

An approach toward wireless brain-computer interface system using EEG signals: A review

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ABSTRACT

The wireless brain-computer interface (BCI) system can become as powerful aids for people with disability (PWD), especially to help them move independently. The BCI system captures the user's brain activity and classifies into a signal to which a robot or a computer device can respond. In this article, a review of various electrodes for capturing the electroencephalogram (EEG) signals, key techniques, and their applications of wireless BCI headset along with future development issues proposed by many researchers have been discussed. The central idea is a study on the brain rhythm related to the user's movements for the control of mobile robots, humanoids, and robotic wheelchair. The BCI system is capable of improving and enriching the lives of PWD and people with neuromuscular disorder and bringing back the quality of free movement for PWD.

KEY WORDS: Electroencephalogram (EEG); Brain-Computer Interface (BCI); wireless BCI headsets

INTRODUCTION

In the last 10 years, brain-computer interface (BCI) is a field of research that has been traversed. It facilitates the control of machines through the study of classification of signals directly obtained from the human brain. The BCI system translates the brain signals into intelligent commands to control electronic devices such as prosthetic limb, wheelchair, etc. In the early days, BCI system applications were extensively used for those diagnosed with a neurodegenerative disorder or quadriplegia and Parkinson's disease. These applications mainly focus on upgrading the patient's communication through thinking.^[1] The BCIs are now widely considered as one of the most successful applications of the neuroscience, because they are significantly improving the quality of the life of people of disability (PWD) from severe motor disabilities, cerebral palsy, and amyotrophic lateral sclerosis.^[2] The BCI system provides a

direct contact path between the user's brain and the external devices such as computers and personal digital assistants (PDAs). The activities of electrical signals can be obtained by firing millions of neurons in the brain. When we think, millions of neurons are fired together, and each cerebral state generates different patterns of activity. These electrical activities can be measured and recorded from the scalp of the human. Normally, the electrical activities of the brain signal can be recorded by invasive, partially invasive, or noninvasive methods. In invasive method or partially invasive method, the electrodes are implanted into or on the gray matter of the brain during neurosurgical operations. In noninvasive method, the electrodes are placed on the surface of the scalp. The brain signals from electroencephalography (EEG), magnetoencephalogram (MEG), blood-oxygen-level dependent (BOLD) signals, electro-oculogram (EOG),^[3] and oxyhemoglobin concentrations are used as inputs for noninvasive BCIs.^[4] Over the past two decades, many paradigms for forming the EEG-based BCI systems were tried out. Many classification methods are used to classify the EEG signals by using biofeedback by interacting with the stimuli of the different paradigms, which occur in EEG. Each method has its own advantages and disadvantages. The human brain can be divided into four structures: cerebellum, cerebral cortex, brain stem, and hypothalamus. The cerebral cortex consisting mainly cell bodies and capillaries is the gray matter of the brain. The cerebral cortex has two hemispheres.

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The BCI system can be classified into two parts: (i) signal acquisition (ii) translation part.^[5] The signal acquisition part consists of electrodes, analog-to-digital converter (ADC) circuit for capturing the neurosignals, recording, and transmission. The process of translating the signals can be done in computing devices such as PDA and laptop by performing the signal classification and algorithmic process on raw neurosignals. According to the type of connection, the BCI can be classified into two kinds: (i) wired and (ii) wireless BCI system. In the earlier days, the conventional type of BCI was wired, and it mainly focused on cursor control and speller applications, which were developed for helping the PWD to do their work. Even though, owing to the high cost and difficulty, BCI system utilization was limited, but the technologies of NeuroSky and Emotiv EPOC headset are extensively accepted because of being relatively inexpensive and presenting reduced complexity.

The article is ordered as follows. Section II details the electroencephalography. Section III explains the recent electrodes for signal acquisition. Section IV describes the wireless BCI system design, and Section V explains the signal features and applications of BCIs.

ELECTROENCEPHALOGRAPHY

The electrical activities of the brain can be recorded by using EEG along the scalp. The function of EEG is that when we think, millions of neurons are fired together to produce distinct patterns of activity. These electrical activities can be measured by electrodes located on the scalp of the brain. There are three types of BCIs that are denoted as invasive, partially invasive, and noninvasive BCIs.

