On electronic tools supporting people with disabilities

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Abstract: - There is a group of people that have special communication needs, because of some disabilities. Problems in interactions with others cause deficits in social experiences and thus influence quality of life and have devastating effect on their personalities. Therefore it seems reasonable to try to amend such situations with a support of technologies involving computers. Unfortunately, the computers interfaces are usually handled with the help of keyboards, mice and display monitors and some people are not able to access such usual equipment. However, contemporary hardware and software may help impaired or handicapped people communicate, live and work more or less normally, because there are several ways of analyzing their intentions that are expressed, e.g., by brain activity, eye movement, head movement, facial gestures, touch, speech, use of feet, use of breath and mouth.

In this article, we discuss human-computer interface systems, consisting of a device analyzing physical signals coming from the sources described above and a graphical or non-graphical user interface that could be operated by the disabled persons. We also describe in some details a new electronic platform, called C-Eye, that not only makes possible a communication with a person using it, but also allows an integration of some medical measurements and computer techniques based on man - computer interaction.

Key-Words: - Electroencephalogram, Eye Tracking, Tactile Systems, Speech Recognition, C-Eye.

1 Introduction

The communication with other people is necessary to fulfill our basic needs such as interaction with family or friends, education, work, entertainment etc. But there is a group of persons in society that have some problems with exchange of even very basic information and therefore must use some special communication means. It consists, among others, of people that cannot speak, because of large neurological damages in their brains or nervous systems. Deficits in communicational relations cause significant lack of experiences of various social situations, which may result in impairment of conversational skills, may block motivation to initiate a contact with other people, decrease ability to express emotions, feelings and needs, and make it difficult to describe intellectual states. Persons without speech in most cases are passive observers in human relationships and remain only dumb witnesses in various situations. The state of frustration and the lack of attempts to make contact with other people has a devastating effect on personality. Thus the shortage of communicational activity causes deficits in social and psychological bonds, consequently resulting in disintegration of personality and in the social exclusion and marginalization.

Certainly, the use of computers could somehow help in such situations, but in general the standard computer interfaces are handled with the help of a keyboard, mouse and display monitor and not everybody is able to access such usual equipment. Fortunately, contemporary hardware and software offers a help for impaired or handicapped people and allow them to live and work normally to some extent. Multiple ways of analyzing their intentions exist and a selection of alternative communication means is listed below:

- medical signals – EEG;
- eye and head movements and facial gestures;
- tactile systems;
- speech recognition systems;
- use of feet, breath and mouth.

In this article, we discuss various types of human-computer interface systems, consisting of a device analyzing physical signals coming from the sources described above as well as a graphical or non-graphical user interface that is operated by a possibly disabled person using alternative communication methods. At the very end we focus on a very innovative platform called C-Eye (CyberEye) that applies new methods of tracking eye movement on computer screen and special algorithms that allow to determine the degree of concentration of a computer user and in this way help to improve the quality of life and health of people with disabilities.

2 EEC

Electroencephalogram [11] is a method monitoring human brain electrical activity using electrodes attached to a scalp. The activity is shown as waves divided in ranges, also called bands, pertaining to a different location in the brain and different mental states. These bands have different signal frequencies. The table presented below shows the band names and wave frequencies corresponding to them.

Band	Frequency range in Hz
Delta	< 4
Theta	4 - 7
Alpha	8 - 15
Beta	16 - 31
Mu	8 - 12
Gamma	> 32

It is worth noting that the lower and upper limits in the table should be considered fuzzy since researchers do not agree about them; for example, the lower end for Beta waves frequency range varies from 12Hz up to 16Hz.

In order to use brain waves as a possible communication means, the original signal has to be processed [14]. It contains two components: the DC component and the AC component. DC refers to the constant current and AC refers to the alternating current. The physical signal is a superposition, which can be thought of as a sum of these two components and can be expressed by the following formula:

$$S(t) = d\,D(t) + a\,A(t),$$

where:

$S(t)$ - signal seen on the electroencephalogram;
$D(t)$ - DC component;
$A(t)$ - AC component;
$d, a > 0$ - scalars;
t - time.

However, the DC component does not carry any information. Therefore, filters, most often high-pass ones, are used to remove the DC components from the signals. Low-pass filters can be used to remove the high-frequency components of the signal. It is useful, because those components, also called Gamma range, are rarely analyzed [5]. Among brain waves, only Gamma waves correspond to the frequency above 32 Hz. Researchers are not sure about an answer to the question what Gamma range is responsible for. It probably has something to do with subjective awareness or attention [16]. Neither of them is highly important for a communication system, therefore this range is often ignored in them.

