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From the Editors

The history of human-system interactions is as long as this of human civilization. Human beings by natural evolution have been adapted to live in groups and to commonly fight for food and shelter against other groups or against the natural forces. The effects of this fight was depended on two basic factors: on ability to communicate among collaborating groups or persons and on capability to understand and to preview the principles and behavior of the opponent groups or forces. This, in fact, is also the main contemporary human-system interaction (**H-SI**) problem. A *system* is in this case – in a narrow sense – considered as a system created on the basis of electronic, optoelectronic and/or computer technology, in order to aid humans in reaching some of their vital goals. So-defined system is not only a passive tool in human hands; it is rather an active partner equipped with a sort of artificial intelligence, having access to large information resources, being able to adapt its behavior to the human requirements and to collaborate with the human users in order to reach their goals. The area of such systems' applications practically covers most of human activity domains and is still expanding. Respectively, the scientific and practical **H-SI** problems need a large variety of sophisticated solution methods. This is why the **H-SI** problems in the last decades became an important and extensively growing area of investigations.

In this book some examples of the **H-SI** problems and solution methods are presented. They can be roughly divided into the following groups: **a)** Human decisions supporting systems**, b)** Distributed knowledge bases and WEB systems, **c)** Disabled persons aiding systems, **d)** Environment monitoring and robotic systems, **e)** Diagnostic systems, **f)** Educational systems, and **g)** General **H-SI** problems**.** As usually, some papers to more than one class can be assigned and that is why the classification suits only to a rough characterization of the book contents.

The human decisions supporting systems are presented by papers concerning various application areas, like e.g.: enterprises management (A. Burda and Z.S. Hippe; T. Żabiński and T. Mączka; S. Cavalieri), healthcare (E. Zaitseva), agricultural products storage (W. Sieklicki, M. Kościuk and S. Sieklicki), visual design (E.J. Grabska), sport trainings planning (J. Vales-Alonso, P. López-Matencio, J.J. Alcaraz, et al.). The papers by I. Rejer; J.L. Kulikowski; K. Harężlak and A. Werner; E. Nawarecki, S. Kluska-Nawarecka and K. Regulski; A. Grzech, A. Prusiewicz and M. Zięba; A. Andrushevich, M. Fercu, J. Hopf, E. Portmann and A. Klapproth to various problems of data and knowledge bases exploration in computer decision-aiding systems are devoted.

The WEB-based, including distributed knowledgebases based systems, are presented in the papers by N. Pham, B.M. Wilamowski and A. Malinowski; M. Hajder and T. Bartczak. K. Skabek, R. Winiarczyk and A. Sochan present a concept of a distributed virtual museum. An interesting concept of managing the process of intellectual capital creation is presented by A. Lewicki and R. Tadeusiewicz. A document-centric instead of data-centric distributed information processing paradigm in a paper by B. Wiszniewski is presented. New computer networks technologies by K. Krzemiński and I. Jóźwiak and by P. Rożycki, J. Korniak and J. Kolbusz are described. The last two Authors also present a model of malicious network traffic. Selected problems of distributed network resources organization and tagging are presented by A. Dattolo, F. Ferrara and C. Tasso as well as by A. Chandramouli, S. Gauch and J. Eno.

Various problems of disabled persons aiding by their communication with external systems improvement in a next group of papers are presented. The papers by M. Porta and A. Ravarelli and by D. Chugo, H. Ozaki, S. Yokota and K. Takase to physically disabled persons aiding systems are devoted. The spatial orientation and navigation aiding problems by P. Strumillo; A. Śluzek and M. Paradowski and by M. Popa are described. A proposal of an ubiquitous health supervising system by P. Augustyniak is presented. The problems of hand posture or motions recognition for disabled persons aiding by R.S. Choraś and by T. Luhandjula, K. Djouani, Y. Hamam, B.J. van Wyk and Q. Williams have been described while similar problems for a therapy of children supporting by J. Marnik, S. Samolej, T. Kapuściński, M. Oszust and M. Wysocki are presented.

A paper by Mertens, C. Wacharamanotham, J. Hurtmanns, M. Kronenbuerger, P.H. Kraus, A. Hoffmann, C. Schlick and J. Borchers to a problem of communication through a touch screen improvement is devoted. Some other problems of tactile communication by L. M. Muñoz, P. Ponsa and A. Casals are considered. J. Ruminski, M. Bajorek, J. Ruminska, J. Wtorek, and A. Bujnowski present a method of computer-based dichromats aiding in correct color vision.