In invasive BCI method, the signal capturing electrodes are placed inside the gray matter of the human brain through neurosurgery. The invasive method is used for the application of repairing damaged sight and provides new functionality in the life of PWD. The advantage of this method is that it provides high quality signals, but it scars the tissue while surgery. It causes the signal to become weaker.^[6] A partially invasive method captures the signal inside the skull rather than within the gray matter. The electrodes are implanted in a thin plastic pad and placed above the cortex region. It gives better resolution signals. In noninvasive method, the small electrodes are implanted on the surface of the scalp. Depending on the placement of the electrode, several methods exist to study the brain function. The methods are—EEG, near-infrared spectroscopy (NIRS), functional magnetic resonance imaging (fMRI), electrocorticography (ECoG), nuclear magnetic resonance spectroscopy (NMRS), single-photon emission computed tomography (SPECT), and event-related optical signal (EROS). Figure 1 shows the sections of the brain.

The implementation of the BCI model was done by using two-level approach. The first part dealt with capturing the signals and generate different control signals from the obtained EEG signals. The next level consisted of commanding and controlling the devices such as PDAs. Figure 2 shows the

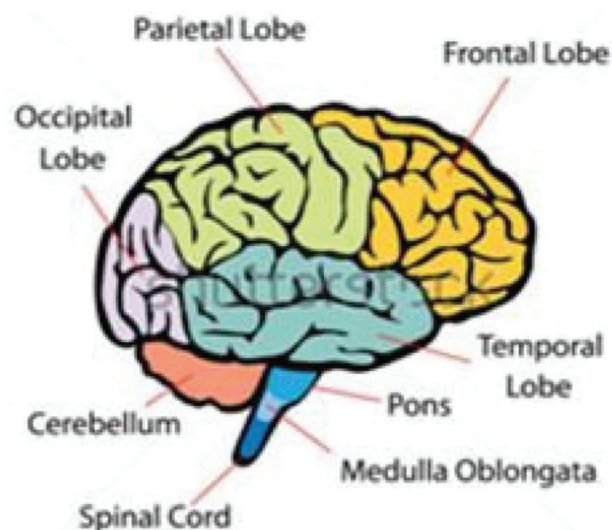


Figure 1: Sections of the brain.

placement of electrodes as stated by the 10–20 system and the diagram of BCI system.

The BCI system was tested by two distinctive actions that generated the EEG signals.

The EEG signals obtained from these two methods were used in calculating the BCI. The controlling signals after the calculations were used to control the robotic devices accordingly.

EEG refers to electrical activities recorded usually for 20–40 min. Using the EEG acquisition techniques, the event-related potentials (ERPs) and evoked potentials (EP) information were recorded. The related information was gathered from the recorded signals by placing the electrodes in their corresponding part of the brain.^[7] The electrical activities of the brain produce the signal with an amplitude generally below a voltage of 100 μ V.

RECENT ELECTRODES FOR SIGNAL ACQUISITION

Recent EEG electrodes that are used to measure the brain activities with low noise is the biggest challenge. In general, the wireless BCI headset contains signal acquisition part for preprocessing the signals and translation part for sending the signals to the remote devices. Emotiv EPOC and Neurosky technology headsets contain 14 single-channel sensors with small, integrated circuit. The entire system is powered by a battery source for processing and transmitting the signals. In this, the captured signals are analyzed either using online mode or offline mode on a computer device.

In a conventional BCI system, usually ring- and disc-shaped passive electrodes are used to measure the signals that are made of Ag/AgCl.^[8] These systems have many disadvantages that are extra treatments needed for recording the signals of EEG, because the potential values are on several microvolts and,

