Advances in Intelligent Systems and Computing 300

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Zdzisław S. Hippe
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Human-Computer Systems Interaction: Backgrounds and Applications 3

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Editors

Human-Computer Systems Interaction: Backgrounds and Applications 3

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From the Editors

We are very proud to handle the consecutive book devoted to **H**uman-**C**omputer **S**ystems **I**nteraction (**H-CSI**). The previous monographic volume (**H-CSI**: Backgrounds and Applications **2**, Part I and Part II) received quite good assessment from the scientific community; it also fulfilled our anticipation as a source of up-to-date knowledge in the considered area. This situation encourages us to work out the next volume, giving an insight into the current progress in **H-CSI**. This time however, papers were gathered on our individual invitation of recognized researchers, having significant scientific record in this area. In this way the content of the book contributes the profound description of the actual status of the **H-CSI** field. By chance, it is also a signpost for further development and research.

It is a delightful pleasure to express our gratitude to numerous individual authors, working in: Canada, France, Germany, Indonesia, Ireland, Italy, Japan, Portugal, Malaysia, Mexico, Norway, Slovakia, Slovenia, South Korea, Spain, Syria, Sweden, Tunisia, Turkey, USA and Poland. Many of authors worked together using nets, supplying common articles. In this way, the new volume (**H-CSI: Background and Applications 3**) contains an interesting and state-of the art collection of papers, say reports, on the recent progress in the discussed field.

The contents of the book was divided into the following parts: **I.** General human-system interaction problems; **II.** Health monitoring and disabled people helping systems; and **III.** Various information processing systems.

The general human-system interaction problems (**I**) are presented by papers concerning various application areas, like e.g. brain computers interface systems (A. Materka and P. Poryzała), recognition of emotion (A. Kołakowska, A. Landowska, M. Szwoch, W. Szwoch and M.R. Wróbel), recognition of sign language (M. Oszust and M. Wysocki), multimodal human-computer interfaces (A. Czyżewski, P. Dalka, Ł. Kosikowski, B. Kunka and P. Odya), case studies on audience response systems in the computer science course (L. Jackowska-Strumiłło, P. Strumiłło, J. Nowakowski and P. Tomczak), or on global collaboration of students (A.E. Milewski, K. Swigger and F.C. Serce).

Various problems of health monitoring and disabled people helping systems (**II**) are presented in the next group of papers. Many important problems have been touched, for example the detection of sleep apnea by analysis of electrocardiographic signals (P. Przystup, A. Bujnowski, A. Poliński, J. Rumiński and J. Wtorek), the phone recognition of objects as a personal aids for the visually impaired persons (K. Matusiak, P. Skulimowski and P. Strumiłło) or a general research on aiding visually impaired people (S. Yakota, H. Hashimoto, D. Chugo and K. Kawabata**;** M. Yusro, K.M. Hou, E. Pissaloux, K. Ramli, D. Sudiana, L.Z. Zang and H.L. Shi). Besides, in the paper by S. Coradeschi et all, a system for monitoring activities and promoting social interaction for elderly is described.

The group concerning various information processing systems (**III**) consists inter alia of the papers aimed at human life conditions improvement (by A. Astigarraga et all; R. Bianco-Bonzalo et all; P.M. Nauth; S. Suzuki, Y. Fujimoto and T. Yamaguchi).

This book is intended for a wide audience of readers who are not necessarily experts in computer science, machine learning or knowledge engineering, but are interested in Human-Computer Systems Interaction. The level of particular papers and specific spreading-out into particular parts is a reason why this volume makes fascinated reading. This gives the reader a much deeper insight than he/she might glean from research papers or talks at conferences. It touches on all deep issues that currently preoccupy the field of **H-CSI**.

Editors

Zdzisław S. Hippe
Juliusz L. Kulikowski
Teresa Mroczek
Jerzy Wtorek

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Part I

General Human-System Interaction Problems

A Robust Asynchronous SSVEP Brain-Computer Interface Based on Cluster Analysis of Canonical Correlation Coefficients

A. Materka and P. Poryzała

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Abstract. Brain computer interface (BCI) systems allow a natural interaction with machines, especially needed by people with severe motor disabilities or those whose limbs are occupied with other tasks. As the electrical brain activity (EEG) is measured on the user scalp in those systems, they are noninvasive. However, due to small amplitude of the relevant signal components, poor spatial resolution, diversity within users' anatomy and EEG responses, achieving high speed and accuracy at large number of interface commands is a challenge. It is postulated in this paper that the SSVEP BCI paradigm, combined with multichannel filtering can provide the interface robustness to user diversity and electrode placement. A cluster analysis of the canonical correlation coefficients (computed for multichannel EEG signals evoked by alternate visual half-field LED stimulation) is used to achieve this goal. Experimental results combined with computer simulation are presented to objectively evaluate the method performance.

1 Introduction

The number of "smart" devices and appliances around us grows quickly in the last decades. Not even computers, tablets, cellular phones do comprise a processor with a complex program. Operation and performance of cars, washing machines, microwave ovens, TV sets, etc. strongly depend on the computational power and quality of software of the digital electronic systems embedded in it. Still, the rate of progress in the performance of the computational systems is not accompanied by an equally fast development of the interfaces necessary for information exchange between machines and their users.