In the papers by A. Roman-Gonzalez and by J.P. Rodrigues and A. Rosa some concepts of direct EEG signals using to persons with lost motor abilities aiding are presented. Similarly, some basic problems and experimental results of a direct brain-computer interaction by M. Byczuk, P. Poryzała and A. Materka are also described.

A group of papers presented by Y. Ota; P. Nauth; M. Kitani, T. Hara, H. Hanada and H. Sawada; D. Erol Barkana, and by T. Sato, S. Sakaino and T. Yakoh contains description of several new robotic systems' constructions.

The group concerning diagnostic systems consists of papers mainly to medical applications devoted (K. Przystalski, L. Nowak, M. Ogorzałek and G. Surówka; P. Cudek, J.W. Grzymała-Busse and Z.S. Hippe; A. Świtoński, R. Bieda and K. Wojciechowski; T. Mroczek, J.W. Grzymała-Busse, Z.S. Hippe and P. Jurczak; R. Pazzaglia, A. Ravarelli, A. Balestra, S. Orio and M.A. Zanetti; M. Jaszuk, G. Szostek and A. Walczak; Gomuła, W. Paja, K. Pancerz and J. Szkoła). Besides, in a paper by R.E. Precup, S.V. Spătaru, M.B. Rădac, E.M. Petriu, S. Preitl, C.A. Dragoş and R.C. David an industrial diagnostic system is presented. K. Adamczyk and A. Walczak present an algorithm of edges detection in images which in various applications can be used.

In the papers by L. Pyzik; C.A. Dragoş, S. Preitl, R.E. Precup and E.M. Petriu and by E. Noyes and L. Deligiannidis examples of computer-aided educational systems are presented. K. Kaszuba and B. Kostek describe a neurophysiological approach to learning processes aiding.

The group concerning general **H-SI** problems consists of the papers presented by T.T. Xie, H. Yu and B.M. Wilamowski; H. Yu and B.M. Wilamowski; and G. Drałus. General problems of rules formulation for automatic reasoning are described by A.P. Rotshtein and H.B. Rakytyanska as well as by M. Pałasiński, B. Fryc and Z. Machnicka. Close to the former ones, S. Chojnacki and M.A. Kłopotek consider a problem of Boolean recommenders evaluation in decision systems. Various aspects of computer-aided decision making methods are presented in the papers by M.P. Dwulit and Z. Szymański, L. Bobrowski and by A. Pułka and A. Milik. A problem of ontology creation by A. Di Iorio, A. Musetti, S. Peroni and F. Vitali is described. At last, A. Małysiak-Mrozek, S. Kozielski and D. Mrozek present a concept of proteins structural similarity describing language.

This panorama of works conducted by a large number of scientists in numerous countries shows that **H-SI** is a wide and progressive area of investigations aimed at human life conditions improvement. It also shows that between different scientific disciplines new and interesting problems arise and stimulate development on both sides of the borders.

Editors

Zdzisław S. Hippe
Juliusz L. Kulikowski
Teresa Mroczek

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Part VII: General Problems

Part IV

Environment Monitoring and Robotic Systems

SSVEP-Based Brain-Computer Interface: On the Effect of Stimulus Parameters on VEPs Spectral Characteristics

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Abstract. It is demonstrated that spectral characteristics of steady-state visual evoked potentials (SSVEPs) in a brain-computer interface (SSVEP-based BCI) depend significantly on the stimulus parameters, such as color and frequency of its flashing light. We postulate these dependencies can be used to improve the BCI performance – by proper design, configuration and adjustment of the visual stimulator. Preliminary results of conducted experiments show also that SSVEP characteristics are strongly affected by subjects biodiversity.

1 Introduction

Brain-Computer Interface (BCI) is an alternative solution for communication between human and machine. In the case of traditional interfaces, the user is expected to make voluntary movements to control a machine (e.g. movements of hands and fingers are required to operate a keyboard). In contrast to commonly used human-machine interfaces, BCI device allows sending commands from brain to computer directly, without using any brain's normal output pathways or peripheral nerves and muscles [Wolpaw et al. 2000]. This unique feature contributed to great interest in the study of neural engineering, rehabilitation and brain science during last 30-40 years. Currently available systems can be used to reestablish a communication channel for persons with severe motor disabilities, patients in a "locked-in" state or even completely paralyzed people. It is predicted that within next few years BCI systems should be practically implemented.