Furthermore, a feature extraction is needed, in order to perform classification and identification of information from the filtered signal. There are a few such types of features: time domain features, frequency domain features and synchronicity features. Time domain features can be extracted using methods based on statistical properties (mean, standard deviation) and physical ones, such as entropy. The function describing the signal in the time domain can be represented in the frequency domain by using the Fourier transform. These methods are computer-aided. Synchronicity features can be found by examining the relationship between multiple EEG channels, often by the means of EEG tomography, which computes active regions inside the brain and needs a higher number of electrodes (over 30).

After features are extracted, it is time to select the features relevant for communication [2]. Feature selection, also called variable selection or attribute selection is a machine learning topic, that solves the problem of elimination of unwanted input variables in a knowledge model. It reduces the complexity of the data system, which allows a better classification in the next steps of the processing.

The final step is the classification of selected features, which is performed by a separate subprogram. This program has to be trained using machine learning beforehand, based on a larger training data set. If the training data set is not selected properly, a classifier can work badly. The good classifier should be able to tell a category of communication, desired by the user, based on input data. The category can be, for instance, a spatial direction (up, down, left, right etc.) that a pointer should go in or another choice that can be made in a graphical interface.

3 Eye tracking

First scientific observations of the eye movement were made at the beginning of the 19th century [7]. In 1879, Louis Émile Javal observed the behavior of people reading a text. He found out that their eyes are not moving in a continuous way. An average person focuses its gaze on the center of the read word. Afterwards, Alfred Yarbus did an important study in 1950, showing that the trajectory of eye movement depends on the task given to the person being tested [18]. The first real-time eye tracking tests were attempted in the 1980s. The main goal of the experiments was to help the disabled, but it was not the only reason. Human-computer interaction of users and interfaces was examined, which resulted in the constant improvement of the software and the usability thereof. For example, eye tracking is used nowadays to design websites so that they are easier and faster to use.

One of the biggest software libraries made to help to solve various computer vision and machine learning problems is OpenCV (https://opencv.org/). It focuses on issues that allow to detect, locate and follow in real time target objects like eyes. Thanks to eye tracking software, a disabled person, who for instance cannot use standard keyboards, can write text using an accessibility tool like Dasher [10], [17]. Dasher is a graphical input system, that allows users, who cannot use their hands, to write words only by looking at the right direction. The program is intuitive and simple. The screen is divided into three parts. On the left part, the previous character is depicted. In the center, a horizontal line determines the currently selected sign. Apart from letters, punctuation signs like space, new line or full stop can be written. After a letter is selected, the area is zoomed in and the letter moves to the left part. After a complete word is composed, the word disappears. The speed of movement can be adjusted. If a user makes a mistake, can point left removing the wrong characters. Every character occupies a certain area on the right part of the screen. Its size depends on the probability of the occurrence within a word in the selected language. For example, on writing the letters 'Sam', the biggest areas correspond to the letters a, e and p, because the most probable words beginning with 'Sam' are Samantha, Same and Sample. Several other characters like b, i, o, s are visible as well (sample words: Samba, Sami, Samoa, Samson). The other characters are not visible at first, since they are little probable to occur. They can be accessed after zooming in a certain area, marked in a specially chosen color. Apart from English there are about 150 supported languages. Dasher can learn prediction of letters basing on the words that are often selected by the user.

4 Tactile systems

Tactile systems [12], [15] take a touch as the input information. A user, who can be a person with a motor disorder or a deaf-blind person, typically wears a wired glove that is called CyberGlove (http://www.cyberglovesystems.com/). It is not only a tactile system but also a haptic (a combination of both tactile and kinesthetic) one as it also collects kinesthetic, physical data such as changing of position, rotation or shape of the hand. Sensors can be individually configured for each finger. Some wired gloves provide tactile feedback using a vibration or a simulation of touch sensation. The tactile feedback can be given to each of the fingers or palm. The gloves enable a person to navigate in a virtual 3D environment. However, a tactile feedback alone is not enough for all the applications. To grasp objects, a feedback on elasticity and plasticity of an object is needed and CyberGrasp is a solution made exactly for that purpose. It is more built-up than a basic glove and consists of two parts. The first part is a wearable glove and the second one is a hand device, separate from the glove. A system of wires and weights bound to the glove provides kinesthetic feedback on the forces that the hand device deals with.

5 Speech recognition

Automatic speech recognition [1], [8], [13] can help many people with difficulties in using a keyboard to operate a computer. The history of speech recognition software begins in the 1950s, when Bell Labs company devised a system for a single speaker. It could recognize digits (around ten words). Therefore, the vocabulary was very limited. Further research funded by institutions like DARPA, BBN, IBM and Stanford Research

Institute brought about some changes, but the vocabulary was still limited. During the next years, new algorithms like Hidden Markov Model were invented, which enabled the software to use context-based recognition. Nevertheless, computing power and storage size that were provided for researchers were insufficient. A powerful computer of that time had 4MB of memory and was about 1000 times slower than nowadays. Therefore, the area of speech recognition had to wait a couple of decades until the computer capabilities increased to a decent extent. Like in EEG analysis systems, features have to be extracted from a speech recording, selected and classified. The features include voice pitch, a degree of separation between the sounds and vocal timbre.