In particular, there is a need to develop interfaces that would allow users, who cannot move their limbs, cannot speak, but whose mind operates normally, to enter data into computers without involving the traditional motor pathways of the human nervous system. A solution is a brain-computer interface (BCI) [Wolpaw et al. 2000]. In those interfaces, the intention/will of a user is not expressed by any movement, gesture or command; it is rather "guessed" by the analysis of some measured signals that reflect the brain activity.

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Research projects aimed at development of noninvasive BCI started about 40 years ago. The key factors of focus are speed, number of independent symbols that can be transmitted over the interface and accuracy (lowest error rate). However, due to small amplitude of the signal components, poor spatial resolution, diversity within users' EEG responses, electrode misplacement, and impedance problems its functionality is still far from the expectations. This gives motivation to further research on the interface performance improvement.

In this paper, spatial filtering of the multi-electrode signals is used to make the SSVEP BCI robust to the measurement electrodes displacement and diversity within the operators' EEG responses. The SSVEP paradigm is believed to ensure fastest operation of the interface [Materka and Poryzala 2013]. The asynchronous BCI operation is optimized by identifying best weighted combinations of electrode signals – with the use of cluster analysis of canonical correlation coefficients. Results of experiments with 21 volunteered BCI users are described and discussed to demonstrate the developed method superiority over a number of known alternative techniques.

2 Brain Computer Interfaces

In a brain–computer interface system, users perform mental tasks that invoke specific patterns of brain activity. Those may be invoked by an external stimulation (such as light or sound) or a mental effort of user solely (Fig. 1). The EEG signal is measured, and its relevant features extracted, after necessary preprocessing. A pattern recognition system determines which brain activity pattern a user's brain is producing and thereby infers the user's mental task, thus allowing users to send messages or commands through their intentional brain activity alone. Any particular activity is attributed to a unique symbol transmitted through the interface. The present technological advancement limits applications of the BCIs to a simple cellular phone keyboard with a dozen or so keys or a few-command manipulator for control of a prosthetic or a virtual reality game. The main beneficiaries of the interface are now handicapped persons. It is expected, as BCIs become sufficiently fast, reliable and easy to use, the range of their future applications will encompass many other groups of users.

Most of the phenomena observed in EEG recordings originate in surface layers of the brain cortex, where majority of neurons are positioned perpendicularly to the surface. Due to large number of mutual connections of the cortex neurons, the subsequent waves of depolarization/polarization of their cellular membranes cause synchronization of their activity [Niedermeyer and Silva 2005]. The synchronous activity of a population of nervous cells leads to changes of electric potential on the surface of the cortex, and consequently, on the surface of the skin.

The recording of EEG signal is performed by measuring differences of electric potential between selected points defined on the surface of the human head. Example of standardized locations of the electrodes, defined in 1958 [Oostenveld and Praamstra 2001] to make the measurement points independent of the actual size of the skull is the well-known "ten-twenty" system.

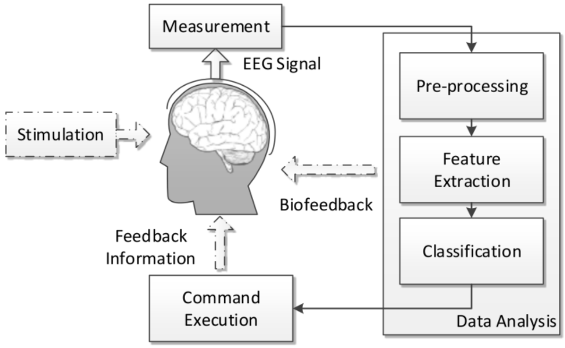

Fig. 1 Basic functional blocks of a brain-computer interface. Optional elements are marked with broken lines

The potential measured on an electrode is a sum of potentials generated by millions of neurons. Thus the measured signals are an average of signals from individual neurons located over some area of the cortex. That is why EEG features poor spatial resolution. Moreover, the potentials of individual neurons have to pass the regions filled with cerebrospinal fluid, bones of the skull and through the skin until finally they reach the electrodes. This causes severe attenuation of the functional waves. The EEG signal that represents electrical brain activity is then very weak, its values are in the range of tens of microvolts. Moreover, the measured signal contains not only the brain activity components of interest. There are other, sometimes many times larger components present (in the order of millivolts), called artifacts. Their sources are of technical or biological origin.

The fact that the EEG signal components that carry the information about the brain activity are weak and are buried in large-amplitude noise makes detection of the BCI user intention difficult. This is the main drawback of the EEG-based brain-computer interfaces. Significant efforts have been taken to design and built EEG measurement devices that would suppress the artifacts and reduce the power of noise relative to the brain signal components of interest [Mason et al. 2007]. One of the latest projects along these lines is described in [Zander et al. 2011]. Advanced signal processing algorithms is another means that leads to reliable detection of the components generated with users intentions.

Four basic categories of noninvasive BCIs have been described in the literature. These categories are related to the brain electrical activity that is invoked, detected and used for sending messages or commands to machine [Wolpaw et al. 2002]. Accordingly, the BCIs use P300 potentials, SSVEP, slow cortical potentials and event-related desynchronization (ERD).

