

Self adaptive BCI as Service-oriented Information System for Patients with Communication Disabilities

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Abstract- A new service-oriented information architecture is presented that can help the communication-disabled to socialize in their private and public environment. The service is designed for physically handicapped people who cannot communicate without expensive custom-made tools. Statistics show that, e.g., in Belgium 1:500 persons suffer from some form of motor or speech disability, mostly due to stroke (aphasia patients). Patients with severe motor or speech disabilities need expensive tailor-made devices and individualized protocols to communicate. About 1:6000 do have problems with information exchange in their daily practice, such as patients with severe autistic disorders, and Amyotrophic Lateral Sclerosis (ALS), Locked-in Syndrome (LIS) and Speech and Language Impaired (SLI) patients, and their communication is often limited to care takers and family, because the interaction with other people through electronic systems often fails. In fact, all these disabled yearn to basically participate in our society. Enhancing the amount of adapted devices and personal care takers has huge consequences and is mostly unfeasible by firm limits in specialists, infrastructure and budget. The quality of life can be graded up by a service-oriented information architecture that supports an on-line ‘Mind Speller’[®], i.e., a Brain-Computer Interface (BCI) that enables subjects to spell text on a computer screen, and potentially have it voiced, without muscular activity, to assist or enable patients to communicate, but also to provide speech revalidation, as in autism spectrum disorder patients. The ‘Mind Speller’[®] operates non-invasively by detecting P300 signals in their EEG. With the support of predictive text algorithms, the mind spelled characters will be words and sentences, and even stories (story telling), enabling the communication-disabled to participate in either the physical environment as – by the Internet – the global digital world.

I. INTRODUCTION

The verbal and motor handicapped persons — estimated to be 100 million people worldwide (source: World Health Organization) — are often faced with poor integration facilities into public environments and social communities. About 12 million have to rely on, or at least qualify for personalized (hence, expensive) niche equipment, such as prostheses, also for speech, and personalized care. Brain-Computer Interfaces (BCI’s) are now the only means of communication available to patients who are locked-in (LIS), that is for patients who are completely paralyzed, yet are fully conscious. Research and development to help them

are dependent upon a variety of science domains including cognitive neuroscience, computer science, electrical engineering, psychology, psychophysiology, neurology and rehabilitation engineering. The field of information and communication technology (ICT), including multimedia, is recently attached to, and pushes – enabled and driven by miniaturization, signal processing technology and the increase of computing power – the development of brain interfaces connected to computer controlled systems.

II. NON-INVASIVE BCI AS NEUROPROSTHETICS

A brain-computer interface (BCI) is a communication device that enables subjects to communicate with other people by translating brain activities into machine/computer commands, creating a direct communication pathway between the brain and an external device, bypassing the need for a physical embodiment. ^(*)

In 2002, Wolpaw et al., Laboratory of Nervous System Disorders in New York, surveyed the state of the art BCI developments. Then, BCIs determined the intent of the user using one of a several different types of electrophysiological signals. These signals include slow cortical potentials, P300 potentials, and mu or beta rhythms, all recorded from the scalp (non-invasive BCI), and cortical neuronal activity recorded by implanted electrodes (invasive BCI). They are translated in real-time into commands that operate a computer display or other device. BCIs had maximum information transfer rates up to 10-25 bits/min.[1] Another issue in BCI research is the training time for users to develop competence. BCIs that do not depend on external stimuli provide direct control over the environment, but these BCIs often require extensive training, from several hours (Kostov and Polak, 2000 [2]) to several months (Pfurtscheller et al., 2000 [3]).

