HOW SCIENCE SPIES ON NATURE AND HOW TECHNOLOGY IMITATES NATURE

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PREFACE

In the past years, tremendous investments in time, energy and resources have been made to learn the mutual relationship in the triangle of science-technology--nature. Successes in science and technology have been achieved due to the possibility of spying on nature by means of various methods and techniques. Recent exceptional advances in science and technology suggest that the above mentioned triangle will fascinate scientists, engineers, physicists and philosophers of science for a very long time to comein, and have prompted us to organize the conference in Gdańsk on 25–28.September 2011 entitled „*How Science Spies on Nature and How Technology Imitates Nature*".

The objective of this conference was to create a forum for researchers who are involved in natural sciences, technology and in the philosophy of science in order to share views, learn about the relationship expressed by the triangle of science-technology-nature, and to develop new ideas or points of view for the benefit of their own research efforts. Another aim of the conference was to inform the public about this relationship. Consequently, we have proposed a discussion panel at the end of the conference entitled „*The Relationship Between Science*, *Technology and Nature*".

We gratefully acknowledge the generous financial support received firstly from **The University of Gdańsk** and then from the **Societas Humboldtiana Polonorum.**

Andrzej M. Kłonkowski & *Marian Jaskuła*
Editors
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HOW AND WHY BRAIN-COMPUTER INTERFACES SPY ON OUR INTENTIONS

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1. INTRODUCTION

There are ~10^{12} neurons in the brain, each of them making up to 10^4 connections with the others. Electrical impulses carried by these connections sum up at the receiving neurons, eventually causing them to fire up, and send another impulse.

Even with this dramatically oversimplified binary model of neurons operation, any approximate count of different possible connection schemes is huge, compared e.g. to the number of protons in the Universe or its age. That should humble our declarations about cracking the neural code, especially given that to decode the workings of the brain we have no better tool than the brain itself.

In spite of that, nowadays brain-computer interfaces (BCIs) have definitely moved from the domain of science-fiction (*Matrix*, *Avatar*, *Surrogates*, *Spiderman 2*…) into the scientific laboratories, and today we are working on the transfer of this technology to the bedsides of the most needing patients.

2. HOW

The aim of a brain-computer interface (BCI) is to provide a non-muscular communication channel, or "*to liberate the brain from the constraints imposed by the body and make it capable of using virtual*, *electronic and mechanical tools to control the physical world*. *Just by thinking*".[1] In the following we shall explain how this can be possible using the traces of brains electrical activity recorded from the surface of the head.

3. EEG AND EVOKED POTENTIALS

As described in the 1. Introduction, communication and information processing inside the brain is carried mostly by means of electrical impulses. If large populations of neurons operate synchronously, sum of their activities can be recorded from the surface of the head. This signal, presented in Fig. 1, is called electroencephalogram (EEG) [2].

Figure 1. Sample few seconds recording of the electroencephalogram (EEG), that is potential difference between two electrodes placed on the surface of the skull. Green arrows mark the time occurrences of repetitive stimuli

As we observe in Fig. 1, the signal *per se* does not seem to reveal much information about the underlying processes and thoughts. To detect a stimulus-related and phase-locked signal features we may use averaging in the time domain. Fig. 2 presents subsequent epochs of one second after each repetition of the stimulus and their average. Positive deflection of the average around 300 ms after the stimulus is called the P300 evoked potential. It reflects the phenomenon of selective attention, because it occurs only in response to the stimuli that we concentrate upon. If we average the EEG epochs time locked to occurrences of stimuli to which we do not pay attention, there will be no significant deflection.

P300 is a direct correlate of the selective attention, that allows us to build a non-muscular communication channel. It can be implemented by repetitive flashing subsequent choices of a menu and evaluating evoked potentials evoked by each item, to determine to which of the items subject was paying attention. Conscious concentration on the item that we want to select can be achieved, *e.g*., by counting its occurrences.

And it works! Communication channel built upon the above idea is called P300-based BCI, and it does exactly what a BCI is supposed to do: transfer to the computer a conscious selection – that is a decision – using nothing but the brain's activity, without using muscles.

In practical applications P300 BCI has drawbacks, related to the necessity of:

1) averaging several (usually a few) repetitions of brains responses, which decreases the resulting speed of communication,
2) keeping the flashing symbols in sight, which at least severely impairs the visual control of the environment during communication *via* BCI.