To compare performance of different BCI systems, one should use some standard evaluation criteria [Schlogl et al. 2007]:

- Detection time (a time period between the moment user starts to express their intention to the moment of taking decision by the system).

- Classification accuracy (a ratio of true positive classifications to the sum of true positive, false positive and false negative ones).
- Information transfer rate (bit rate, a parameter used to estimate a theoretical rate of information transfer to the computer) [Kronegg et al. 2005].

The most promising type of the BCI is based on steady-state visual evoked potentials (SSVEP). Relatively large information transfer rate and the number of distinct messages are achieved with the use of the SSVEP-based BCIs [Zhu et al. 2010]. At the same time, high accuracy and speed are obtained at rather small training effort of the user. Thus this type of BCI is the subject of research project discussed in the next Sections.

3 SSVEP BCIs

Most of the SSVEP BCI systems use frequency encoding of the messages. Therefore, detection of potentials generated in result of user's intention is usually based on amplitude or power spectrum analysis (Fig. 2).

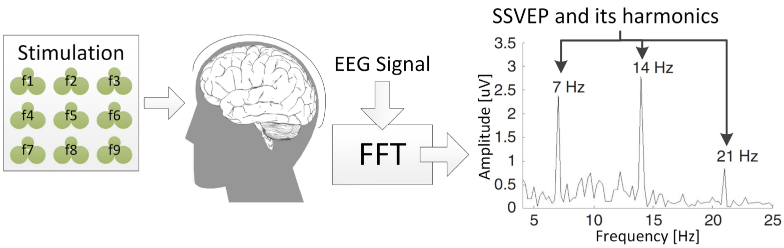

Fig. 2 An SSVEP BCI system with frequency encoding

Referring to Fig. 2, the user concentrates his/her sight on one element (intended to be selected – a target) of the photo-stimulator. Each target is a light source flickering with a unique frequency. There is a message or command attributed to each frequency, so the stimulator plays a role of a virtual keyboard [Materka et al. 2007]. When user focuses his/her attention on a light source of a specified frequency, EEG signals (especially from above primary visual primary cortex) include components of the same frequency and/or its harmonics [Regan 1989]. It is measured over the user's skull and its amplitude spectrum is computed. In the example illustrated by Fig. 2, the user is looking at the stimulator element that is flickering with the frequency of 7 Hz. The SSVEP response is composed of the fundamental frequency, its second and third harmonic, 7 Hz, 14 Hz and 21 Hz, respectively.

In the classical, spectrum analysis based approach, for each stimulation frequency the signal to background ratio (SBR) is computed from the EEG spectrum with the use of Fast Fourier Transform. The background noise could be e.g. the total power of spectrum components in a neighborhood of a given frequency. When the SBR ratio exceed a predefined threshold, a symbol attributed to that frequency of stimulation [Middendorf et al. 2000; Trejo et al. 2006] is decided to be generated at the interface output. In some works, the amplitude of the SBR coefficient is considered a signal feature, which is classified with the use of linear discriminant analysis [Luo and Sullivan 2010]. Other methods include autoregressive spectral analysis [Allison et al. 2008] and wavelet decomposition [Wu and Yao 2008].

The signal-to-background ratio is an essential characteristic of the SSVEP signal. Larger values of SBR lead to shorter time of taking decision and increase the BCI accuracy. Typical stimulators have a form of rectangular fields displayed on an LCD computer screen, each flickering with a different frequency [Cheng et al. 2002]. But it is worthwhile to optimize the visual stimulation to increase the difference between the power of the SSVEP and noise (for e.g. using alternate half-field stimulation method can increase SBR value [Materka and Byczuk 2006]).

Even if the stimulus has been optimized and care has been taken to design measurement equipment as to obtain high signal-to-noise ratio, still the EEG signal is weak and noisy. Then, further signal processing and advanced VEP detection techniques are needed to ensure high accuracy, speed and capacity (i.e. the number of different messages sent over the interface). Taking into account individual anatomical and psycho-physiological differences between users, it is difficult to tell in advance what is the right position for the EEG electrodes to capture most of the information related to BCI users intention. On the other hand, it is impractical to use, say 22 electrodes covering densely the whole skin area on the head. Thus, as a compromise, a limited number of channels (say, 8 electrodes) is considered representative to the problem. The multichannel measurements is a standard now.

It is hypothesized in most research projects that some linear or nonlinear combinations of the channels, individualized for each user, carry the information which is searched for [Cichocki et al. 2008]. An example of obtaining a linear combination (spatial filtering) of the multichannel EEG recordings is shown in Fig. 3.

The optimum linear spatial filter of Fig. 3 should produce new “channels” S for which a ratio of the power of the signal of interest to the noise power is maximum. Among different goals of this procedure, there are Best Bipolar Combination (BBC) of electrodes [Wang et al. 2004], Minimal Energy Combination (of noise), Maximum Contrast Combination (MCC) [Friman et al. 2007] and Canonical Correlation [Bin et al. 2009]. Those multichannel, spatial filtering based detection methods should be (to some extent) immune to small amplitudes of the signal components, poor spatial resolution, diversity within operators’ EEG responses and electrode displacement problems. Optimized, weighted combinations of electrode signals should be identified whenever it is possible.