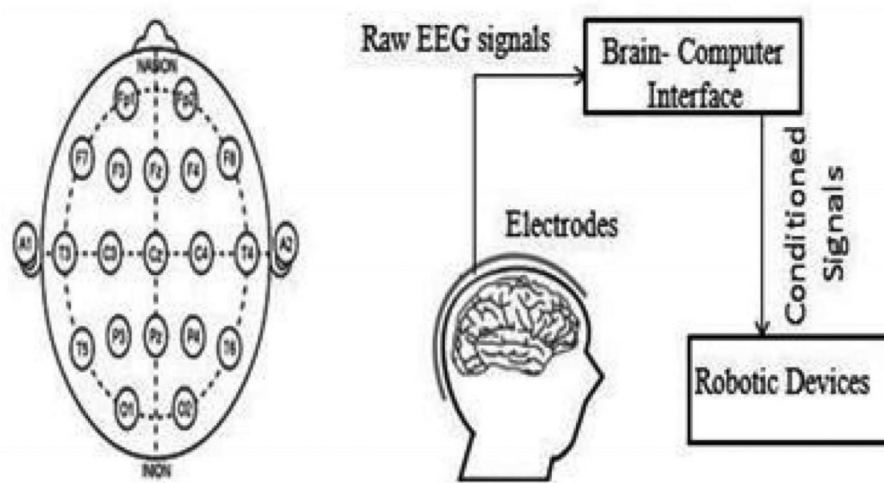


Figure 2: Placement of electrodes as stated by the 10-20 system and the diagram of BCI system.

thus, very noise sensitive. For better attachment and conductivity, hair arrangement and gels are needed. But these preparation steps cause discomfort and is a time-consuming process. Conductive gels may easily remove the moisture from electrodes and lose their adhesion. Sometimes, the cable vibrations may decrease the quality of the EEG signals.^[9] For these difficulties, passive electrodes are not feasible for monitoring the EEG signals for a long time.

To overcome these, recently, dry electrodes are used. The dry electrodes do not require any conductive gels and hair arrangements for the installation process. Many brain-monitoring wireless BCI systems have released them for research purpose. They are the B-Alert X24, Quasar DSI 10/20 system, and StarLab Enobio system. Each type has different channels and applications such as mobile neurophysiological analysis, cognitive workload, and neurofeedback. The researchers described several types of electrode materials and their structures. The various types of electrodes^[8,10-12] are shown in Figure 3.

The impedance between the brain and the electrodes is higher in dry sensors, and signal quality of the dry electrode is not that much higher than the passive electrodes. To overcome this, research has been done with active electrodes. The active electrodes have an amplifier circuit located between the electrode and signal acquisition front-end.^[13] It provides high input impedance, and the active circuit reduces the distortion of the calculated signals. The advantage of the active electrodes is that the quality of the signals can be in the desirable state, even after the signal processing.^[14]

WIRELESS BCI SYSTEM DESIGN

Several papers have discussed the wireless BCI system block diagram.^[15,16] Figure 4 shows a typical wireless BCI system. To enable the transmission of exact neurosignals, additional

signal conditioning is necessary. Physiological interference and power line noise are present in capturing EEG signals. The biopotential signals such as ECG, EMG, and EOG are useful. They have higher amplitudes about 50 μ V. At the same time, EEG signal amplitude is approximately 10–100 μ V. To obtain the user's intention carefully, the system needs to plan correctly to avoid the interface from other components. The system is classified into two parts. They are (i) signal acquisition and (ii) translation part.

(i) acquisition Part: The acquisition part consists of two subsystems namely analog and digital systems.

(a) An analog system:

It consists of filters and amplifier circuit that make reliable and robust EEG signals from the captured signals. In the amplification process, the wireless BCI system widely used an operational amplifier and instrumentation amplifier.^[17]

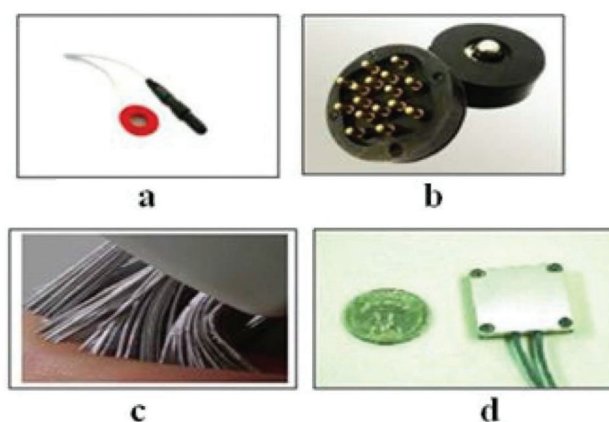


Figure 3: Various types of electrodes.

