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SURVEY OF BRAIN SIGNALS AND METHODS USED IN A BRAIN COMPUTER INTERFACE

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Abstract - Brain computer interface (BCI) system offers communication and control possibilities to people with severe disabilities, like patients with amyotrophic lateral sclerosis (ALS) disease. The most of current BCI's use the electroencephalographic (EEG) activity recorded directly from the scalp, and are used to different control tasks, such as computer cursor movement, letter selection, etc., but there are other ways to record brain signals too. Unfortunately they are invasive methods (ECoG, MEAs, etc.) and are facing ethical issues.

In this article there will be presented the signals used by the BCI systems.

The use of the BCI system depends on the interaction between two adaptive controllers: the user's brain and the BCI system, which will adapt to the brains output signals.

Some applications that can be used as examples are as follows: EEG-based brain-controlled mobile robots, immersion and interaction with virtual reality, user state monitoring, brain-control of prosthetic extremity devices in people with paralysis, etc.

Keywords - BCI, BCI signal description, BCI signals, brain signals, brain-computer interface, EEG, SSVEP, Survey.

I. INTRODUCTION

THERE are a lot of techniques and methodologies to record brain signals for BCI. They can be divided in two categories: noninvasive and invasive record methods.

The noninvasive recording methods include:

1) *recording of electrical or magnetic fields electroencephalography[EEG], magnetoencephalography [MEG];*
2) *functional magnetic resonance imaging [fMRI];*
3) *positron emission tomography [PET];*
4) *infrared [IR] imaging;*
5) *near-infrared spectroscopy [NIRS];*
6) *fetal magnetoencephalography [fMEG];*
7) *single photon emission computed tomography [SPECT]* [1].

Other BCI researchers have used invasive record methods: (electrocorticography [ECoG] or microelectrode arrays [MEAs]) [2].

II. SIGNALS AND METHODS USED IN A BRAIN COMPUTER INTERFACE

The techniques and technologies were presented in the introduction. Most of these methods in reality are at present not practical for clinical use because of their high technical demands, prohibitive expense, limited real time capabilities, and/or early stage of development. It seems that only electrical field recording is likely to have significance and high practical value for clinical applications in the future.

The electrical fields produced by brain activity can be recorded from the scalp using EEG recordings; from the cortical surface - using the electrocorticography activity (ECoG); recording signals from within the brain - recording local field potentials (LFPs) or neuronal action potentials - materialized in spikes. Each recording method has its own advantages and disadvantages, like the EEG recording: it is easy and non-invasive, but has limited topographical resolution and frequency range [1].

The ECoG method has better topographical resolution and frequency range, but requires implantation of an electrode array on the cortical surface, which was done only for short periods of time - a few days or weeks - in case of humans.

Intra cortical recording provides the highest resolution signals, but requires insertion of electrode arrays in the brain tissue and faces yet unresolved problems like minimizing the tissue damage and/or ensuring long-term recording stability [1].

The practical bit rate (PBR) and raw bit rate (RBR) describe the speed and volume of character selection in a BCI system. The PBR estimates system speed in a real-world setting by subtracting incorrect selections from total selections and time between selections from total online time during calculation [3]. The RBR represents all the selections made by the user of the BCI. Today current BCI's have practical information transfer rates of 5–25 b/min [1].

II.1 EEG-BASED BCI PARADIGMS DESCRIPTIONS

In [2] are presented the used techniques to realize EEG based BCI systems. The EEG-based BCI articles are classified in [2] into seven categories according to the experimental paradigm used to elicit different kinds of brain activities:

1) *motor imagery;*
2) *visual P300;*
3) *steady-state visual evoked potential (SSVEP);*
4) *nonmotor mental imagery;*
5) *auditory;*
6) *hybrid;*
7) *other paradigms.*

The detailed descriptions of each BCI paradigm is as follows [2]:

Motor imagery: Motor imagery is defined as imagination of movements of the left hand, right hand, foot, tongue, and so on and during it appears the event-related (de)synchronization phenomenon. This phenomenon can be shown appearing around the motor cortex and it can be used for the classification of the person's intention and translating it into commands.