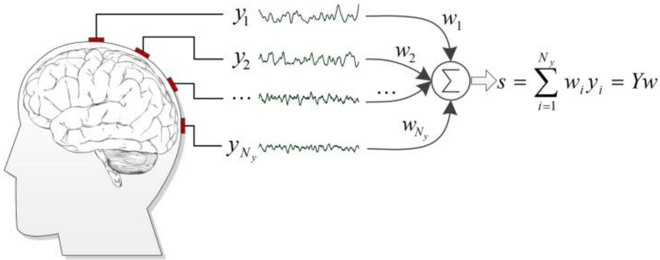

Fig. 3 The concept of spatial filtering of EEG signals

A novel, Cluster Analysis of Canonical Correlation Coefficients (CACC) method for detecting steady-state visual evoked potentials (SSVEP) using multiple channel electroencephalogram (EEG) data has been developed by the authors and described in [Poryzala et al 2012]. Accurate asynchronous detection, high speed and high information transfer rate can be achieved with CACC after a short calibration session. Spatial filtering based on the Canonical Correlation Analysis method proposed in [Bin et al. 2009] was used for identifying optimal combinations of electrode signals that cancel strong interference signals in the EEG. The proposed algorithm, a standard spectrum analysis approach, and two competitive spatial filtering and detection methods were evaluated in a series of experiments with the use of data from 21 subjects [Byczuk et al. 2012]. The obtained results showed a significant improvement in classification accuracy and in an average detection time for a large group of users.

In our recent research we addressed the problem of changing the designed SSVEP-based BCI laboratory demonstration to practically applicable system. Performance of the device evaluated in the carefully controlled lab environment will be decreased in real world conditions, where small amplitudes of the signal components, relatively high power of noise, diversity within users' EEG responses, electrode misplacement, and impedance problems cannot be controlled. Practical device should be convenient and comfortable to use (ideally a limited number of dry, active electrodes should be used) and its performance should be stable and reliable in all possible working conditions [Wang et al. 2008]. Those problems have to be addressed before BCI devices can be put into practical use.

In offline experiments we have evaluated how the misplacement of the measurement electrodes and diversity within users' EEG responses affect the performance of the designed asynchronous Brain-Computer Interface with the CACC detection method (Fig. 4).

As in [Poryzala et al 2012], users were qualified to one of three groups:

Group A (best results, 5 subjects). Subjects who used the device (in our previous studies and tests).

Group B (average results, 10 subjects). Subjects who were not familiar with a BCI device, but actively participated in the experiments.

Group C (poor results, 6 subjects). Subjects with concentration problems or very high unstimulated, spontaneous brain activity.

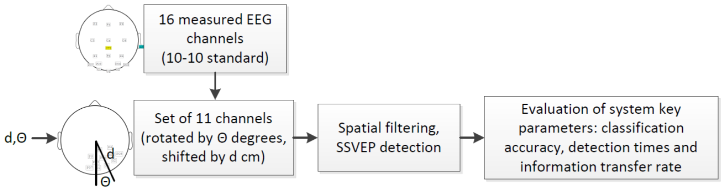

Fig. 4 Effect of displacement of the measurement electrodes on the parameters of the SSVEP based BCI system

For each user from Groups A, B and C, the original, 16-channel EEG data (seven electrodes over the primary visual cortex: PO7, PO3, O1, OZ, O2, PO4 and PO8; nine electrodes evenly distributed over the remaining cerebral cortex: P3, PZ, P4, C3, CZ, C4, F3, FZ and F4) were interpolated (for given displacement defined by shift d and rotation Θ) to the new set of eleven displaced measurement points (Fig. 5a). Data was interpolated both in space and time domain (tessellation-based linear interpolation) in the wide range of rotations ($\Theta = \pm 50$) and shifts ($d = \pm 4$ cm). Rules for d and Θ directions are depicted in Fig. 5b.

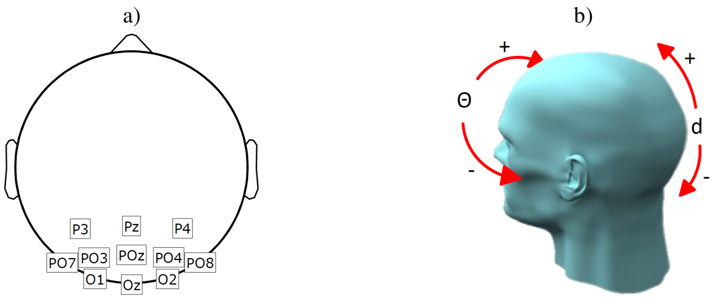

Fig. 5 Set of 11 EEG electrodes for $\Theta = 0$ and $d = 0$ cm (a). Rules for d and Θ directions (b)

Data for subjects were divided after the interpolation into shorter fragments, containing several stimulation patterns (extracted based on the binary stimulation on and off markers recorded along the original measurement data). The algorithm was evaluated with window length of 2.56 s. Data window step was set to 0.16 s.