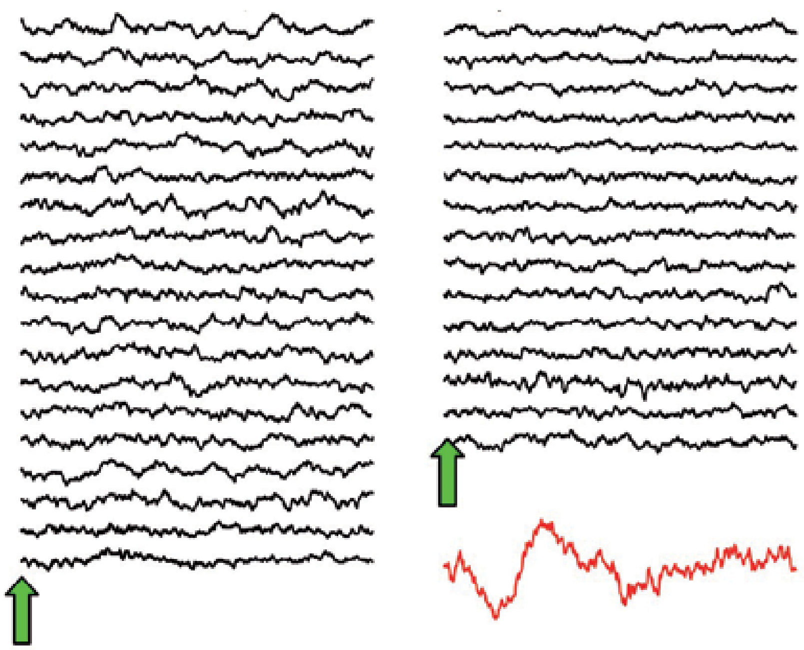

Figure 2. Black traces – subsequent 1-second epochs of EEG, cut from continuous recording in such a way that each epoch starts in the time instant of a subsequent stimuli. Red trace – their average

As for the latter, there is a BCI paradigm that does not involve vision and relies on motor imagery. EEG traces of imagination of the left or right hand movement (called also event-related desynchronization ERD or synchronization ERS) can be translated into commands to turn left or right. However, such systems are much more complicated than P300: they require using more electrodes on the head, much more complicated signal processing and extensive training of the user prior to using the system – using a kind of neurofeedback procedure, user learns to produce such a imagination of movement that can be decoded by a computer; this may take several session, and some people fail to achieve satisfactory performance in this paradigm.

As for the speed, a faster but still relatively simple to use BCI can be built upon a phenomenon called steady-state visual evoked potential (SSVEP).

4. STEADY-STATE VISUAL EVOKED POTENTIALS (SSVEP) AND BCI

SSVEP occurs when we watch a symbol flickering with a stable frequency – the frequency of its flickering is reproduced in the EEG signal recorded from the surface of the head above the visual cortex (back of the head). Selective attention enters into play when we see several items, each flickering with different frequencies. SSVEP reveals the frequency of the item that we mentally choose (concentrate upon), providing another straightforward way for implementation of a brain-computer interface. If computer can control different flicker rates of symbols, the algorithm can decode which symbol does our brain choose by finding corresponding frequencies in EEG. However, implementation of this paradigm poses some challenges and problems:

1. The strongest SSVEP response occurs usually for stimuli flickering with frequencies in the range around 10–20 Hz; however, these frequencies cause fatigue when viewed for extended period of time, and, in a very small percent of photosensitive subjects, may induce an epileptic attack.
2. Higher frequencies, above 35 Hz, pose difficulties in stable rendering on a standard computer screen, because of the limited refresh rate of displays and non-realtime nature of contemporary operating systems, and produce a much smaller SSVEP response.

To cope with these problems, LEDs driven by dedicated hardware generators are often used for rendering stable frequencies. However, such a separate box with LED can be either connected to only one symbol printed on its front, or, in a more flexible setup, it can be related dynamically to the varying meanings displayed on the computer screen in the neighborhood of the LED box, as in the left panel of Fig. 3. This allows for dynamic changes of menu, but such an ATM-like interface has natural limitation in terms of comfort of use and, in some cases, requires the user to significantly switch gaze or even move the head in the direction of chosen LED, which contradicts the principle of independence from muscular activity.