BCI device measures ongoing subject's brain activity, usually electroencephalographic (EEG) signals, and tries to recognize mental states or voluntarily induced changes in the brain activity. Extracted and correctly classified EEG signal features are translated into appropriate commands which can be used for controlling a computer, wheelchair, operating a virtual keyboard, etc. The various systems differ in the way the intention of the BCI user is extracted from her/his brain electrical activity. Among the approaches, two groups of techniques are most popular, based on:

Z.S. Hippe et al. (Eds.): Human – Computer Systems Interaction, AISC 99, Part II, pp. 3–14.
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- identifying changes of the brain activity which are not externally triggered,
- detecting characteristic waveforms in EEGs, so called Visual Evoked Potentials (VEP), which are externally evoked by visual stimulus.

The class of VEP based BCI systems offer many advantages: easy system configuration, high speed, large number of available commands, high reliability and little user training.

Visually evoked potentials can be recorded in the primary visual cortex which is located at the back part of the human brain. VEPs reflect user's attention on visual stimulus which may be in the form of short flashes or flickering light at certain frequency. VEPs elicited by brief stimuli are usually transient responses of the visual system and are analyzed in time domain. VEPs elicited by flickering stimulus are quasi periodic signals, called Steady-State VEP (SSVEP), and are analyzed in frequency domain.

Fig. 1 shows the simplified block diagram of a typical VEP based BCI system. Each target (a letter, direction of a cursor movement, etc.) in a VEP based BCI is encoded by a unique stimulus sequence which in turn evokes a unique VEP pattern. A fixation target can thus be identified by analyzing the characteristics of the VEP: a time of appearance (for flash VEP detection) or fundamental frequency (for SSVEP detection).

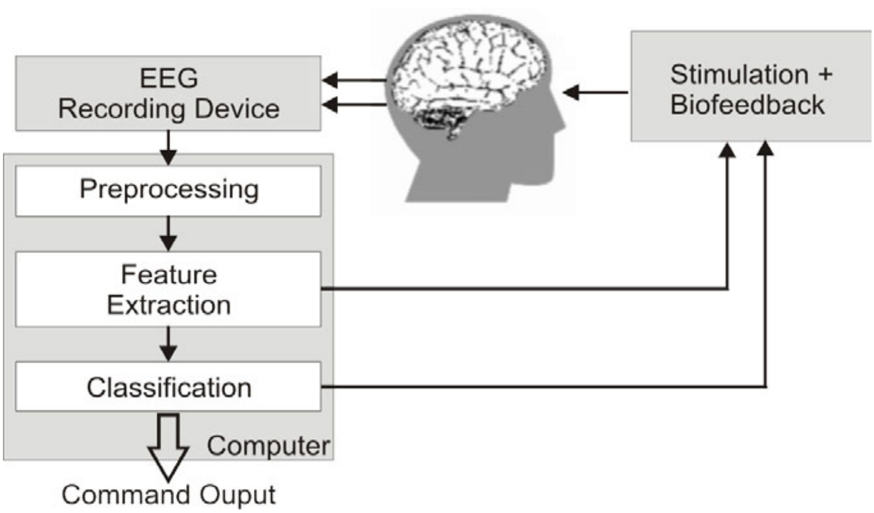

Fig. 1 A simplified block diagram of a typical VEP-based BCI system

2 SSVEP-Based BCI Systems

In majority of VEP-based BCIs, frequency encoding is used (interface operation is based on SSVEP detection). Energy of SSVEP signals is concentrated in very narrow bands around the stimulation frequency and its harmonics, whereas spontaneous EEG signal may be modeled as a Gaussian noise whose energy is spread over the whole spectrum. Thus SSVEPs can be easily detected using feature extraction based on spectral analysis and classification algorithms. Moreover neither system nor user requires any training since the EEG response to stimulus is known in advance. This approach results in a minimal number of electrodes required for proper operation of BCI, the ability of real-time operation and low hardware cost. Therefore, steady-state visual evoked potentials give raise to a very promising paradigm in brain-computer interface design.