Results (classification accuracy, average detection times and information transfer rates) were evaluated in a 5° x 5 cm grid of Θ and d displacement coordinates independently in each group (Fig. 6, Fig. 7 and Fig. 8). Classification accuracy was defined as the number of correctly classified commands relative to the total number of commands classified by the system. Detection time was measured from the moment when the stimulation symbol was switched on to the moment when BCI system detected a command. Information transfer rate (amount of information which can be transferred between the human brain and the BCI system per minute) was defined as:

$$B_t = \frac{60}{T_D}\left(\log_2(N) + P\log_2(P) + (1-P)\log_2\left(\frac{1-P}{N-1}\right)\right), \tag{1}$$

where N denotes the number of commands (5 in case of this particular system), P denotes classification accuracy and T_D denotes average detection time. All system parameters obtained for each user, were averaged in each of the subject groups for every considered misplacement.

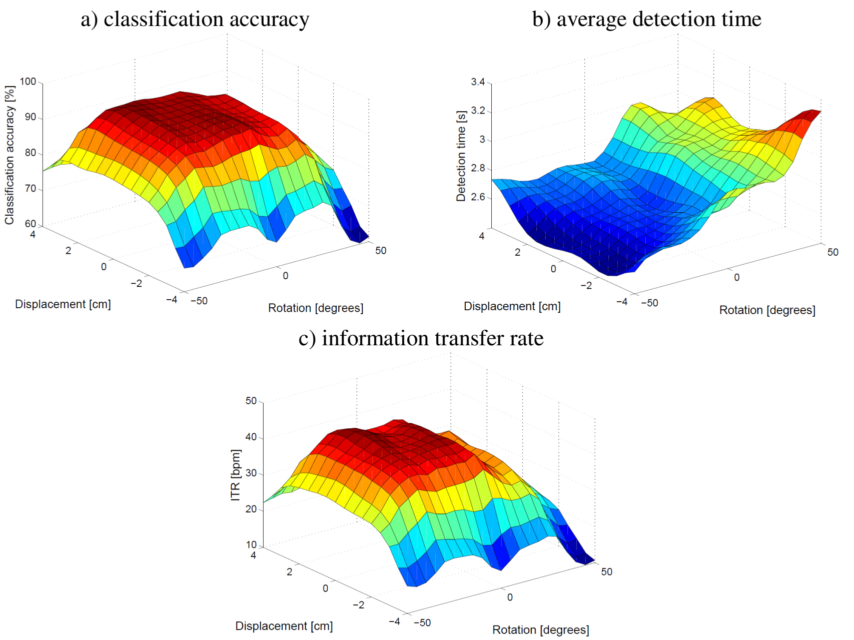

Fig. 6 Parameters of the SSVEP-based BCI system for Group A. Acceptable rotation Θ = -40° - +25°, acceptable shift d = -2.5 - +3.0 cm

Additionally, acceptable rotation and shift values were determined for each case (areas on Θ-d plane, over which classification accuracy does not change by more than ±10% in terms of the value calculated for Θ = 0° and d = 0 cm).

It can be observed in Figures 6, 7 and 8, that the proposed CACC method provides a high tolerance for the SSVEP BCI system electrode placement. Allowable, average misplacement of the electrode set (regardless of the subjects' group), within which none or only limited decrease of the device performance is observed can be defined in proposed displacement coordinates as rotation Θ = ±25° and shift d = ±3.0 cm.

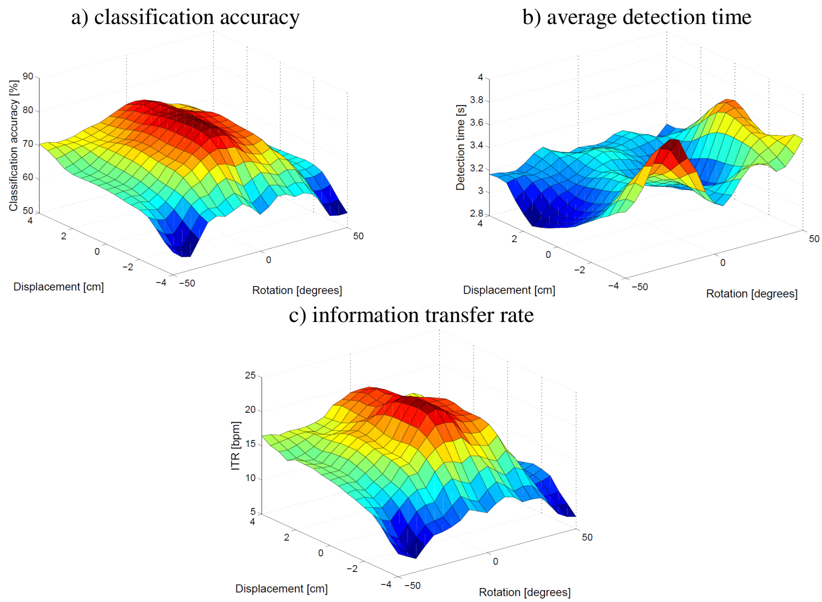

Fig. 7 Parameters of the SSVEP-based BCI system for Group B. Acceptable rotation Θ = -25º - +25º, acceptable shift d = -2.0 - +3.0 cm