Solution to these problems, proposed by the first author of this paper, is presented in the right panel of Fig. 3. LEDs under the LCD screen prozob. stable flickering of designated areas of the LCD, while computer-controlled LCD allows for context-sensitive symbols or letters in these areas [3]. Hardware implementation of this idea was first presented in May 2009. In March 2012, fifth version of the BCI Appliance was presented at the Polish national stand at the CeBIT computer fair (Fig. 4).

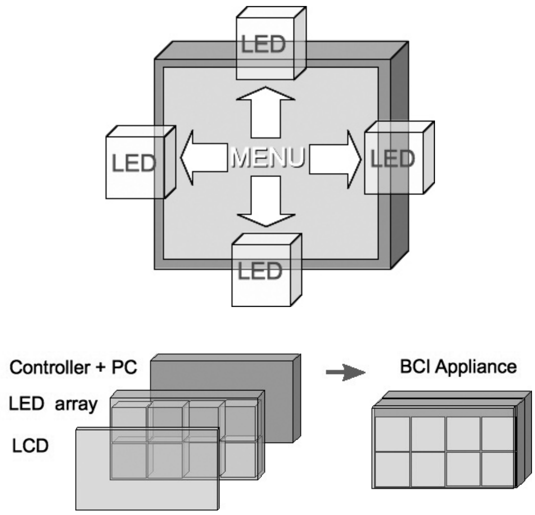

Figure 3 (Left). Scheme of an ATM-like approach to SSVEP-based BCI. (Right). Solution allowing for a stable delivery of SSVEP stimuli via LED array highlighting designated areas of an LCD — the BCI Appliance

Figure 4. BCI Appliance presented at the CeBIT 2012 computer fair: tablet-sized box, connected wirelessly to the EEG amplifier, is attached to the armchair. Display on the wall plots the brain waves, analyzed in real time by the Appliance to detect the user's intentions – this element is only for demonstration

5. OPEN SOFTWARE

Operation of a BCI requires quite a complicated software. Several modules must communicate in almost real-time, performing online several complicated tasks, including:

– communication with the EEG amplifier,
– signal analysis for extraction of relevant features,
– logical decisions based upon the above features,
– context-dependent rendering of the stimuli, menus and user feedback,
– operation of external devices.

When constructing the OpenBCI software framework [4], we added additional constrains:

– centralized data flow allowing for connection of new modules on the fly,
– avoiding commercially licensed libraries,
– possibility to base the system on a specially tailored Just Enough Operating System (JeOS), increasing hardware efficiency.

OpenBCI is freely available from the Internet on terms of the General Public License ([4], upper panel of Fig. 6). As the module for viewing the signal we use Svarog – Signal Viewer, Analyzer and Recorder on GPL ([5], lower panel of Fig. 6). These two systems together constitute world's first Open Source system for EEG registration and display with functionality matching commercial solutions.

6. WHY

BCIs may be the only way of contacting the world for people suffering from neurodegenerative diseases like ALS, and a great help in multitude of less severe cases, like that of the author of the book *The Diving Bell and the Butterfly*. Apart from emerging gaming and military applications, this is the main motivation behind the BCI research. As presented in the previous sections, some success was achieved in pushing the BCI technology from lab to bedside. However, the state of the art in BCI is still so that and interface built on any remaining muscular activity will be faster and more reliable than BCI.

7. ASSISTIVE TECHNOLOGIES IN THE XXI CENTURY

There is a huge gap between the possibilities offered by the cutting edge technologies and those available to the most needing target users; quoting William

Gibson „*the future is already here – it's just not very evenly distributed*". We are spending hundreds of millions on advanced medical research, while at the same time availability of simple 50-dollar wheelchairs would change lives of thousands disabled people in Africa. Classical mode of cooperation between Academia and Industry is of course targeted at maximizing profit from cooperation and patents, but some important issues are often left aside in this race.

The first public presentation of a working BCI in Poland took place in June 2008 at the Faculty of Physics, University of Warsaw. This achievement was driven by enthusiasm of a group from the Department of Biomedical Physics [6], with no coherent funding – our grants for BCI were rejected by the ministries six times in a row. Nevertheless, it raised hopes of many people living in Poland with dramatically reduced communication capabilities, who started contacting our group. Analysis of their needs revealed two common facts:

1. BCI can be a system of choice for the most severe cases of locked-in states, but in most cases a simpler technology, like communication based on gaze tracking, would be enough or even more stable.
2. Cost of an advanced eyetracker (≈ $20000) in many cases still exceeds the financial possibilities of disabled persons and their families.