Currently, development of BCI systems for real-life applications is emphasized. Research teams still encounter many problems in changing demonstrations of SSVEP-based BCIs into practically applicable systems [Wang et al. 2008]. Two major constraints are: system capacity (a number of available targets or commands) and detection time. They are directly related to speed and reliability of BCI. The overall performance of the BCI system can be expressed numerically with information transfer rate (ITR), which describes the amount of information transferred per unit time (usually minute). ITR is defined as [Wolpaw et al. 2000]:

$$ITR = s \cdot \left[\log_2 N + P \log_2 P + (1-P) \log_2 \left(\frac{1-P}{N-1}\right) \right], \qquad (1)$$

where s is the number of detections per minute, N is the number of possible selections, and P is the probability that the desired selection will actually be detected. It is assumed that each selection has the same probability of being the one that user desires and each of the other selections have the same probability of selection. ITR of currently available systems usually varies from 10 up to 50 bits/minute.

System capacity is limited by the stimulation frequency band (number of available stimulation frequencies), which is directly related to brain electrophysiology and visual information processing mechanisms [Regan 1989]. Detection speed is limited by signal-to-noise ratio (SNR), which may be decreased in subjects with strong spontaneous activity of the visual cortex.

Limitations described above can be addressed with different approaches:

- Research on stimulation methods that will increase interface capacity when using a limited number of stimulation frequencies: time, frequency or pseudorandom code modulated VEP stimulations [Bing et al. 2009], phase coding, multiple frequency stimulation methods [Mukesh et al. 2006], etc. Advanced methods of stimulation can be used to design interface with more commands available without a need to extend the stimulation frequency band.

- Research on lead selection for the purpose of SNR enhancement – performance or even applicability of SSVEP-based system is limited due to biological differences between users [Wang et al. 2004]. For subjects with different SSVEP source locations, optimized electrode positions can help achieve high signal-to-noise ratio and overcome SSVEP detection problems.
- Research on stimulation methods for the purpose of SNR enhancement – for example half-field alternate stimulation method described in [Materka and Byczuk 2006].

3 Prototype BCI System

In our previous research we focused on SNR enhancement. The result of our work was a novel technique of alternate half-field stimulation. The method was practically implemented and tested in the prototype BCI system [Materka et al. 2007] designed in the Institute of Electronics at the Technical University of Lodz. The system can be classified as a noninvasive, SSVEP-based, frequency encoded BCI. Simplified block diagram of the prototype interface is depicted in Fig. 2.

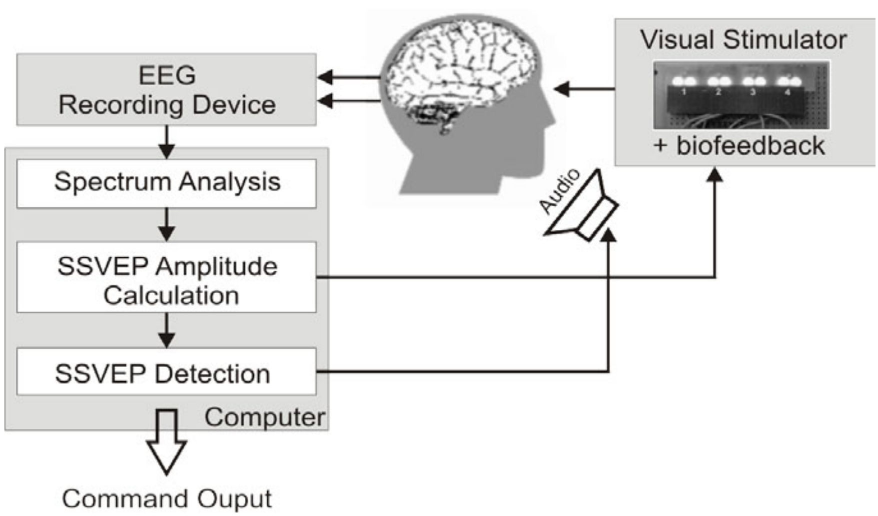

Fig. 2 A block diagram of the prototype SSVEP-based BCI system

The system was implemented as a virtual keypad. Visual stimulator consisted of 8 labeled targets (keys) flickering at different frequencies (Fig. 3). Each target contained three light-emitting diodes (LEDs): two LEDs for alternate stimulation (B) and additional LED as a biofeedback indicator (A), which constantly provided real-time information about amplitudes of the measured SSVEP signals.