Visual P300: it is an event-related potential (ERP) evoked by infrequent, task-relevant stimulus around 300 ms after each stimulus onset.

Steady-state visual evoked potential (SSVEP): it is a periodic brain response evoked by the repetitive presentation of a flickering visual stimulus with a certain fixed frequency, usually under 30Hz [2].

Nonmotor mental imagery: it means mental imagery tasks – any other than motor imagery tasks, such as mental calculation, internal singing or speech, etc.

Auditory: it is the use of brain signals generated by auditory stimuli, such as auditory P300 and auditory steady-state response.

Hybrid: it represents a simultaneous use of more than two paradigms mentioned above [2] [3].

In [4] we can find a description list of the recording technologies used to record brain activity:

1) *MEG*: Magnetoencephalography (MEG) is a non-invasive neurophysiological technique and it measures the magnetic fields generated by neuronal activity of the brain.
2) *MRI*: In this technology the subject is placed in a strong magnetic field. Hydrogen atoms are excited by radio waves in the body, and returning of the excited hydrogen atoms to the unexcited state causes a release of radio waves. The broadcasting radio waves are then measured. From this measurements a computer calculates the location of the hydrogen atoms in the body.
3) *fMRI*: Same basic theory and technique is used at functional MRI as used in case of the structural MRI. It uses the BOLD (Blood Oxygen Level Detection) response [4].
4) *PET*: The subject is injected with labeled tracer (Flurodeoxyglucose - FDG). In the first 30 minutes (during the tracer uptake) the subject is presented with a set of stimuli or a task. Exactly after the uptake period, the subject is placed in the scanner and imaged.
5) *SPECT*: Single Photon Emission Computed Tomography: it can detect a different type of photon. SPECT provides lower resolution but is much less expensive than PET. It is usually used for early detection of dementias.
6) *TMS*: Trans cranial magnetic stimulation: is used to stimulate brain tissue by applying strong magnetic fields to specific brain areas [4].

TABLE I
EEG SIGNALS CLASSIFICATION [4]

EEG signals	Band Frequency (Hz)
Delta	1
Theta	4
Alpha	7
Beta	13
Gamma	30+

The description of these EEG signals and their classification: [4]

1) *Delta*: It is the highest in amplitude and the slowest in frequency. It is seen normally at adults in slow wave sleep state.
2) *Theta*: It is seen normally in young children, but it can be seen in drowsiness or arousal in case of older children and adults; it can also be seen in meditation.
3) *Alpha*: It emerges in amplitude with closing of the eyes and/or with relaxation, and attenuates with eye opening or in case of mental exertion.
4) *Beta*: It is closely linked to motor behavior and it is seen usually on both sides in symmetrical distribution.
5) *Gamma*: it is supposed that the gamma rhythm represent binding of different populations of neurons together to carry out a certain cognitive or motor function.

Suitable Brain Signals used in BCIs can be:

1) P300 potentials: a visual, auditory or somatosensory desired stimulus which is interlaced with other routine stimuli, it will evoke a positive peak at about 300 ms after stimulus onset, in the EEG over centroparietal cortex.

2) Steady state visually evoked potential (SSVEP): are signals that occur when the retina is excited by visual stimulus at a frequency ranging from 3.5 Hz to 75 Hz, will transmit the signal to the brain, which in turn will generate electrical activity in the visual stimulus frequency or multiple of that value.

3) Event-related desynchronization (ERD) and event-related synchronization (ERS): are induced in brain by performing mental tasks, like motor imagery, mental arithmetic, or mental rotation is usually accomplished by SMR (sensorimotor rhythms) decrease in the first case – ERD, or in opposite with rhythm increase, after movement and relaxation for the second case - ERS [5].

Among the different ERP types, P300 has been used the most frequently, and a few BCI studies used other ERPs such as N100, N200, P100, P200, movement-related ERP, and error-related ERP [2].

In addition to the main brain signals that are mentioned previously, two additional types of brain signals that are used to develop brain-controlled mobile robots are:

1) error-related potential (ErrP), which occurs after a user becomes aware of an error made by himself/herself or by another entity;

2) the synchronization of alpha rhythms, which significantly occurs in the visual cortex when the eyes are closed [5].

