better utilizing wireless BCI systems in a wide range of applications. For example, a user may need to wear a wireless EEG acquisition device for a long time and may need to move anywhere for something like workload monitoring (Matthews et al., 2008). In this situation, the accuracy of applications could easily decline due to vibration and noise. The training of applications is essential for achieving higher accuracy, because people have different, characteristic, EEG features. For these reasons, commercial wireless BCI systems are utilized for entertainment, but generally have not been extended to accuracy-critical applications. Scientists have tried to improve accuracy of EEG signals.

Killer applications for wireless BCI systems are needed. A killer application means a useful application helping ordinary people in their daily lives, entertainment, or medical engineering. Wireless BCI is a part of the human computer interface (HCI). HCI includes such as speech recognition, motion recognition, and eye tracking. In many cases, there are other, easier means, perhaps with faster and more accurate performance, than BCI can provide. Companies of wireless BCI system have mostly made applications to play games and control utilities used by gamers. It is possible to choose other control interfaces such as speech recognition, motion recognition, or eye tracking, instead of the EEG signals; so perhaps researchers need to find new inspiration to make new killer applications. Valuable applications related to smart living environments (Lin et al., 2012), and communications (Wang et al., 2011), have been developed for wireless BCI systems, but they are still not suitable due to insufficient field verification. Therefore, the identification of a killer application still remains to an urgent need if wireless BCI systems are to thrive.

VIII. CONCLUDE

BCI systems are rapidly growing convenient communication, control, and diagnosis instruments. Researchers are still studying BCI technology to enhanced system performance and the design of electrodes. As new BCI systems are developed, new applications are created to utilize them. Thanks to advanced, wireless BCI systems, users can operate applications at any time, and anywhere due to conveniently portable size and easily wearable interface devices. These new applications have the potential to substantially improving human quality of life, and will likely come to serve people for a wide variety of purposes.

However, current applications of wireless BCI systems have limitations caused by control issues and a narrow range of applications. Wireless BCI systems also have problems of inaccuracy in EEG signal interpretation, and inadequate channels for measurement. When researchers have solved these problems, users will be able to wear BCI systems and use these applications to control medical devices, consumer electronics, and many other machines.

This chapter reviewed the multiple applications of wireless BCI systems in daily life, medical engineering, and entertainment that provide users with benefits. These include: control of home systems, robots, and wheelchairs; diagnostic devices for diseased people; drowsiness detection for drivers; systems for effective purchases; and fun games that anyone could enjoy. The chapter also addressed difficult issues relevant to wireless BCI studies, the limitations on application controls, using the applications, and the problem that may arise with time-limited studies. The ultimate goal should be wireless BCI systems that are easy to use, reliable, and long-lasting. The applications based upon these systems should be safe, attractive, diverse, effective, and capable of being used by everyone.

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ADDITIONAL READING SECTION

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KEY TERMS & DEFINITIONS (SUBHEAD 1 STYLE)

Keyword: Definition of Keyword.

EEG: EEG is the recording of electrical activity along the scalp. EEG measures voltage fluctuations resulting from ionic current flows within the neurons of the brain.

Application: The term application is a shorter form of application program. An application program is a program designed to perform a specific function directly for the user or, in some cases, for another application program.

P300: The P300 (P3) wave is an event related potential (ERP) component elicited in the process of decision making.

SSVEP: Steady State Visually Evoked Potentials (SSVEP) are signals that are natural responses to visual stimulation at specific frequencies. When the retina is excited by a visual stimulus ranging from 3.5 Hz to 75 Hz, the brain generates electrical activity at the same (or multiples of) frequency of the visual stimulus.

ERPs: Event-related brain potentials (ERPs) are a non-invasive method of measuring brain activity during cognitive processing.

Dry electrode: Dry electrode does not require the use of conductive gels or glues for installation process unlike wet electrode.

Bluetooth: Bluetooth is a wireless technology standard for exchanging data over short distances from fixed and mobile devices.

Information transfer: Information transfer is the process of moving messages containing user information from a source to a sink via a Communication channel.