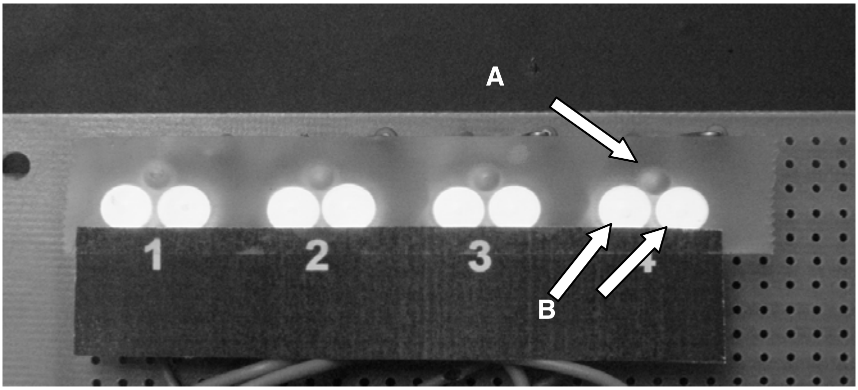

Fig. 3 A view of stimulator targets: A – fixation point and biofeedback indicator, B – stimulating lights

Proper arrangement of stimulation lights within single symbol ensures their images are positioned on the left and right half of the visual field on the human retina. This leads to SSVEP responses (with opposite phases) in the right and left half of the visual cortex, respectively. Differential measurement of the EEG signals from both halves of the visual cortex allows significant SNR increase of the measured SSVEP signals.

System operation and usability was tested with contribution of 10 volunteers. Tests showed it is much faster than conventional BCI devices based on SSVEPs. For the user who achieved the best results, detection time was 1.5s (40 detections per minute) with 0% error rate. In this case information transfer rate calculated according to formula (1) equals 120bits/minute.

High transfer rate of the interface was obtained mainly due to short detection times (direct result of SNR enhancement). Communication speed of the designed system would be sufficient for most applications but limited capacity makes its usage as a full-alphabet keyboard difficult. Thus new methods for increasing the number of available commands must be developed in order to design fully keyboard-compatible computer interface.

Preliminary observations showed that amplitudes of the detected SSVEP signals and the frequency band in which strong SSVEPs can be observed depend on some parameters of the stimulation, e.g. color, size, intensity, layout of stimulation lights and their frequency. Further investigation of the influence of these parameters on the spectral properties of the SSVEPs is the subject of our present research.

4 Experimental Setup

Two experiments were carried out using an alternate half-field stimulation technique. The EEG signal was measured differentially using two electrodes located on the left and right side of the occipital part of the scalp (positions O1 and O2 of the international 10-20 system of EEG electrode placement) with a reference electrode placed between them (position Oz). Amplified EEG signal was sampled at 200Hz. The user was sitting on a comfortable ergonomic chair to minimize activity of neck muscles which might produce EMG artifacts.

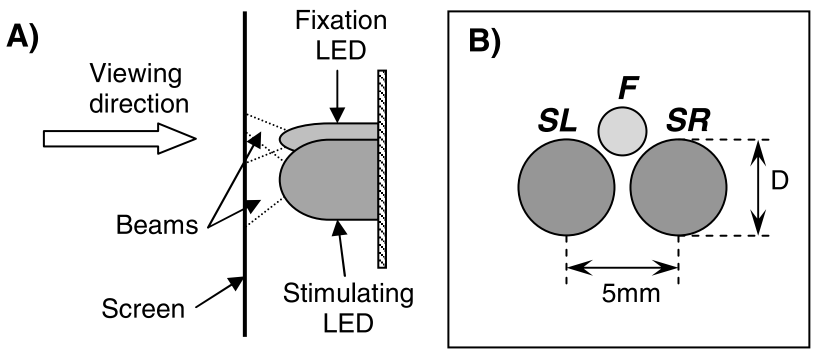

Fig. 4 A side view of the stimulator (A), a view of stimulating lights *SL*, *SR* and a fixation light *F* on the screen of stimulator (B)

Visual stimulator used in experiments consisted of three LEDs which were projecting the stimulus on the screen (Fig. 4) – to diffuse (blur) the image of the contrastive shape of the light-emitting semiconductor region in the LED devices. The stimulus was in the form of two lights (left – SL, and right – SR) that flash with the same frequency, alternatively in time. An extra light source (F) was placed between two stimulating lights, slightly above them. This light was used as a fixation point. Additionally, intensity of the light F was changing according to the calculated SSVEP amplitude, to provide a feedback between the user and the system. This helped the user to concentrate his/her attention on the fixation light F.