P300 BCIs and SSVEP BCIs based on external stimulation are called exogenous, stimulus-dependent BCIs, or synchronous BCIs, whereas ERD/ERS BCIs independent of external stimulation are called endogenous BCIs or asynchronous BCIs [5].

The main disadvantages of asynchronous BCIs are:

1) they require long training periods (may take even weeks)*;*

2) their performance is variable between users;

3) the accuracy is not as high as at synchronous BCIs.

Synchronous BCIs require minimal training (compared with asynchronous BCIs,) and have stable performance and high accuracy. SSVEP BCIs can issue commands typically every 2–4 s, and their accuracy is typically about 80%–90%. P300 BCIs take longer time to issue commands, but have higher accuracy and a more natural graphical user interface [5].

Steady-state visual-evoked potential (SSVEP)-based BCIs have a wide applications palette in recent years because of their unique features of fast-response, high information transfer rate (ITR > 25 bits/min), relatively few EEG channels, and minimal user training sessions. SSVEP-based BCIs are often designed by using different flickers for distinct frequencies.

III. Signal acquisition

EEG signals are recorded with electrodes placed on the surface of the human scalp.

The most widely used electrodes are the silver or silver-chloride electrodes (Ag/AgCl), because of their low cost, low contact impedance, and good stability in time. Using Ag/AgCl electrodes, the procedure of using it requires removing outer skin layer of the scalp and filling a special conductor gel between electrodes and scalp – this is why this kind of electrodes are called “wet electrodes” [6]. These operations take long time to prepare and are uncomfortable to users.

Some researchers have been exploring other types of electrodes – the “dry electrodes”, which do not need to use gel and skin cleaning. The biggest disadvantage of dry electrodes is that the acquired EEG signals are worse and with less amplitude than those acquired with conventional electrodes due to the increase of contact impedance [5], [6].

In case of other BCI systems, other invasive recording methods are used, like the electro-corticography [ECoG] or microelectrode arrays [MEAs], but both of them need surgical interventions.

In [3] was described an experiment, where EEG signals were recorded, using a g.USBamp and a g.EEGcap (from Guger Technologies, Graz, Austria), having a sensitivity of 100 µV and band pass filtered between 0.1 Hz and 30 Hz, and the resulted signal was sampled at 256 Hz. The signals were recorded in EEG electrode positions F3, Fz, F4, Cz, Pz, P3, P4, P7, P8, Oz, O1, and O2 – positions defined in the extended International 10-20 system. EEG was referenced at the right mastoid and grounded at the front electrode (FPz) [3]. Electrode locations F3 and F4 were monitored to examine the N400 signals.

Fig. 1: Different active dry EEG electrodes [7]

IV. Signal processing

The order of processing the recorded signals is: the recorded signals are first preprocessed in order to remove the appeared artifacts from the recording procedure, such as power line noise, electrocardiogram (ECG), electrooculogram (EOG), electromyogram (EMG) and any other body movement. Specific features are then extracted from the preprocessed signals. In the last phase, the classifier translates these extracted features into commands that will be realized by the executive parts of the BCI [2], [5].

A BCI records brain signals and processes so that these signals produce device commands.

Signal processing stage has two major parts:

1) feature extraction: it represents the calculation of the values of some specific features of the signal - measuring simple features, like amplitudes or latencies of specific potentials, or even specific rhythms. The feature extraction stage of the signal processing must focus on features that encode the user’s intent and extract those features.

2) the translation algorithm: the above mentioned extracted features are translated into device commands, like cursor movements, icon / letter or symbol selection, wheelchair movement commanding, etc. [6].

Translation algorithms can be very simple or very complex, like P300 vs. neural networks.

In [3] a third order Butterworth band pass filter was used to filter the EEG signals between 0.1 Hz and 12 Hz. After filtering, every seventh sample point was selected from the EEG data; the original signal was down-sampled from 256 Hz to 36.6 Hz and one-thousand ms sub-trials were extracted from the data [3].