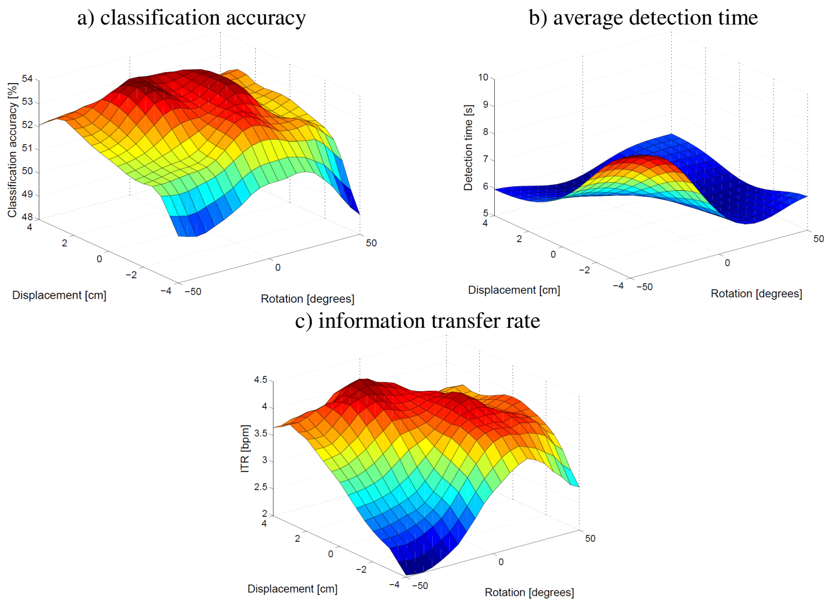

Fig. 8 Parameters of the SSVEP-based BCI system for Group C. Acceptable rotation Θ = -45º - +45º, acceptable shift d = -3.5 - +4.0 cm

4 Summary and Conclusions

It has been shown the SSVEP is a promising paradigm for fast and accurate brain-computer interfaces. The results of our offline experiments demonstrated that the proposed CACC detection method provides stable performance, robustness and reliability in a wide range of measurement electrode misplacements and diversity within users' EEG responses. It is able to identify optimized, weighted combinations of electrode signals and compensates shifts of the electrodes set on top of the subject's head for a large group of users within rotations of ±25° and displacements of up to ±3 cm. This shows its potential to account for individual user anatomical and physiological characteristics. It also proves, that the optimization of SSVEP detection algorithms and their hardware/software implementation for real time SSVEP detection is an important research avenue. But it must be remembered that the BCI research and its various possible applications raise important ethical issues that need to be discussed in different communities to promote acceptance and develop adequate policies [Nijboer et al. 2011].

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Domain Usability, User's Perception

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Abstract. The term 'usability' is generally used today to identify the degree of a user interface[1], application or a device to which it satisfies the user during usage. It is often referred to as "user friendliness" or "software ergonomics". In this paper we argue that usability is formed by two inseparable parts. The first is the *ergonomic usability*, the second aspect we call *domain usability*. During our research we found out, that domain usability is equally important as ergonomic usability, however, it is often neglected by software designers. In this paper we introduce new definitions of understandability and domain usability. Finally the total usability is formed by two aspects – domain and ergonomic. We hope this paper to be a guide or a rule for creating applications that are as close as possible to a domain user. The goal of this paper is to draw attention to domain usability and to stimulate further research in this area.

1 Introduction

> „Current graphical user interfaces are based on metaphors of real world objects and their relations which are well known to anyone from everyday life. Metaphors are presented by the user interface in graphical form as windows, icons and menus".
>
> K. Tilly and Z. Porkoláb [Tilly and Porkoláb 2010]

Usability is often connected with such words as "ergonomics", "human friendliness", user satisfaction with using the application or device, usefulness, effectiveness. Nielsen's definition of usability [Nielsen 1994] is up to this day still used as the cornerstone of defining and evaluating usability and also for placing additional guidelines for creating UIs. But neither the Nielsen's definition nor the known guidelines (such as the ones defined by Badashian [Badashian et al. 2008] or the Java look & feel design guidelines, W3C Web Content Accessibility Guidelines and Android UI Guidelines) explicitly deal with the side of the usability related to the domain content or consistency of UI domain dictionary at all, or they refer to it only in specific boundaries of their context.

[1] It is natural, that the general term *usability* refers also to software applications or devices in general. Our research is however aimed at UIs therefore, when referring to our research, we will refer to the usability of UIs. Our definitions can also be applied generally to any application or device used in a particular domain.

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We think there is a need for defining domain usability as an important attribute of usability. That way at least a basic guide would exist for designing and creating applications, which would correspond to the real world and which would be closer to a domain user. Billman's experiment [Billman et al. 2011] shows the importance of matching the application's terminology with the real world. Billman proved that applications, which have a domain structure better matching the real world, have better usability and thus provide higher performance to their users.