^(*) Since German neurophysiologist Emil Heinrich du Bois-Reymonds founded in 1848 the modern electrophysiology people have speculated that electrophysiological brain measures, such as brain electroencephalographic (EEG) activity or other function, might provide a new non-muscular channel for sending messages and commands to the external world. A brain-computer interface (BCI), sometimes called a brain-machine interface (BMI) or a direct neural interface, is a direct communication pathway between a brain and an external device. BCIs are often aimed at assisting, augmenting or repairing human cognitive or sensory-motor functions. Research on BCIs began in the 1970s at the University of California Los Angeles (UCLA). Simultaneous a variety of signal processing technology with the increase in computing power has made great progress, promoting a human-computer interaction (HCI) technology. Over the past 25 years, productive BCI research programs have arisen and some commercial brain-computer interfaces are manufactured as a special kind of human-computer interaction channel.

Non-invasive BCIs currently offer approximately the same performance as invasive systems. They lack expensive surgery, scarring, risk of infection, and regular medical check-ups, and their long-term stability is significant better. (eg. Andersen et al., 2004[4];Shain et al., 2003[5];Wolpaw et al., 2006 [6])

In the last few years, research in the field of brain computer interfaces has witnessed a spectacular development (see [7], [8], [9]). Such systems can provide a significant improvement of the quality of life of neurologically impaired patients suffering from pathologies such as amyotrophic lateral sclerosis (ALS), brain stroke, brain/spinal cord injury, etc.

There are two major categories of BCI devices. In the invasive ones, a micro-electrode array is implanted in the brain (mainly in the motor or premotor frontal areas or into the parietal cortex [9]), while in the non-invasive BCIs, mainly electroencephalograms (EEGs) are recorded from the scalp. Using fMRI could be seen as a Brain Computer Interface, but do not have the precise output as regular EEG devices and lacks – at this moment – a simple data interface.

Three types of EEG-based BCIs can be distinguished. The first one is based on the Steady-State Visually Evoked Potential (SSVEP, [10]): a subject focuses on a visual stimulus flickering at a given frequency, which is then detected in the EEG signal. With this paradigm subjects were able to navigate a small car on a computer screen [11], or to "mentally" dial a phone number [12].

The second type of EEG-based BCIs relies on the detection of mental tasks (imagination of right/left hand movements, subtraction, word association, etc.) which are detected through slow cortical potentials (SCP) [13], the readiness potential [14], and event-related desynchronization (ERD) [15].

The third group, the one this article is focusing on, is based on the "oddball" evoked potential. An Event-Related Potential (ERP) is a stereotyped electro-physiological response to an external or internal stimulus [16]. One of the most known and studied ERP is the P300 ERP. It appears when a subject performs the classification of two types of events, one of which is only rarely presented (oddball paradigm). The rare event will elicit in the EEG of the subject an ERP with an enhanced positive-going component at a latency of about 300 ms [17]. The most popular P300-based BCI is the speller [18]: it allows a subject to spell words by focusing on the corresponding characters shown in a matrix display (Fig.1), while the rows and columns of the matrix are consecutively and randomly highlighted. Highlighting a row or a column containing the target

A	B	C	D	E	F
G	H	I	J	K	L
M	N	O	P	Q	R
S	T	U	V	W	X
Y	Z	1	2	3	4
5	6	7	8	9	0

Fig. 1. User display for the P300 BCI speller (Courtesy of: Brain-Computer Interface Laboratory at East Tennessee State University)

character will elicit a P300 ERP and, by detecting this ERP, the BCI is able to retrieve the character the subject has in mind.

Despite of its promised support for patients with communication disabilities, the challenge to turn this device into an effective one is multifold.

First, to detect this P300 ERP in the very low signal-to-noise ratio EEG, a common practice is to average over many trials (often more than 10). The drawback of averaging is that it leads to a dramatic increase of the time needed to communicate a single character, hence, the continued effort to develop new signal features and classifiers to reduce the required number of trials.

Second, the commonly used (passive) Ag/AgCl ring electrodes require the scraping away of dead skin cells, in order to bring the electrode impedance into the acceptable range of about 5 kOhm. This operation is not only time consuming, but also uncomfortable for the subject. Especially for elderly subjects, it may lead to a damaging of the skin.

