BCI-Related Research Focus at HCI International Conference

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Abstract. Brain Computer Interface (BCI) is an emerging research area which has been studied over thirty years extensively in the fields of clinical neurophysiology and neuroscience however it is now recognized as an interdisciplinary field involving neurobiology, psychology, engineering, mathematics and computer science. HCI community has begun to deal with BCI and substantial publications have been made in HCI related journals and conferences in recent years. In the scope of this research we conducted a systematic mapping study with the articles published in proceedings of HCI International Conferences to reveal the trends, general aims of the articles, which signal recording modality were used, for what kind of practical applications were developed, which feature types and classification algorithms were used and what are the nationalities and institutes of contributing authors in the scope of HCI International conference. The aim was to give insight to the researchers who were studying or would like to study in the area of BCI. According to the results of the mapping, research type of BCI articles were mainly in the category of emerging applications not related to communication and control. General aim of the articles was determined as practical applications of BCI technologies first and then development or improvement of methodologies for signal processing issues. Visual P300 was the mostly applied BCI paradigms and SSVEP and motor imagery followed next. Most of the articles had reported EEG as a signal acquisition method, ICA or bandpass filter as a preprocessing or filtering method, ERP as a feature type and LDA and LR as a classification algorithm method.

Keywords: Systematic mapping study · Brain - computer interface · BCI · BCI research trends · HCI International

1 Introduction

Brain Computer Interface (BCI) is an emerging research area, which has been studied over thirty years extensively although its roots can be taken back to 1929 when Berger [1] first recorded electroencephalographic activity (EEG) from the scalp. BCI can be defined as a system that make people interact with outside world by translating their brain signals into commands rather than using their motor movements to control

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computers or use communication devices [1]. BCI systems are primarily studied with the goal of helping severely disabled people as an assistive technologies. In addition, these systems have the potential of providing a more natural and intuitive interface that understands human intentions [2].

Despite early BCI studies were conducted mainly in the field of clinical neurophysiology and neuroscience, it is now recognized as an interdisciplinary field involving neurobiology, psychology, engineering, mathematics and computer science [1]. In addition, as the field enhanced its scope from clinical value and practicality of BCI systems to BCI technology for the needs of people, Human Computer Interaction (HCI) related issues such as meeting the needs of specific user groups have been emerged [3]. Therefore HCI community has begun to deal with BCI and substantial publications have been made in HCI related journals and conferences in recent years.

Previously considerable number of research dealing with BCIs have been published in various fields such as biomedical engineering, clinical neurology, neuroscience and neurorehabilitation [4]. Some literature reviews or survey studies that tried to determine the research trends in the BCI field have been conducted based on these. Mason and colleagues [5] have conducted a comprehensive survey of brain interface technologies prior to year 2006 and they have created a meta-analysis of brain interface designs, targeted application areas and possible opportunities for new research or technological advances in the field. They classified the publications according to functional model and taxonomy of the brain interface design framework [6]. Lin et al. [7] conducted a mini-review focusing especially on wireless and wearable EEG systems and brain-computer interfaces. They have also adapted Mason et al. [5]'s taxonomy for the classification of 32 BCI system related papers. Another review summarized the trends in hardware and software for BCI applications [8]. They categorized BCI applications into basic research, clinical/translational research, consumer products, and emerging applications and they summarized technical aspects for these categories for the development of better integrated and more robust BCI hardware and software. Gürkök and Nijholt [2] conducted a survey covering BCI survey specifically focusing on multimodal interaction, while Bi, Fan and Liu [9] focuses on especially EEG-based brain-controlled mobile robots in their survey. Another recent detailed literature survey was again conducted on EEG-based BCIs covering the publications between 2007 and 2011 [4]. This study reported the number of published BCI articles for a five-year period, BCI paradigms, and aims of the articles, target applications, feature types, classification algorithms, BCI system types, and nationalities of the author.