The most popular, state-of-the-art speech recognition software solutions include Microsoft's Cortana, Apple's Siri and Google Voice.

6 Use of face, head, feet, breath and mouth

To recognize a facial gesture (e.g., eyebrow gesture or smile), a complete vision system has to be set up. A camera captures a human face, which has to be properly lit. Otherwise, possible poor contrast of image might preclude further processing of it. What is more, the camera's resolution has to be big enough so that the resulting image is sharp. When all of the above is fulfilled, the face can be detected, located and isolated from the background and potential noise. Moreover, various head tracking devices are used as well. They are similar to the eye tracking ones. Instead of moving their eyes, users move their head. The user has to wear a small, recognizable dot on their head or hat which is tracked by a computer camera.

Most devices that are controlled by feet consist of a pedal detecting and measuring a foot pressure and buttons that are pressed by the second foot. An adapter converts signals from pedals and buttons to signals understandable by a computer or another target device.

Another way of communication for the disabled people is the usage of their breath and mouth. A mouthpiece similar to a straw, but shorter, is held between their lips. Sensors detect breath and lips pressure on the mouthpiece.

4 C-Eye

C-Eye (CyberEye) is the world first electronic system (platform) that makes possible an integration of some medical measurements and computer techniques based on the man - computer interaction. This increases accuracy of a diagnosis and provides various possibilities for systematic rehabilitation of patients with brain damage resulting for example from cranio-cerebral injury, strokes, oxygen deficiency or circulatory arrest; but also for people awaken from the coma, without full awareness, with minimal awareness or in a vegetative state.

The C-Eye system may also support alternative communication by using the technology of eye tracking for people with aphasia or dysarthria, for instance, individuals with various types of cerebral palsy, for persons fully aware but immobile, with multiple sclerosis, amyotrophic lateral sclerosis, and Alzheimer's or Parkinson's diseases.

The platform also can be useful for old people having significant problems with communication and memory, children with developmental disorders and patients of the intensive care units.

It has been created in Department of Multimedia Systems of Gdańsk University of Technology (Poland) and applies new methods of tracking eye movement on computer screen and algorithms determining concentration degree of a computer user. The main idea and rules on which it is based originate from the theory and scientific research in neurology and rehabilitation. Namely, these are two principles of the neurological theory: Neural Darwinism and Neuroplasticity of Brain.

Neuroplasticity (also known as Brain Plasticity and Neural Plasticity) means the brain ability to change throughout the life of a person (even in adulthood); i.e., the brain activity that is associated to a given function can be shifted to a different location (healthy structures of a brain replace those damaged), some parts of the gray matter may change (even self-repair), and synapses are strengthening or weakening in time. Certainly, the developing brain shows a higher degree of such plasticity than the adult one [9]. Such processes can be stimulated during special exercises and communication with a patient by the visual way.

Very roughly speaking, the Neural Darwinism is a theory stating in particular that there occurs a process in the development of the nervous system, which is responsible for creating, sustaining and decaying of synaptic connections between nerve cells. We can increase the probability that the same network will respond to a similar or identical signal in future, through a special strengthening of particular neuron-to-neuron connections along a fairly quick timetable [6]. This can be achieved by specially selected activities having an influence on the synapses.

The device consists of a monitor with four diodes, placed on the corners of a screen, and a device that register data. Person’s eyes react to the displayed pictures and their corneas reflect a light that is registered. Thus, by that reaction of the eyes we can determine where the patient gazes at. This allows a significant transfer of information by the eyes movements, because any place of a screen can be precisely indicated. Using the information obtained in this way, the levels of brain awareness and of other processes can be diagnosed. For instance, an evaluation is possible of the state of consciousness of a person with coma that have no noticeable contact with the environment.

The C-Eye system contains also a multimedia package, which can be used for diagnosis and therapy. Moreover, there is a possibilities to add new information that might allow to adapt the system to the needs of a particular user.

One of the elements of C-Eye platform is the visual interface, which allows a communication with the paralyzed patients, a stimulation of cognition functions, and improvements of attention, concentration and visual coordination.

There are two variants of the C-Eye system: a professional version for therapists and medical institutions and a less advanced version for a use at home. The main purpose of the latter is to support neurorehabilitation by the sensory stimulation (in the case of some perceptual isolation it helps in the recovery of somatosensory function), activation of the cognition functions, and an improvement of communication. The technology of visual interface may help to entertain, relax and relieve difficulties and improve in this way the quality of life.