Table 1 Stimulator parameters

Experiment	1	2
Diameter (D)	4mm	6mm
Color of lights SL and SR	Green	Red
Color of light F	Red	Green
Intensity of lights SL and SR	Low	High

The distance between the screen of stimulator and the user's eyes was about 50cm. Two experiments were carried out using different sets of light, described in Table 1. Intentionally all stimulation parameters were changed in the experiment 2 compared to experiment 1, just to demonstrate that these parameters have measurable influence on the SSVEP characteristics. More comprehensive examination of the effect of systematic changes in parameters on the SSVEP BCI performance is currently under way in our laboratory In both experiments, the diameter of fixation light F was 3mm and modulation depth of stimulating lights was 100% (sinusoidal modulation). Stimulation frequency was changing every 5-10 seconds within the range 20-50Hz with a fixed step of 0.78Hz. Each experiment lasted about 5-7 minutes.

5 Results

For rough comparison of SSVEP amplitudes in both experiments, power spectral density (PSD) of EEG signals were computed in a sliding window of 1.28s duration (256 samples). This window corresponds to the frequency resolution of about 0.78Hz which was a frequency step of the stimulus. Prior to FFT calculation, the measured signals were filtered using comb filters to reduce the spectral leakage of Fourier analysis [Materka and Byczuk 2006]. Computed spectrograms are shown in Fig. 5 and Fig. 6 for experiment 1 and 2 respectively, carried out by the same user (subject 1).

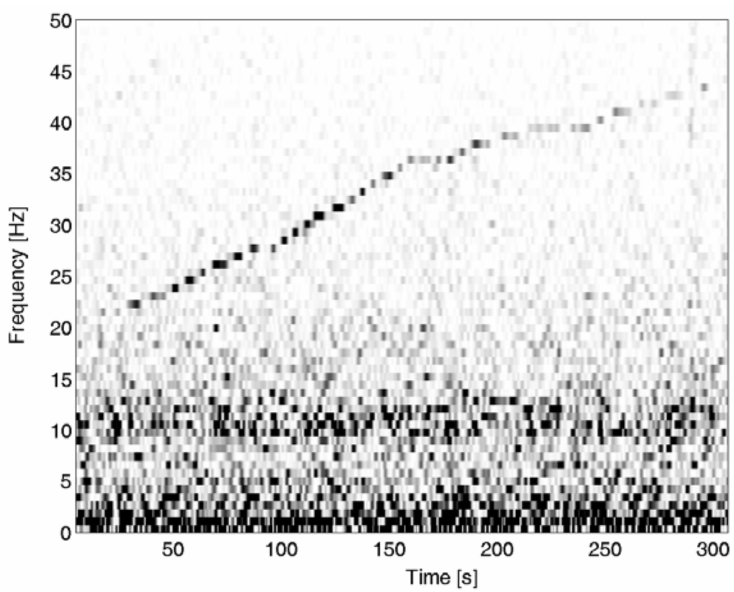

Fig. 5 A spectrogram of measured EEG signal in experiment 1

A comparison of the spectra illustrated in Fig. 5 and Fig. 6 demonstrates different frequency ranges with strong SSVEP components. In experiment 1 strong SSVEPs are visible in the range 20-40Hz whereas in experiment 2 SSVEP components may be observed at higher frequencies, in the range 30-50Hz. It seems that evoked potentials are easier to detect in Fig. 5 (because they have higher amplitude than SSVEPs in Fig. 6), so stimulation settings used in experiment 1 are better. However, they are not necessarily weaker in terms of signal power distance from the noise power floor, as will be discussed below.