As it is mentioned above, BCI and HCI fields become closely related in the recent years, in this research we mainly tried to deal with what HCI community was interested in BCI research. Therefore we have conducted a systematic mapping study that covers the articles presented during the last decade of HCI International conference [10] to reveal the trends, general aims of the articles, which signal recording modality were used, for what kind of practical applications were developed, which feature types and classification algorithms were used and what are the nationalities and institutes of authors.

2 Method

In this study, a systematic mapping was conducted with the articles published in proceedings of HCI International Conferences since 2005 covering the last decade to determine the BCI research trends in HCI community. In the study, steps of evidence-based software engineering approach proposed by Kitchenham et al. [11] was adopted. Evidence based software development approach was a method to gather best practices and results of the research studies and the approach had its roots in evidence based medicine. There are two main types of studies which are systematic literature review and systematic mapping studies in evidence-based software development approach. These two study methods had similarities but they had significant differences regarding the research question, search process, requirements of search strategy, quality evaluation of studies and their results. These differences can be seen Table 1 below. Petersen et al. [12] summarized the aim of systematic mapping studies as presenting a general idea about a research area and giving information about the number, type and results of the studies conducted. These studies were conducted to determine the trends based on time.

Table 1. Differences between systematic mapping studies and conventional SLR [13]

Process	Mapping Study	SLR
Research Question	General – related to research trends. Which researchers, how much activity, what type of studies etc.	Specific - related to outcomes of empirical studies. Of the form: Is technology/method A better or not than B?
Search process	Defined by topic area	Defined by research question
Search strategy requirements	Less stringent if only research trends are of interest	Extremely stringent – all relevant studies must be found
Quality evaluation	Not essential	Important to ensure that results are based on best quality evidence
Results	Set of papers related to a topic area and counts of the number of papers in various categories	Answer to specific research question, possible with qualifiers (e.g. results apply to novices only).

The research steps proposed by Kitchenham et al. [11] was modified according to the requirements of this study. Since the articles published in the scope of one conference, some steps of Kitchenham's processes were removed. In this scope, study was conducted in three-phases which were planning, investigation and reporting [14]. Research process can be seen in Fig. 1.

The research questions of this study were determined as follows for determining the general trends in the scope of HCI International Conference;

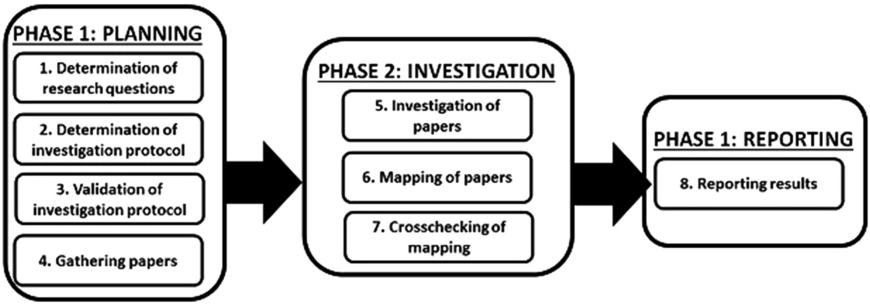

Fig. 1. Research process

- What are the number of BCI-related articles?
- What are the research types studied?
- What are the aims of BCI related articles?
- Which BCI paradigm are used in the articles?
- What are the practical applications of BCI technologies?
- What is used for BCI signal acquisition and signal processing?
- What are the research institutions and authors of the studies?

2.1 Development of the Systematic Mapping Protocol

A systematic mapping protocol was formed based on the research questions to classify the published articles. The protocol was formed of nine sections. These were article general record, research type, aim of the article, BCI paradigm, practical application of BCI technology defined in the article, applied BCI signal acquisition, applied BCI signal processing including filtering, feature extraction and classification methods and finally the subjects. These sections were briefly explained below.