Without the correct terms used in the application's UI, the UI is less usable. Although the UI is really good-looking and ergonomic, if the users do not understand the labels of buttons or menu items, they cannot work with it and hence the whole application is useless. Consequently the domain usability is of a great importance and it can be the decisive point between the application success and failure.

Currently there is a huge amount of applications, which differ not only by their appearance, but also by the terminology used. Even different systems in one specific domain differ in their textual content. During the design and implementation software designers and programmers usually aim to create good-looking and perfectly error-free applications. They arrange the UI components effectively so the end users would not be restrained in their work. The well-known rule of thumb is as follows: "The application should assist the user while performing their work, not getting in the way of it". Programmers however often have a different perspective of how to work with the application in opposite to domain users. Programmers are often more experienced in working with computers and they have their established style of work. But from the domain point of view, they often-times have only a little knowledge about the specific domain, for which the application is developed, because usually they are not domain experts. Thus oftentimes they are not capable of transferring the domain terms, relations and processes correctly into the application.

To summarize our knowledge we identified the main problems as follows:

- There are no clear rules for designing the **term structure** of an application, so it would correspond with the domain.
- There are no official guidelines describing applications, which should match the real world or map domain **terms** and **processes**.
- Even if there were any guidelines and rules, the variety of human thinking, ambiguity and diversity of **natural language** represents a problem when evaluating the correctness of the terminology of applications.

To solve the first two problems, we strive for defining domain usability and introduce examples to illustrate the domain usability definition. We realize that defining the domain usability is not and will never be exact, because of the ambiguity and diversity of the natural language and variety of each person's thinking. It can however serve as a guide or rule for creating applications in a manner, that they would be as close as possible to a domain user.

The goal of this paper is to define and explain domain usability and thus to: i) point out to the problem of the existence of UIs, which are created without respect to their domain; ii) to draw attention to the importance of domain usability; and iii) to stimulate, as much as possible, the research in this area and the creation of domain usability evaluation methods and tools.

This research was not a standalone idea. Our general research area is *automatized domain usability evaluation (ADUE) of UIs*. During the previous three years we conducted an extensive analysis in the area of automatic usability evaluation and semantic UIs and we conducted a research in ADUE. Currently we are preforming experiments in the area of automatized formalization of UIs and automatized domain analysis of UIs which is a presumption for ADUE. Our DEAL extraction tool and its potential for ADUE was described in [Bačíková and Porubän 2013]. During our research we determined that without the proper domain usability definition, heuristics for ADUE cannot be defined. Based on our research and experience in these areas, we argue for this definition.

The contributions of this paper are:

- Identifying the main problems associated with domain application UIs,
- Providing a new definition of domain usability,
- Identifying domain usability in the context of the general usability definition,
- Supporting the creation of applications, which better match the real world,
- Stimulating the research in the area of ADUE.

2 Original Definition of Usability

Usability was first defined by Nielsen [Nielsen 1994] as a whole (but diverse) property of a system, which is related to these five attributes: *Learnability, Efficiency, Memorability, Errors* and *Satisfaction*. Although different usability guidelines have been evolving through time, the usability definition remained unchanged since Nielsen first defined it in 1994 and it still serves as a fundamental guide to create usable software systems and to create new usability guidelines and usability evaluation and testing systems.

3 Ergonomic vs. Domain Usability

The common perception of usability is usually in the terms of user experience, satisfaction with using the application, application quality and effectiveness. Often it is seen from the ergonomic point of view and the domain aspect is neglected or omitted, even if it is included in the definition.

Each software system is developed for a concrete domain therefore its UI should contain *terms*, *relations* and describe *processes* from this specific domain for the user to be able to work with it. If the user does not *understand* the terms in the system's UI, then the whole application is less usable. This application feature can be called understandability. Based on our experience and research and pursuing the existing current work in the area of usability, we will define understandability as follows:

Understandability is the property of a system that affects usability and which relates to the following factors:

- *Domain content*: the UI terms, relations and processes should match the ones from the domain, which the UI is designed for.
- *Adequate level of specificity*: the UI made for a specific domain should not contain terms too general, even if they belong to a parent domain. On the other hand, the terms should not be too specific, if the system is used by people from a more general domain.
- *Consistency*: words used throughout the whole UI should not differ, if they describe the same functionality, the dictionary should be consistent.
- *Language barriers*: there should be no foreign words, the translation should be complete. The language of the UI should be the language of the user.
- *Errors*: a UI should not contain stylistic and grammatical errors.

We can use the term ***domain usability*** to describe the aspect of usability, which is affected by the factor of UI understandability. Although domain usability is affected by understandability, it is not true that understandability = domain usability. Understandability can affect other attributes besides domain usability, for example accessibility.

In the context of usability, understandability can also be perceived as the *relation between the user* (his language) *and the product* (the system).

In the end the *overall usability* can be defined as a connection of two basic aspects: ergonomic usability and domain usability. These two types can be combined together when evaluating usability. Consider a test of the number of steps needed to execute a particular task as an example: a user gets a task which he should execute on two different UIs made for the same domain. Both ergonomic and domain factor affect the completion of the task.