The home version of C-Eye system consists of the modules for neurorehabilitation, alternative communication and entertainment, and database containing results of one patient. The multimedia games were created, validated and accepted by specialists - doctors, psychologists, educators, and physiotherapists. A patients can implements her/his own multimedia content such as pictures, photos, sounds, etc.

4 Conclusion

The betterment of quality of communication of persons with special communication needs, by using high technology systems and tools, may improve significantly their quality of life.

The neurobiological stimulus obtained from such alternative communication have the following influences:

- reduces the frustration caused by the feeling of being not understood;
- prevent from acquired helplessness;
- help to learn activity and proper attitude;
- enhance self-esteem and self-acceptance;
- enhance the motivation for social contacts.

All these effects may stimulate a further desire to learn more advanced methods of alternative communication and thus improve significantly their ways of contact with other people. The proper application of various types of high technology devices offers people with disabilities an opportunity to control their own lives and a feeling of being in charge of something important.

Certainly, the ways of reading the intentions thorough such means as medical signals EEG, eye movement, head movement, facial gestures, tactile systems, speech recognition systems, use of feet, use of breath and mouth still needs some betterment, but they already provide many significant possibilities.

We should distinguish in this area the platform C-Eye, which is a very innovative technology that may be very helpful in communication, but also in assessing and supporting the psychomotor development of a child. Certainly, as a new tool, it still needs more investigations on its efficiency and possibilities, creating in this way a large field for further scientific research.

All of the electronic devices depicted in this paper have some, bigger or smaller, disadvantages and still await for some further improvements of their hardware and software. But we observe a constant progress in this area, which allows to make the life of numerous people much better and easier.

For some information on several complementary systems, not discussed in this paper, we refer to [3] and [4].

References:

[1] H. Beigi, *Fundamentals of Speaker Recognition*, Springer, New York, 2011.

[2] J. Brownlee, An Introduction to Feature Selection, *Machine Learning Process* Vol. 6, 2014.

[3] E. Brzdęk, The educational and technological aspects of the Alternative and Augmentative Communication (AAC), *International Journal of Education and Information Technologies* Vol. 12, 2018, pp. 75-79.

[4] E. Brzdęk, The Warnke method as a support in education of children with mild intellectual disabilities, *International Journal of Education and Information Technologies* Vol. 12, 2018, pp. 64-68.

[5] G. Buzsaki, *Rhythms of the brain*. Oxford University Press, Oxford, 2006.
[6] G. Edelman, *Neural Darwinism - The Theory of Neuronal Group Selection*, Basic Books, New York 1987.
[7] E.B. Huey, *The Psychology and Pedagogy of Reading*, MIT Press, Cambridge, MA, 1968. (First published in 1908 by Macmillan)
[8] B.H. Juang and L.R. Rabiner, *Automatic speech recognition – a brief history of the technology development*, Georgia Institute of Technology, Atlanta and Rutgers University and the University of California, Santa Barbara.
[9] R.B. Livingston, Brain mechanisms in conditioning and learning, *Neurosciences Research Program Bulletin* Vol. 4 (3), 1966, pp. 349-354.
[10] D.J.C. MacKay, *Information Theory, Inference, and Learning Algorithms*, Cambridge University Press, 2003.
[11] E. Niedermeyer and F.L. da Silva, *Electroencephalography: Basic Principles, Clinical Applications, and Related Field*s, Lippincott Williams & Wilkins, 2004.
[12] V.F. Pamplona et al., The image-based data glove, in: *Proceedings of X Symposium on Virtual Reality (SVR'2008*), Joao Pessoa, 2008, pp. 204-211, Anais do SVR 2008, SBC, Porto Alegre, 2008.
[13] D. Reynolds and R. Rose, Robust text-independent speaker identification using Gaussian mixture speaker models, *IEEE Transactions on Speech and Audio Processing* Vol. 3 (1), 1995, pp. 72-83.
[14] S. Sanei and J.A. Chambers, *EEG Signal Processing*, John Wiley & Sons Ltd., 2013.
[15] D.J. Sturman and D. Zeltzer, A survey of glove-based input, *IEEE Computer Graphics and Applications* Vol. 14 (1), 1994, pp. 30-39.
[16] C.H. Vanderwolf, Are neocortical gamma waves related to consciousness?, *Brain Research* Vol. 855 (2), 2000, pp. 217-24.
[17] S.A. Wills and D.J.C. MacKay, DASHER - an efficient writing system for brain–computer interfaces?, *IEEE Transactions on Neural Systems and Rehabilitation Engineering* Vol. 14 (2), 2006, pp. 244-246.
[18] A.L. Yarbus, *Eye Movements and Vision*, Plenum, New York, 1967.