1. *Article general record*: This section involved information related to the year, authors, author's affiliation, proceeding information (volume, issue, etc.), the number of references and the keywords defined for the article.
2. *Research type*: Brunner and colleagues [8] had determined four classification types for the BCI applications as basic research, clinical/translational research, consumer products and emerging applications and their classification scheme was adopted.
3. *Aims of article*: This section was mainly adopted form Hwang et al.'s [4] study to classify the aims of the articles. These were development/improvement of new BCI paradigms, practical applications of BCI technologies, investigation of factors influencing the performance of BCI systems and review studies. In addition to this list, one more item was added as "usability-related BCI studies" since the list did not cover all the studies.

4. *BCI paradigm*: Articles were classified according to the BCI paradigms that were used for gathering brain activities. These were listed as motor imagery, visual P300, SSVEP (steady-state visual evoked potential), non-motor mental imagery, auditory, hybrid and other [4].
5. *Practical application of BCI technologies*: In this section articles were analyzed according to which purpose the BCI system was developed for. The target applications of BCI systems were listed as mental speller, mouse control, robot arm control, game applications, navigation and others.
6. *Applied BCI signal acquisition*: In this section the methods used for measuring brain activity in the articles were determined as invasive and non-invasive according to the sensor placement method that had been used [2, 7]. Invasive methods were ECoG (electrocortigography) and MEA (multi-electrode array) while non-invasive methods were classified as immobile and mobile. MEG (magnetoencephalography) and fMRI (functional magnetic resonance imaging) were considered as immobile while EEG (electroencephalography) and NIRS (near-infrared spectroscopy) were considered as mobile brain activity acquisition methods.
7. *Applied BCI signal processing*: In this section the methods used in articles for interpreting brain activity were determined. First, filtering should be applied to the acquired brain activity to remove noise or body movement related artifacts. Articles were analyzed according to applied filtering method such as low-pass, high-pass, band-pass or notch filtering or ICA (Independent Component Analysis) [9] in the first sub-section here. Then which features that were extracted for the BCI systems were analyzed based on Hwang et al.'s [4] classification scheme which covered five groups of PSD (power spectral density), ERP (event related potential), use of more than two feature types, phase information and others. Finally in the signal processing section, articles were analyzed according to the classification algorithms that had been used. Classification algorithms used were LDA (Linear discriminant analysis), SVM (support vector machine), use of more than one classifier, Bayesian classifier, finding max. value, LR (Linear regression), thresholding, NN (Neural networks), and others [4].

2.2 Systematic Mapping Process

In the scope of this study, BCI-related articles published in the proceedings of HCI International Conference between years 2005 and 2015 were mapped according to the developed protocol. The article list related with BCI studies were gathered from previous years' conference web sites based on their titles. Afterwards articles were gathered from the conference proceedings' publisher database. However very few number of 2005 articles could only be gathered from general search engines. Some articles were removed from the list since they were realized that they were not in the scope of BCI research during the mapping. The total number of mapped articles can be seen in Table 2. Only full papers rather than posters were included in the mapping process.

Table 2. Total number of articles mapped

Year	# of articles mapped
2005	5
2007	24
2009	48
2011	38
2013	36
2014	28
2015	28
TOTAL	207

Articles were mapped by two authors independently first and then two came together and compared their results to reach a consensus. Articles assigned at least one category in each section but they could be assigned more than one category whenever possible. Therefore, the number of total articles mapped in each category showed some variance.

3 Results

In the scope of this research a systematic mapping was conducted regarding with the BCI related articles presented in HCI International Conference between 2005 and 2015 years. Based on the systematic mapping protocol defined in Sect. 2.1, articles were mapped to identify the BCI research types, general aims, BCI paradigm used, practical application areas, signal acquisition and processing methods used in studies and the countries and institutions that contributed to the BCI research in the conference. Detailed findings are presented in the following subsections.