Nielsen's definition may also, in a certain context, involve aspects of domain usability, which can be identified in the following attributes:

- *Learnability*: A system is easier to learn if it contains the proper terms, known to its users. If the correct terms, relations and processes are described by the system, then the users remember the actions better.
  If a UI would not contain any terms, then a user would remember the sequence of steps needed to perform a task as a sequence of clicks on different graphical UI components. The user would remember these sequences as a visualization of these graphical elements and their sequence. However, if the UI also contains the right terms and their sequence is correct (describing a real task in practice), then this sequence is remembered by user not only in the graphical form, but especially as a sequence of terms (e.g. *File* → *Open* → find a file → *OK*) which the user is looking for in the UI when performing the task. This implies that the combination of *both* graphical *and* textual form is more memorable when compared to *only* graphical.

- *Efficiency*: The better the users remember a sequence of steps needed to perform a task, the more efficiently they can perform their work.
- *Memorability*: This aspect was already described in connection to learnability. There are two types of people: people who primary remember things visually and people who remember the actual content. To provide them the combination of both is always better than to give them only one of them. If a system uses the terms known to a domain user and it has the correct positioning of components and good visual properties, the user can choose to remember one of them to be able to find them faster. If the terms in the UI are not known to the user, then they are harder to remember compared to the previous case, because the user has to remember only the positions and appearance of the components without the possibility to choose the other attribute to remember (terms).
- *Errors*: Errors can be both ergonomic and contextual.
- *Satisfaction*: Since UIs encapsulate both textual and graphical aspects, the overall impression is influenced by both aspects. The good looking system could be pleasant to use, but incorrect terms disrupt the user experience. On the contrary, the system could contain the right terms, but if it is ugly or not pleasant to use, the users are less satisfied.

Both ergonomic and domain are two parts affecting the overall usability and Nielsen's definition perfectly covers both of them. However, we argue that domain usability is hidden in the Nielsen's definition and that is the reason why it is often omitted by software designers. Our definition relates directly to domain content of UIs. And based on our definition it is possible to evaluate domain usability - even in an automatized fashion as we have indicated in our feasibility analysis of ADUE in [Bačíková and Porubän 2013].

Since domain usability is a subset of usability, metrics and categorization applicable on general usability can also be applied on domain usability. For example according to Hilbert and Redmiles [Hilbert and Redmiles 2000], domain usability as well as general usability can be divided into *formative* and *summative*.

4 Aspects of Understandability

The individual aspects of understandability will be further discussed in the following subsections along with illustrative examples.

4.1 Domain Content

Imagine a system manufactured for the domain of medicine. Without any explanation or referring to sources for better understanding the issue, the UI of such a system should not contain technical *terms* and *relations* from domains of building construction or traffic. It however should definitely contain terms from medicine. The logical reason is that a medic is usually not familiar with the technical dictionary of a building constructor or a traffic manager. Logically, the UI should also define *processes* from the specific domain of medicine by implementing sequences of events that can be executed on the UI. When performing a task, the user should follow the steps similar to the ones in the real world. For example, one cannot send money into another account without entering the account number and amount. In addition, the domain content should be mapped correctly.

Fig. 1 describes an example of a user's view of a system, which was developed for a different domain. A *motorcycle seller* uses a system made for a different domain of *Car selling*. While the motorcycle seller is trying to find the functionality for selling motorcycles in the system, the system provides only the functionality for selling cars. The user spends time searching for the right term, which reduces the system's usability.

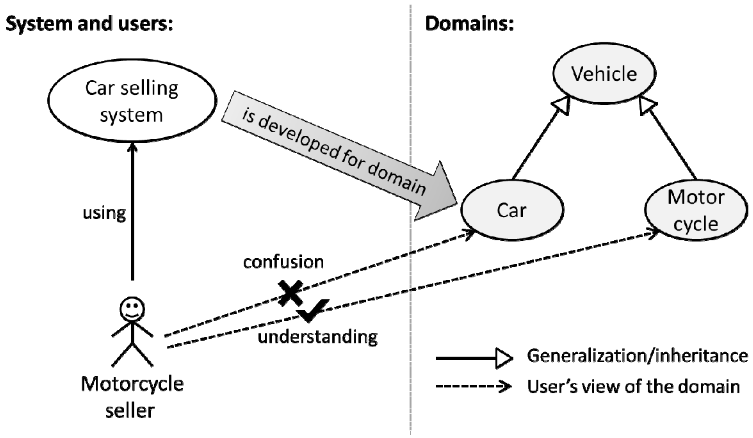

Fig. 1 The perception of a *Car selling system* by a user from the *Motorcycle domain*

While *Car* and *Motorcycle* domains are both subdomains of the *Vehicle* domain, the terms in both domains are not interchangeable. Therefore the *Car selling system* will never be a perfect choice for a *Motorcycle seller* and a *Motorcycle selling system* should be used instead.

Another example is when programmers oftentimes forget about the users and put functionalities and implementation details into the UI, which are very important for programmers, but not important for the users at all. For example logging, icons indicating the state of the system, database ids etc. Such functionalities are unknown to the users and they have no interest to see them in the application.

4.2 Adequate Level of Specificity

It is important to select an adequate level of specificity when creating an application's domain dictionary. Terms that are too generic usually reduce the