Third, when the aim is to take the speller to the market, one should develop a cheap but professional, portable BCI device so as to able to reach a broad range of customers. Portable, cheap devices do exist but their performance is often too questionable to consider them for patients. Furthermore, the device should be self-adaptive and always ready to go.

In 2005 The Institute for Infocomm Research in Singapore designed a P300-based brain computer interface system. [19] Based on this system, two applications are implemented: a word speller and a remote control device, which are to assist physically disabled people to communicate and control. A number of specific implementation techniques are proposed to achieve good performance in terms of accuracy and reliability. Wang et al. claim their word speller can achieve a spelling rate of up to 4-6 letters per minute, while both applications achieve 99% accuracy with healthy subjects.

In 2009 several significant BCI research contributions were published. We examine some of the best bits:

A team of the Zhejiang University already designed a BCI system for virtual hand control and developed (away from the English alphabet input) a set of conduct character input lines for a P300-based Chinese typewriter [20]. The use of Chinese characters is based on the characteristics of a simplified P300 interface, and a virtual keyboard with Chinese characters. The team introduced in 2009 a BCI messenger that can serve as a daily communication tool, with which the patients can type and send messages to either computer clients or cell phones [21]. The P300 typewriter interface is implemented following the design of modern cell phone keypad, where every key can act as a specific element in different input modes, and in multiple input modes including Chinese, English, numbers and symbols. Six subjects participated in the experiments of this BCI system. A short training period was requested to allow task completion, and after about one hour's practice, most of the subjects learned to operate the typewriter. All participators showed a gradual performance increase across sessions and

the average accuracy in the best condition for each subject surpassed 80%.

Cincotti et al. presented the framework of the current research progresses regarding non-invasive EEG-based BCI applications specifically devoted to interact with the environment [22]. The authors argue that, despite of the technological advancement, the operability of a BCI device in an out-laboratory setting (i.e. real-life condition) still remains far from being settled. ‘The BCI control is indeed characterized by unusual properties, compared to more traditional inputs (long delays, noise with varying structure, long-term drifts, event-related noise, and stress effects). Current approaches to this are constituted by post hoc processing the BCI signal in order to better conform to traditional control. A long-term approach is to devise novel interaction modalities. In this regard, BCI can offer an unusual and compelling testing ground for new interaction ideas in the Human Computer Interaction field.

Indeed, Xuedong and Oui presented a multi-dimensional robotic control via a non-invasive BCI for patients with neurological disorders who may not make voluntary muscle contraction [23]. Under reliable detection, humans can intentionally control a two-dimensional robotic motion; right, left, up and down. Hypothesizing that a subject’s intentions to move his right, left hand, leg and tongue can be detected by the somatotopic spatial activation patterns from single-trial MEG signal, a multi-dimensional control is highly demanded for a multi-dimensional robot. The authors’ hypothesis was tested offline; the classification was performed on beta band activation (15-30 Hz) of SAM virtual channels. Cross-validation results using linear discrimination provided high detection accuracy (70-90%) when considering a random level of 25%. This shows that non-invasive BCI methods may support a reliable multi-dimensional control of neuro-prosthetic robots.

Till shortly, all these regular BCI ‘communication’ devices were multiple wired, stand-alone, and not connected to an open network. The ‘anywhere, anytime, anyway’ paradigm of the telecommunications industry seems to run away from the handicapped persons that are left to the tender mercies of care taking people and dedicated equipment. Therefore, their present quality of life can be graded up significantly by a service-oriented information architecture that encompasses the new generation of portable and wireless Brain-Computer Interfaces that enable subjects to spell text on a computer screen by detecting P300 Event-Related Potentials in their electro-encephalograms (EEG).

“) Amyotrophic lateral sclerosis, commonly known as ALS or Lou Gehrig’s Disease, is a progressive neurodegenerative illness that results in weakening of the connections between the brain and body. In the late stages, these patients have no ability to move or speak, though for the most part they retain normal cognitive function. This condition is referred to as “locked-in syndrome” or LIS. By recording EEG signals from the scalp, then detecting specific features of the EEG activity, their brain activity can be translated into actions. The primary function of brain-computer interfaces (BCIs) is to allow people to regain the control and communication they have lost due to paralysis caused by ALS or acute events such as brainstem stroke.