3.1 BCI Research Types Studied

Research types conducted in BCI area were mapped according to four categories defined by Bruner et al. [8]. Majority of articles belonged to emerging applications not related to communication and control and basic research group, while there were less number of articles in clinical/translational research and consumer products as can be seen in Fig. 2. When these findings were evaluated according to the years, it was revealed that there were more articles in basic research group during the early years while there were more articles in emerging applications not related to communication and control group in recent years.

3.2 Aims of BCI Related Articles

Aims of the presented articles at the conferences were mapped according to Hwang et al.'s [4] classification scheme defined for BCI related researches. Many of the studies

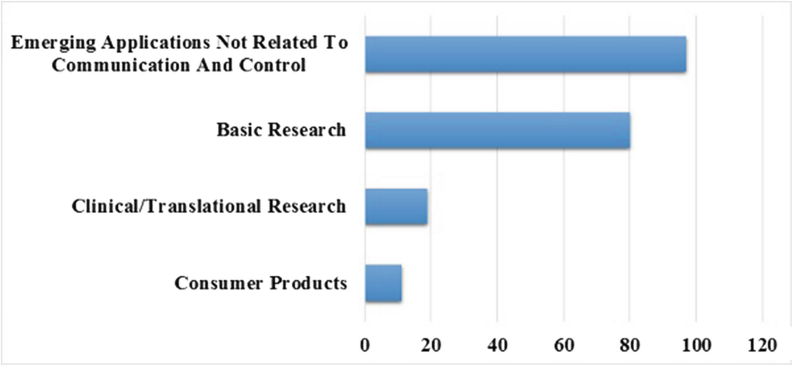

Fig. 2. BCI research types published in HCI International 2005-2015 Conferences

conducted were related with practical applications of BCI technologies. Second most conducted studies were related with development or improvement of methodologies for signal processing, feature extraction and classification. The details can be seen in Fig. 3. When the results were investigated in details according to years, it was revealed that in earlier years, development and improvement of methodologies studies were conducted more while later years practical application of BCI technologies gained more popularity.

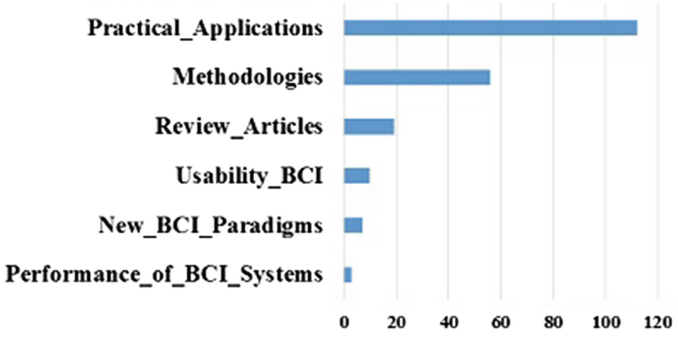

Fig. 3. Aim of BCI related articles

3.3 BCI Paradigm Used in the Articles

When the articles were investigated according the BCI paradigm they adopted, it was revealed that many of the papers adopted visual P300 paradigm for gathering brain activities. Steady state visual-evoked potentials (SSVEP), motor imagery, auditory stimuli or non-motor mental imagery paradigms were used less compared to visual P300 paradigm as can be seen in Fig. 4. There were also some other paradigms applied in few articles such as kinesthetic stimuli, vestibular stimuli or some hybrid stimuli of the mentioned paradigms.