8. OPEN HARDWARE

Again, the solution came from the world of Open Hardware and Open Software: owing to a free sharing of experiences, people around the world were able to build cheap eyetrackers from off-the-shelf parts, including cheap cameras from gaming console (*e.g.* [7]). These eyetrackers are much less robust and accurate than the commercial solutions used mainly for neuromarketing. Nevertheless, this solid proof of concept provided a starting point for an educational project started at Neuroinformatics BSc [8], aimed at improvement of stability by implementation of a novel cursor-like algorithm for communication and integrating with the OpenBCI platform.

Figure 5. The first eyetracker based upon the EyeWriter project instructions, connected to the OpenBCI interface

9. NEUROINFORMATICS

In spite of efforts summarized in this chapter, BCIs still require more or less profound customization for a particular user. Therefore, a real spread of this technology cannot be achieved without the experts trained in a specific interdisciplinary field.

According to the International Neuroinformatics Coordination Facility [9], this expertise falls within the boundaries of neuroinformatics. Faculty of Physics of the University of Warsaw has opened in 2009 world's first BSc course in neuroinformatics [8]. During the practical classes, students learn registration and analysis of biosignals, as well as the basics of brain-computer interfaces. All classes and research are based entirely upon free (as in "freedom") software systems described in previous sections, which students can freely analyze, modify and use at no charge in future work. Volunteers adapt eyetrackers and switches to the needs of disabled persons.

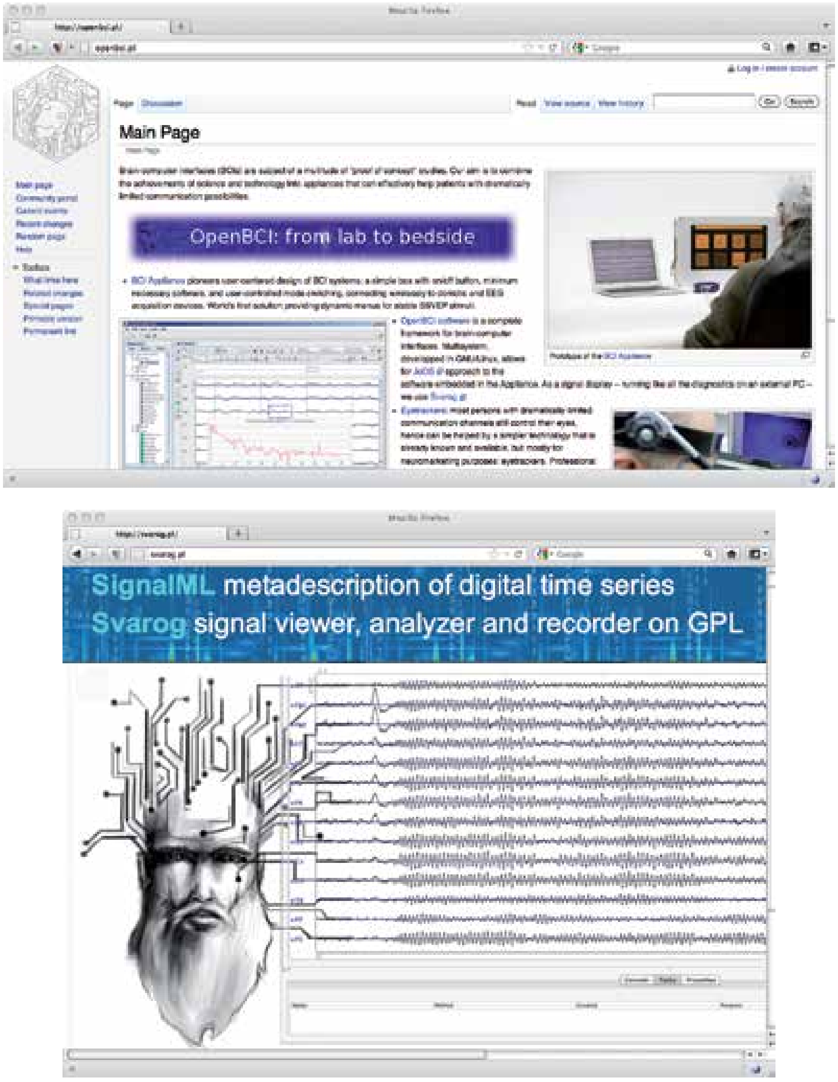

Figure 6. Web sites of the software projects constituting the core of Warsaw University BCI system: OpenBCI.pl and Svarog.pl

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