V. EVALUATION METRICS

They can be classified in two major categories:

1) “Task metrics” - focuses on: “How well specified tasks can be performed with the brain-controlled robots?”. “Task success” is the widely used and easiest task metric, but there are used others as “task completion time” or “mission time” and “BCI accuracy”.

2) “Ergonomic metrics” represent the mental state of the user rather than the user’s performance (measured by task metrics). “Workload” is another commonly used ergonomic metric, measuring the user mental effort when using BCIs.

Two other ergonomic metrics are “learnability” and “level of confidence”. The first one represents the ease of learning to use the robot and the second represents the level of confidence experienced by the users [5]. The cost factor is important too, and must be considered in evaluating the BCI systems.

It is important to evaluate and compare the performance of a variety of BCI systems. However, standardized performance evaluation of the BCI systems has not yet been made.

Another important aspect is that almost all of the existing BCI systems used healthy participants to evaluate their systems, only with several exceptions [6].

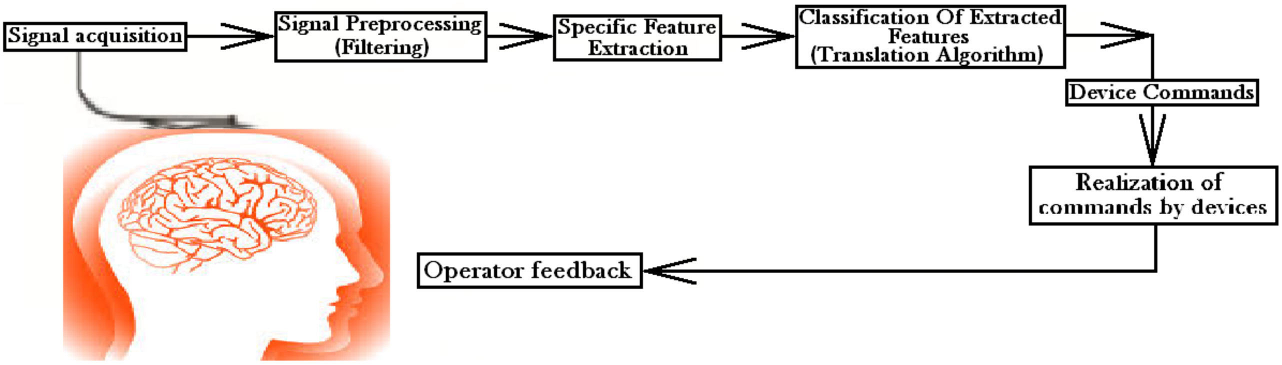

Fig. 2.- The BCI system concept and the above mentioned process steps [6]

REFERENCES

[1] V. R. Pavitrakar, “Survey of Brain Computer Interaction,” *International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering*, Vol. 2, Issue 4, April 2013.

[2] H. J. Hwang, S. Kim, S. Choi, C. H. Im, “EEG-Based Brain-Computer Interfaces: A Thorough Literature Survey”, *Intl. Journal of Human–Computer Interaction*, 2013, pp. 814-826.

[3] J. Jin, E. W. Sellers, Y. Zhanga, I. Dalyd, X. Wanga, A. Cichockic, “Whether generic model works for rapid ERP-based BCI calibration”, *Journal of Neuroscience Methods*, 212, 2013, pp. 94-99.

[4] V. Vashisht, Dr. T. V. Prasad, Dr. S. V. A. V. Prasad, “Technology boon: EEG based brain computer interface - a survey”, *International Journal of Computer Science and Mobile Computing*, Vol. 2, Issue. 4, April 2013, pp. 447-454.

[5] S. Fazli et. al., “Enhanced performance by a hybrid NIRS-EEG brain computer interface,” *NeuroImage* 59, 2012, pp. 519-529.

[6] R. B. Nagy, F. Popentiu, C. Tarca, “Survey of Brain Computer Interface Systems”, Jan. 2014 - Submitted for publication.

[7] http://www.gtec.at/Download#n158, g.SAHARA.PDF-25/03/2011 - 524.63 kB, accessed in 10 Feb. 2014.