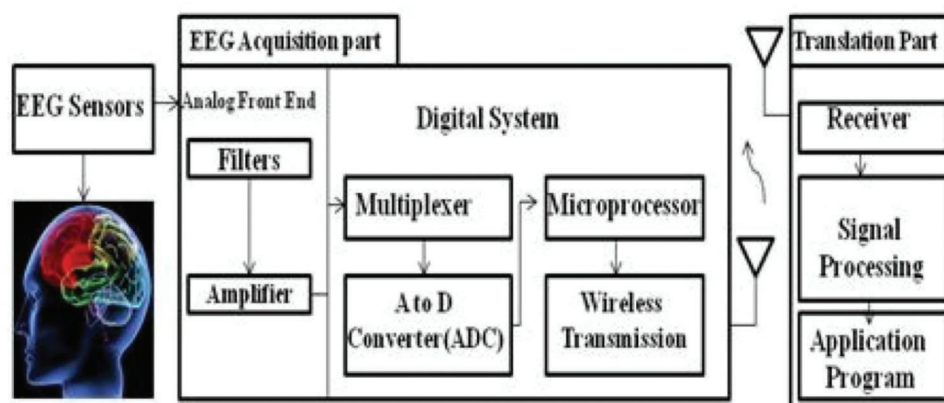


Figure 4: Typical wireless BCI system.

It provides robustness against different noise signals. The EEG signal has a narrow bandwidth from 1 to 50 Hz.^[18] Figure 5 shows the different types of the wireless BCI headset.^[14,19–21]

(b) Digital system:

The digital system consists of a multiplexer, microprocessor, ADC, and wireless transmission unit. A multiplexer is used to access the multichannel. The measured analog EEG signals are converted into digital signals for further processing using ADC. The EEG analog signal transforms into digital signals with a sampling frequency by using integrated circuit. Microprocessor manages the entire system component and the protocol of wireless transmission IEEE 802.15.4, and Bluetooth are used for the transmission of measured EEG signals.

SIGNAL FEATURES AND APPLICATION

After extracting the artifact from the signal, the signal is processed for feature extraction to extract the characteristics of the particular signals. Using a suitable software, the features are extracted and used to generate the commands to direct the robotic devices.

Several techniques are used to extract the particular feature—linear discriminant analysis (LDA), support vector machines (SVM), statistical classifiers, and artificial neural network (ANN). Table 1 shows the characteristics of different classifiers. Software tools are widely used to process the EEG data, such as BCI 2000^[22] and EEGLAB.^[23]