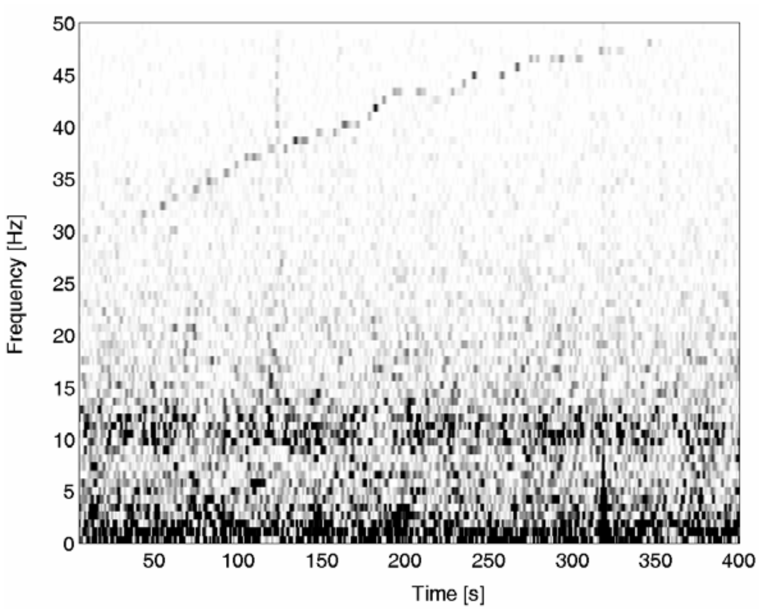

Fig. 6 A spectrogram of measured EEG signal in experiment 2

To compare both experiments more objectively, a signal-to-background ratio (SBR) for each SSVEP component was computed. An SBR coefficient for frequency f is defined here as a ratio of the PSD at frequency f to the mean PSD value of the signal components at N=10 adjacent discrete frequencies:

$$SBR(f) = \frac{N \cdot PSD(f)}{\sum_{k=1}^{N/2} (PSD(f - k \cdot \Delta f) + PSD(f + k \cdot \Delta f))}, \quad (2)$$

where Δf = 0.78Hz is a frequency resolution of Fourier analysis applied for PSD calculation. Maximum values of SBR coefficients for each SSVEP frequency were collected and frequency characteristics for each experiment were estimated using polynomial approximation. A comparison of SBR characteristics for the two experiments carried out by the same subject is shown in Fig. 7.

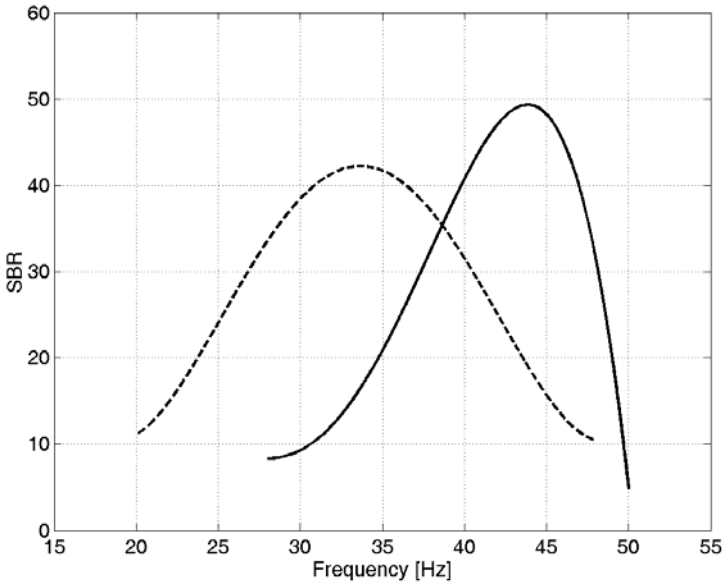

Fig. 7 A comparison of SBR frequency characteristics measured in experiment 1 (dashed line) and in experiment 2 (solid line)

SBR coefficients obtained in experiment 2 have higher peak value than in experiment 1, while Fig. 6 shows smaller SSVEP amplitudes than it is visible in Fig. 5. It means that EEG signal components other than SSVEP (so-called EEG noise) have much smaller amplitude than SSVEPs in experiment 2. This results in higher signal-to-background ratio. Characteristics presented in Fig. 7 confirm different frequency ranges of strong SSVEP in both experiments, shown in spectrograms (Fig. 5 and Fig. 6, respectively). If detection of SSVEP was done by comparing SBR with threshold value T=30, frequency range of detected SSVEPs would be about 27-40Hz (13Hz width) in experiment 1 and 37-48Hz (11Hz width) in experiment 2. Using different stimulation settings (e.g. in terms of color of the stimulus light) in a BCI system for frequencies below and above 38Hz (a cross-point of both characteristics in Fig. 7) it is possible to increase stimulation frequency range to 27-48Hz (21Hz width). This may lead to an increased number of available BCI commands.

Both experiments were repeated for another subject (Subject 2). Fig. 8 and Fig. 9 present SBR characteristics of the EEG signals measured from Subject 2 in experiment 1 and experiment 2 respectively, calculated according to formula (2).