This kind of BCI application is of particular interest for patients who suffer from severe verbal and motor communication disabilities, e.g., due to stroke (aphasia patients), Amyotrophic Lateral Sclerosis (ALS) “), neuromuscular disorders (e.g. cerebral palsy), traumatic brain injuries, severe autistic disorders and speech and language impairments (SLI).

Before starting to develop a dedicated prototype EEG set (instead of buying one), we researched and compared some commercial products, such as Mindset (Neurosky), Emotiv (Epoch), Enobio (Starlab), Brainquiry (Brainclinics), Active Two (Biosemi), TMSI porti (REFA), and Mobilab (g.tec). None of these have the quality of service that is needed. [24]

III. MIND SPELLER®

Our research has recently been focusing on a new miniature, portable EEG-based BCI device (Fig. 2). It consists of an ultra low-power 8-channel wireless EEG amplifier connected to a wireless transmitter and a USB stick receiver, which is plugged into the USB port of a computer, PDA or smart phone. The EEG device is a prototype developed by the Interuniversity Microelectronics Center (IMEC, [25]). In addition to the device being wireless, state of the art active electrodes (ActiCAP, Brain Products GmbH (<http://www.brainproducts.com/>)) were used that do not require any scraping of the skin, and enable a quick mounting of the electrodes, both of which lead to an increased comfort to the subject.

The challenges we were facing with this device were fourfold: 1) the real-time decoding of the EEG activity (note that most of the EEG decoding work is done off-line, using one of the public domain datasets such as those of the Berlin BCI group), 2) the limitations of the wireless transmission protocol, which does not allow for time stamps or electrode labels to be attached to the EEG samples transmitted (unidirectional protocol), 3) the loss, at the receiver side, of EEG samples, calling for their reconstruction at the receiver side, and 4) the slow response time of the EEG amplifiers (actually the filters therein) causing long waiting times for them to settle.

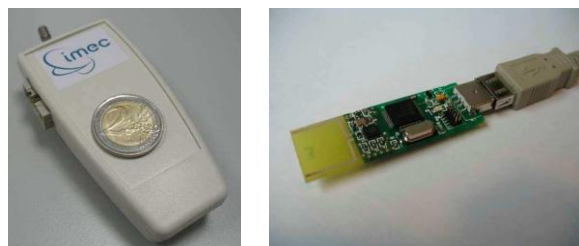


Fig. 2: Wireless 8 channels EEG device. Left panel: amplifier and transmitter. Right panel: USB stick receiver (photo’s: courtesy of IMEC).

As an application, for the portable EEG device, we considered the P300 ‘Mind Speller’®, with which subjects were asked to spell words by focusing on the corresponding characters shown in a matrix display (Fig.1). In a series of articles [26,27,28], the results achieved by our lab were

discussed along with our methodology that relied on advanced Machine Learning techniques leading to new, powerful features, requiring less averaging to detect the P300 event. We have used feature extraction- [26,27] as well as feature selection methods (using a genetic algorithm) [28]. As classifiers, we have only used linear ones, in order to reduce as much as possible the training time, and to arrive at a simple implementation. The advanced Machine Learning approach we have adopted also enables the device and set-up (electrode arrangement) to maximally adapt to the subject. The results show that subjects are potentially able to communicate a character in less than ten seconds with an accuracy of 94.5%, which is more than twice as fast as the state of the art [29].