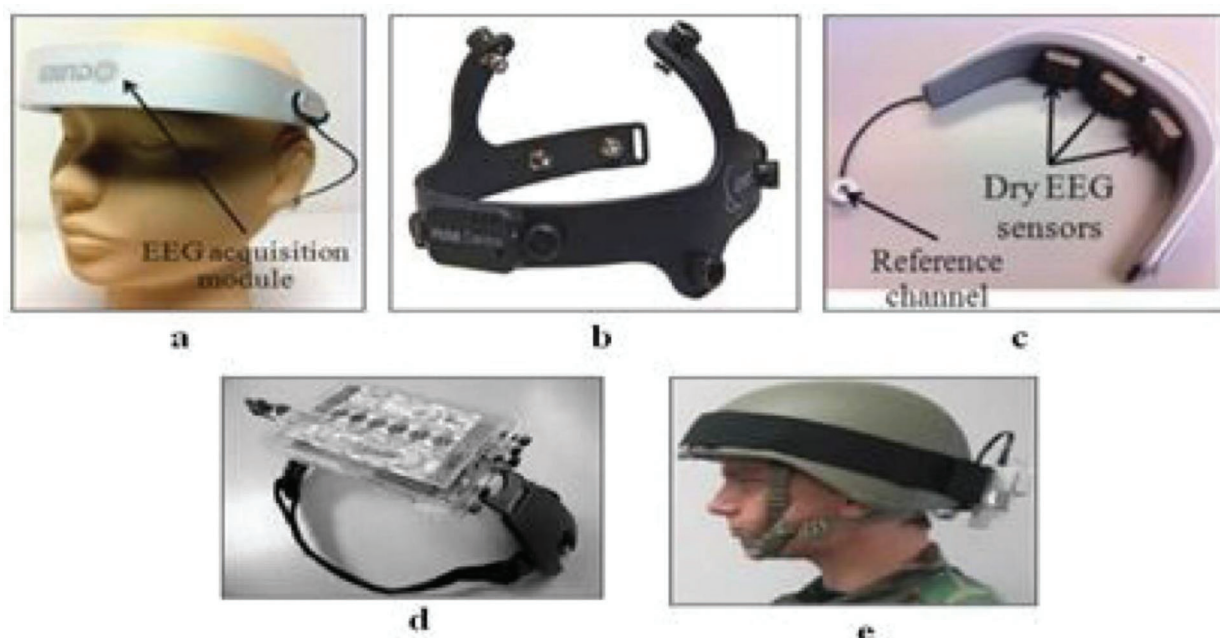


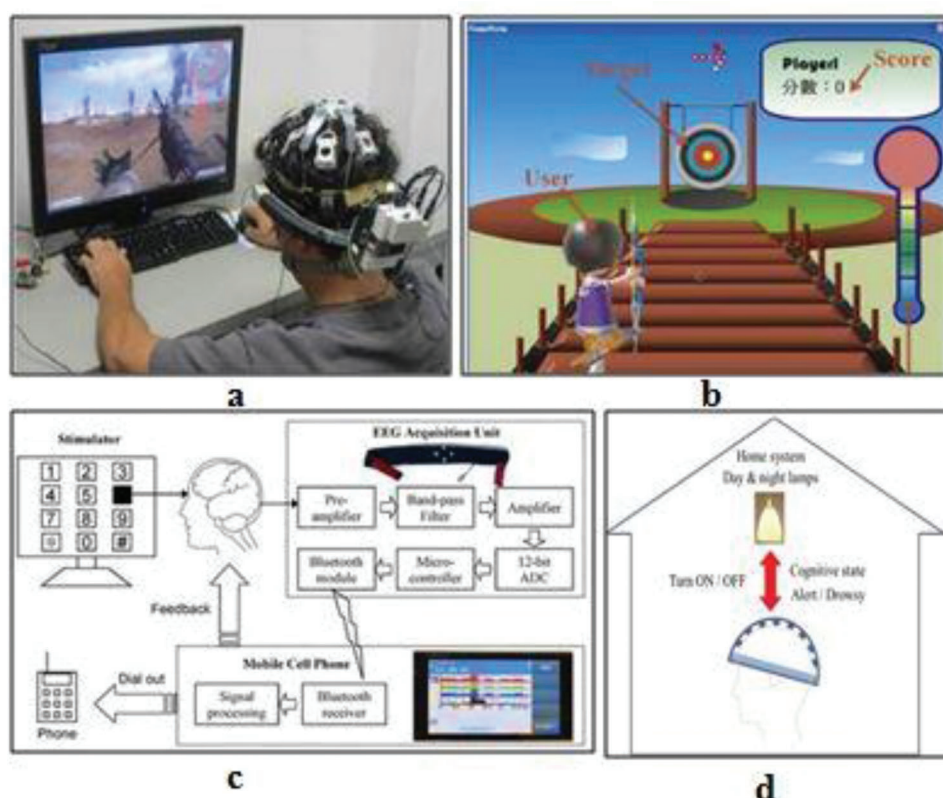
Figure 5: Different types of the wireless BCI headset.

Table 1: Characteristics of different classifiers.

Classifier	Mechanism	Properties
Linear discrete analysis(LDA)	On the basis of the set of features, the LDA classify the specific object from a group of object	• Low computational cost • Poor results on complex nonlinear data[24]
Support vector machines (SVM)	By using a hyperplane, maximize the distance between the different classes ^[25]	• Linear and nonlinear classifier • High computational cost
Statistical classifiers	Calculate the probability of each class and assigns a new class with the highest probability ^[26]	• Nonlinear classifier • Informative
Artificial neural network (ANN)	By minimizing the error in training data, find the nonlinear decision plane ^[27]	• Sensitive to overtraining • High computational cost • Nonlinear classifier