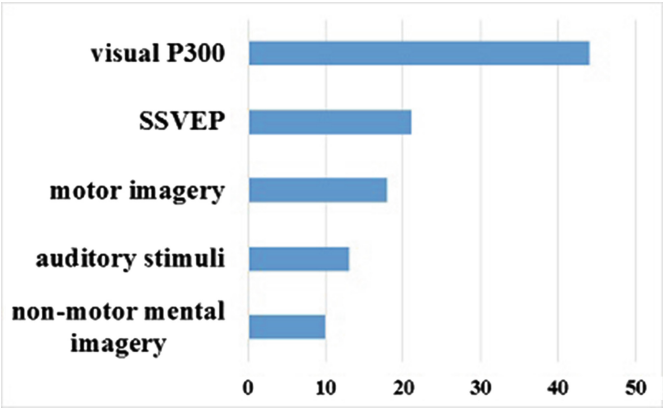

Fig. 4. BCI paradigm used in the articles

3.4 Practical Applications of BCI Technologies

Articles were mapped according to the related practical BCI application that were targeted. It was revealed that articles reported mostly BCI technologies applied for mental or cognitive load detection, emotion detection or attention detection. Other practical applications reported in the articles could be listed as brain-controlled smart home systems, brain controlled game applications, mental speller or mouse control applications as can be seen in Fig. 5.

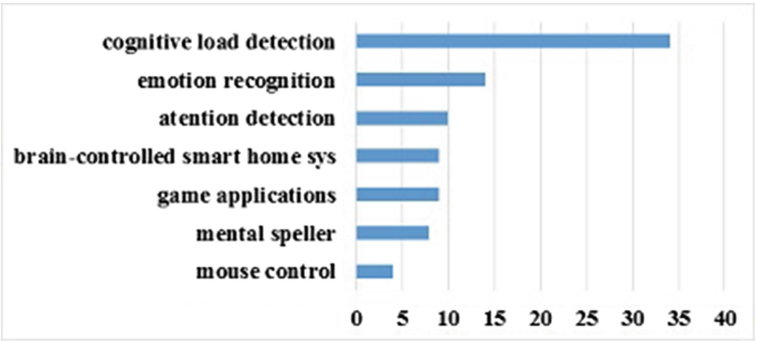

Fig. 5. Practical applications of BCI technologies targeted in the articles

3.5 BCI Signal Acquisition and Signal Processing Methods

Articles were investigated regarding BCI signal acquisition equipment used in the studies as well as signal processing methods. Main equipment used in studies for signal acquisition were EEG and NIRS which were non-invasive devices for measuring brain activity. There are also some articles that reported hybrid use of these equipment.

In addition in some studies they were used together with some other psycho-physiological devices for detecting heart rate, skin conductivity level as well as eye trackers (Fig. 6).

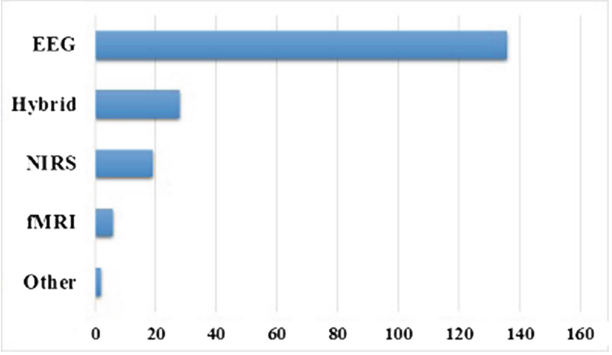

Fig. 6. Brain activity measuring devices used in the articles

For the interpretation of brain activities, gathered brain signals are processes through three main steps which were pre-processing or filtering, then feature extraction and finally classification. Articles were investigated regarding these steps as well. In order to filter noise in acquired signals, bandpass filter was the most used method. Following methods were independent component analysis (ICA), low-pass filter, notch filter and high-pass filter respectively as can be seen in Fig. 7.