IV. OUTLOOK

The portable wireless devices that are now developed are another step in closing the gap towards a fully portable, cheap, user-adaptive BCI for mind spelling and other ways of communication. In this paper we focus on the state of the art of high performance, portable and wireless EEG devices. IMEC (Belgium) and its research affiliate Holst Centre (The Netherlands) have unveiled a miniaturized and wireless 8-channel EEG system. (Fig. 3) The system is suited for remote monitoring of patients in their daily environment, resulting in more natural readings and greatly increasing the patient’s comfort, and can be connected to individual electrodes, standard EEG monitoring hats or proprietary EEG headsets. The system records high quality EEG signals when connected to gel electrodes. Early tests with dry electrode are promising, although more research is required to achieve reliable measurement in non-controlled environments. The data is wirelessly transmitted in real-time to a receiver located up to ten meters from the system. IMEC has also developed algorithms to interpret the brain signals, linking the brain activity to the degree of relaxation.

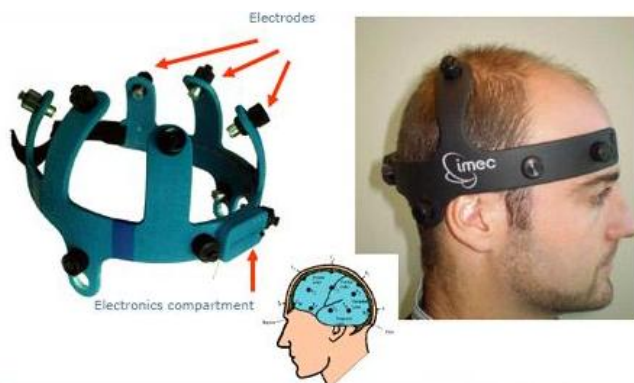


Fig. 3. Portable 8-channel wireless EEG scanner for ambulatory monitoring. (Courtesy of IMEC). The EEG monitoring system is in this case used in a Belgian artistic project [30] to give an acoustic representation of the electrical brain activity. Central is IMEC’s 8-channel ultra low-power analog readout ASIC (application-specific integrated circuit). The electronics, including ASIC, radio, and controller chips are integrated on a printed-circuit board that measures only 47 by 27 mm. The whole system is packaged in a small box with status LEDs, a switch button and interfaces for din32 cables. The packaged system consumes 1.8mA, allowing 3 days of autonomy with a 160 mAh Li-ion battery.

Applications that can be envisaged with this EEG system are, for example, comfortable ambulatory monitoring of epileptic patients, e-learning and gaming.

With the new P300 ‘Mind Speller’[®] paradigm we have taken an important step towards fully portable, wireless BCI applications. First, we have achieved a superior performance, even when using a few trials for averaging, leading to a much faster spelling rate. Second, we have used active electrodes (ActiCAP) which are easy to mount and comfortable to the subject (no scraping of dead skin cells is required). Third, we have introduced a professional, portable BCI device so as to able to reach a broad range of potential customers, with a wide scale of possible applications and services. The future is to integrate the electronics (amplifiers, radio) as well as the wires and the active electrodes into a light weighted trendy-look diadem (Fig. 4): this way, the electrodes are always in the correct position, as well as the ground and reference (on the mastoids), the wires cannot become detached or cluttered (leading to inferior signals), and the set-up is easy to maintain (also for reasons of hygiene) by untrained persons.



Fig. 4. Example of a BCI diadem with wires, electrodes and pre-amplifier electronics integrated (courtesy of TU Eindhoven, Department of Industrial Design). All battery-operated electronics will be integrated into the diadem and it will communicate wirelessly to an external computer or PDA that shows the stimuli and that performs the adaptation of the decoding algorithm to the subject (feature extraction and classification).

If we would be able to exchange the now used wet electrodes for dry ones (which currently is researched at IMEC), the device would always be ready to go (no gel application required). One could argue whether or not to integrate the feature selection/extraction and classification onto the same chip, in the diadem. The problem is that optimizing the feature selection/extraction and the classifier are computationally intensive processes, requiring more substantial computer power, and thus, more power consumption. This would dramatically shorten the battery lifetime, and lead to an uncomfortable heat development on the subject’s skin. In any case, a separate computer is needed, for displaying the stimuli, so that the current solution, an ultra low power EEG device and a low power wireless radio, seems ideal, given the current status of the technology.