Recently, several applications use wireless BCI systems. Liao et al.^[19] proposed the EEG-based archery game control. It consists of three channels and dry EEG sensor. The function of the archery game is that it measures the alpha rhythm value from the user's forehead. Another application of mobile BCI using noncontact and dry EEG sensors has been developed by Chi et al., who proposed graphical user interface (GUI) smartphone phone application for the purpose of monitoring and analyzing the signals. Dry and noncontact sensors were used for capturing the EEG signals. They offer good signal

quality and easy installation.^[13] Figure 6 shows the applications of BCI system.^[14,19,28,29] Lin et al. described the BCI system for drowsiness detection. A real-time drowsiness algorithm has been developed to detect the particular user drowsiness and send the alert to a driver in a car by processing the rhythmic values of theta and alpha of EEG signals.^[30] Soogil et al.^[31] describe the recent wireless BCI-based smart-living environment auto-adjustment control system. To overcome the drawbacks of bulky and expensive EEG devices and high quality acquisition, the environment adjustment control system has


Figure 6: Applications of BCI system.

been developed with the single-electrode EEG channel. The captured cognitive state is used to control the electric home appliances. Using this system, user's can control devices such as smartphones and smart TV.^[30,31]

FUTURE WORK AND CONCLUSION

The research and development of the wireless BCI system have received a great deal of attention because it offers a mobility to the elderly people to do their work without other interaction and improves their quality of life. EEG system, different types of electrodes, and various wireless headsets and their applications are discussed in this review. However, recently, several commercial companies and researchers have introduced the wireless BCI headset for user experience. It provided good signal processing and a useful real-time application at low cost. The wireless BCI shall be further enhanced by making better translation algorithms in the future for more efficient and realistic control. An additional improvement needs to be taken in BCI classifier for more effective performance of both time response and accuracy to process the signals. The BCI system is a helpful technology for the PWD to improve their independence and mobility.