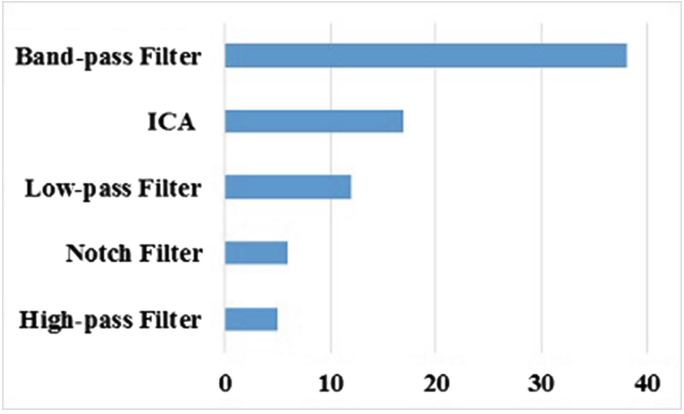

Fig. 7. Filtering methods reported in the articles

After preprocessing step, brain signals are processed through feature selection method. Event-related potentials and power spectral density were the mostly reported method for feature selection in the articles. Researchers applied fast Fourier transformation in many of the PSD based studies. Wavelength transformation, and short-term Fourier transformation were also applied in some studies.

Finally applied classification methods reported in the studies were linear discriminant analysis (LDA), linear regression, (LR), support vector machine (SVM), thresholding, Bayesian classifier and neural networks (NN) respectively as can be seen in Fig. 8. Use of more than one classifier was also reported in many of the articles as well.

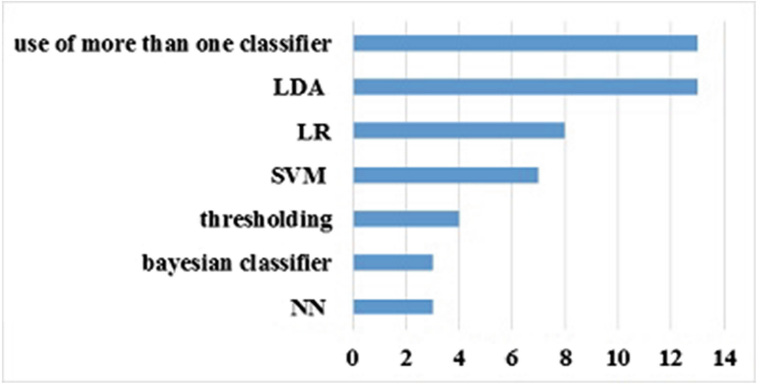

Fig. 8. Classification methods reported in the articles

3.6 Contributing Research Institutions and Countries

Contributing institutions and countries were also investigated. Authors were mapped according to their first affiliation. Institutions and countries were marked once when there were more than one contributing author from the same institution or country. There were more than 900 distinct authors, 250 institutions and 30 countries contributing with research related to BCI research area. Top five contributing institutions were Advanced Bran Monitoring, Inc., Drexel University, Swartz Center for Computational Neuroscience, Electrical Geodesics, Inc. from USA and Guger Technologies OG from Austria. On the other hand, top five contributing countries were USA, Japan, Germany, The Netherlands and Austria.

4 Conclusion

In the scope of this research, a systematic mapping was conducted regarding with the BCI related articles presented in HCI International Conference between 2005 and 2015 years to determine BCI research trends. According to the results of the mapping, research type of BCI articles were mainly in the category of the emerging applications not related to communication and control while a trend could be seen from basic research to this area in the later years. General aim of the articles was determined as practical applications of BCI technologies first and then development or improvement of methodologies for signal processing issues. Visual P300 was the mostly applied BCI paradigms and SSVEP and motor imagery followed next. Most of the articles had reported EEG as a signal acquisition method, ICA or bandpass filter as a preprocessing or filtering method, ERP as a feature type and LDA and LR as a classification algorithm method.

Although findings based on a single conference would not be sufficient to make a general conclusion, the results of this study is expected to provide some general trends related with BCI. This would help and guide researchers who would like to study on this subject area. As a future work it is planned to investigate more articles published at other HCI related conferences and journals. One of the limitation to be considered in these kind of studies is the reliability of the results. Therefore, the study was conducted iteratively. Authors first mapped articles alone and then came together to form consensus about their findings so researcher bias was tried to be overcome.

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