In the next stage of the development, this device should also be able to communicate wirelessly with a service oriented information system [31]. This system can provide improved predictive text information, short links to other interfaces and infrastructures (like the internet) and the updates for the self adaptive interface [32][33]. By this improvement, the disabled are enabled to participate more and more in their local and global society in the Internet environment (Fig. 5)[34]. By the low cost design, the open source software, and the online contact, we expect that — without redesign or replacement of the BCI device — new services will be developed as plug-ins, e.g. for music playing, by with the handicapped person could participate in an amateur orchestra. Also self-help groups can grow up to support and advocate, and in the peer group user-created applications could be shared world wide as widgets.

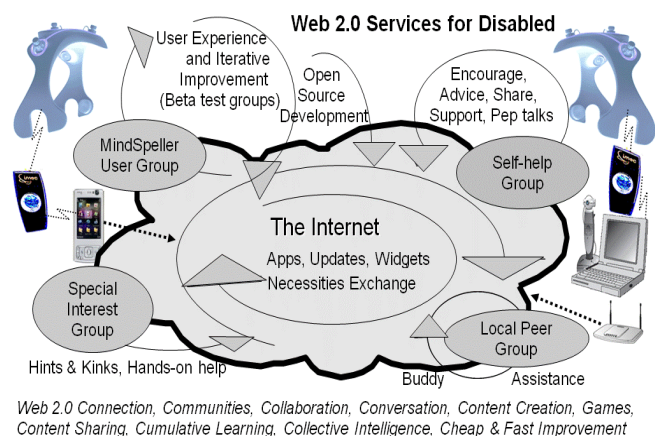


Fig.5. Architecture Impression of a Service Oriented Information System for Communication Disabled in an Internet Web 2.0 environment

Considering the evolution of non-invasive BCI, and the general debate about invasive electrode technology [35], plus the boom of body area networks, we foresee that the future of non-invasive BCI development will focus on 5 main directions:

- Word spellers BCI > characters > words > sentences
- Story tellers BCI > images > cartoon > storyboard
- Neuro robotics BCI > data > robotic motion control
- (Serious) Gaming BCI > HMI control of virtual objects
- Trauma triggers BCI > virtual environment > capturing re-experience of traumatic neurosis.

As the open standards move up, the BCI data more and more interconnects with PC platforms, PDAs and smart phones, and by that with the Internet. Hence, the connection of BCI applications to wireless ubiquitous networks in a hyper connected world unlocks handicapped persons from their isolation.

V. CONCLUSION

In 2008, an EEG BCI scenario was foreseen in which users purchase an affordable computer peripheral that is simply placed on the head and requires no gel [36]. Now, in

2010, the wireless BCI ‘Mind Speller’[®] enables subjects to spell text on a computer screen by detecting P300 signals in their EEG, and increases the mobility of many handicapped persons. With a supplementary service-oriented information architecture the communication-disabled are able to socialize in their private and public environments. Because of the connection to the Internet, the disabled will also be able to communicate independently within their self-help group or peer group and other online communities, and to exchange and/or discuss new applications, features, widgets, updates, etc., of their common device. Using a kind of open source interface stimulates the development of new applications.

The low cost design of the ‘Mind Speller’[®] and the inexpensive services will make the regular handmade devices superfluous and will improve the communication with their care takers and family. Enhancing the amount of adapted devices and personal care takers has huge consequences, and is mostly unfeasible by firm limits in available specialists, infrastructure and budget. Most likely 1:600 do have problems with information exchange in their daily practice, because the interaction with other people through electronic systems often fails. In fact all these, often isolated disabled ‘neighbors’ yearn to basically participate in our society.

Hence, the quality of life (QoL) for many patients with communication disabilities can be graded up by the ‘Mind Speller’[®], supported by a service-oriented information architecture. In addition, the satisfaction of participating in our society will make their handicap more bearable.

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