REFERENCES

- Vishnubhotla S. Examining current and future BCI applications for people with disabilities. Auckland, New Zealand: University of Auckland.
- Chumerin N, Manyakov NV, van Vliet M, Robben A, Combaz A, Van Hulle M. Steady-state visual evoked potential-based computer gaming on a consumer-grade EEG device. *IEEE Trans Comput Intell AI Games*. 2013;5(2):100–10.
- Khare V, Santhosh J, Anand S, Bhatia M. Brain computer interface based real time control of wheelchair using electroencephalogram. *Int J Soft Comput Eng*. 2011;1(5):41–5.
- Nijholt A, Tan D. Brain-computer interfacing for intelligent systems. *IEEE Intell Syst*. 2008;23(3):72–9.
- Lee S, Shin Y, Woo S, Kim K, Lee HN. Review of wireless brain-computer interface systems. In: Fazel-Rezai R (Ed.), *Brain-Computer Interface Systems—Recent Progress and Future Prospects*. Croatia: InTech, 2013.
- Zhang B, Wang J, Fuhlbrigge T. A review of the commercial brain-computer interface technology from perspective of industrial robotics. *IEEE International Conference on Automation and Logistics (ICAL)*, 2010. , New York: IEEE, 2010.
- Stefánsdóttir A. Flogabreytingar í heilariti: Rannsókn á öllum heilaritum með flogabreytingar á Íslandi árin 2003-2004. 2012.
- Nikulin VV, Kegeles J, Curio G. Miniaturized electroencephalographic scalp electrode for optimal wearing comfort. *Clin Neurophysiol*. 2010;121(7):1007–14.
- Liao LD, Wang IJ, Chang CJ, Lin BS, Lin CT, Tseng KC. Human cognitive application by using wearable mobile brain computer interface. *TENCON 2010-2010 IEEE Region 10 Conference*; 2010. New York: IEEE, 2010.
- Liao LD, Wang IJ, Chen SF, Chang JY, Lin CT. Design, fabrication and experimental validation of a novel dry-contact sensor for measuring electroencephalography signals without skin preparation. *Sensors*. 2011;11(6):5819–34.
- Grozea C, Voinescu CD, Fazli S. Bristle-sensors—low-cost flexible passive dry EEG electrodes for neurofeedback and BCI applications. *J Neural Eng*. 2011;8(2):025008.
- Sullivan TJ, Deiss SR, Cauwenberghs G. A low-noise, non-contact EEG/ECG sensorBIOCAS; 2007 Biomedical Circuits and Systems Conference New York: IEEE, 2007.
- Chi YM, Wang YT, Wang Y, Maier C, Jung TP, Cauwenberghs G. Dry and noncontact EEG sensors for mobile brain-computer interfaces. *IEEE Trans Neural Syst Rehabil Eng*. 2012;20(2):228–35.
- Matthews R, Turner PJ, McDonald N, Ermolaev K, Manus TM, Shelby RA, et al. Real time workload classification from an ambulatory wireless EEG system using hybrid EEG electrodes. *Conf Proc IEEE Eng Med Biol Soc*. 2008;2008:5871–5.
- Mahmud M, Hawellek D, Bertoldo A. EEG based brain-machine interface for navigation of robotic device. 3rd IEEE RAS and EMBS International Conference on Biomedical Robotics and Biomechanics (BioRob); 2010 New York: IEEE, 2010.
- Finke A, Hachmeister N, Riechmann H, Ritter H. Thought-controlled robots-Systems, studies and future challenges. *IEEE International Conference on Robotics and Automation (ICRA)*; 2013.New York: IEEE, 2013.
- Hotelling SP, Krah CH. Touch controller with improved analog front end. Google Patents, 2011.
- Mansor W, Rani MSA, Wahy N. Integrating Neural Signal and Embedded System for Controlling Small Motor. Croatia: InTech Open Access Publisher, 2011.
- Liao LD, Chen CY, Wang IJ, Chen SF, Li SY, Chen BW, et al. Gaming control using a wearable and wireless EEG-based brain-computer interface devices with novel dry foam-based sensors. *J Neuroeng Rehabil*. 2012;9(1):5.
- Brown L, van de Molengraft J, Yazicioglu RF, Torfs T, Penders J, Van Hoof C. A low-power, wireless, 8-channel EEG monitoring headset. *Annual International Conference of the IEEE Engineering in Medicine and Biology Society (EMBC)*; 2010. , New York: IEEE, 2010.
- Piccini L, Parini S, Maggi L, Andreoni G, editors. A wearable home BCI system: preliminary results with SSVEP protocol. *Conf Proc IEEE Eng Med Biol Soc*. 2005;5:5384–7.
- Schalk G, McFarland DJ, Hinterberger T, Birbaumer N, Wolpaw JR. BCI2000: a general-purpose brain-computer interface (BCI) system. *IEEE Trans Biomed Eng*. 2004;51(6):1034–43.
- Delorme A, Makeig S. EEGLAB: an open source toolbox for analysis of single-trial EEG dynamics including independent component analysis. *J Neurosci Methods*. 2004;134(1):9–21.
- Bi L, Fan X-A, Liu Y. EEG-based brain-controlled mobile robots: a survey. *IEEE Trans Hum Mach Syst*. 2013;43(2):161–76.
- Sambhu D, Umesh A. Automatic classification of ECG signals with features extracted using wavelet transform and support vector machines. *Int J Adv Res Electr Electron Instrum Eng*. 2013;2:235–41.
- Lambrou T, Kudumakis P, Speller R, Sandler M, Linney A. Classification of audio signals using statistical features on time and wavelet transform domains. *Proceedings of the 1998 IEEE International Conference on Acoustics, Speech and Signal Processing*; New York: IEEE, 1998.
- Suleiman ABR, Fatehi TAH. Features Extraction Techniques of EEG Signal for BCI Applications. Iraq: Faculty of Computer and Information Engineering Department College of Electronics Engineering, University of Mosul, 2007.

28. Wang YT, Wang Y, Jung TP. A cell-phone-based brain-computer interface for communication in daily life. *J Neural Eng.* 2011; 8(2):025018.
29. Zhao L, Xing X, Guo X, Liu Z, He Y. A wireless smart home system based on brain-computer interface of steady state visual evoked potential. *Sheng Wu Yi Xue Gong Cheng Xue Za Zhi.* 2014;31(5):967-970.
30. Lin CT, Chen YC, Huang TY, Chiu TT, Ko LW, Liang SF, et al. Development of wireless brain computer interface with embedded multitask scheduling and its application on real-time driver's drowsiness detection and warning. *IEEE Trans Biomed Eng.* 2008;55(5):1582-30.
31. Woo S, Shin Y, Lee S, Lee HN. Review of applications for wireless brain-computer interface systems. *Emerg Theory Pract Neuroprosthet.* 2014;(2014):128-9.

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