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SPECIFIC WORK GUIDE ON "CYBERNETIC PROSTHESES"

Text by Mr. Óscar Herreras

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Introduction

To a greater or lesser extent, we have all been interested in the possibility of interfering in our surroundings by means of thought,some due to their enthusiasm for fiction films, others due to their professional activity. Scarcely three decades ago, everything was on the recreational side, but nowadays, what formerly seemed likeunattainable fiction has now been reached by reality. Research into the brain mechanisms which control the cognitive and motor processes, on the one hand, and the frenzied progress in diverse technologies on the other, have put on the launchpad what will undoubtedly be the most intriguing field of research and development in the near future and with the greatest impact on human life.

The interest in the development of brain-machine interfaces is utmost: artificial hearing prostheses, exoskeletons operated by interfaces which read the brain's electrical activity, even artificial retinas. A person can communicate with a computer or another electronic device exclusively by the use of thought, and because of this, and beyond the clinical application, social, cultural and industrial opportunities whose limit is still unknown are starting to make their way. Therefore, not far away is the day when we will be able to wear an implanted interface like Yondu in “Guardians of the Galaxy”, like someone wearing a simple pacemaker.

Prostheses and interfaces

A prosthesis is any artificial device which is implanted in the body to develop a lost or poor function in a natural organ. In the context at hand, that of cybernetic prostheses, the control of this function is done through mechanical or electronic devices and, in general, requires or uses feedback systems. The feedbackserves to adapt the performance of the prosthesis to the individual's needs, which are extremely changing and require a continuous adjustment depending on the situation.Let's use locomotion as an example. The locomotor system is used in different ways depending on the aim, the individual's conditions and the surroundings. We don't use our legs the same way to walk as to run or to go up stairs. These adjustments, in a healthy individual, are carried out by the nervous system, which regulates the type of movement coordinating with a great many muscles with precisionthanks to the information which it is continually receiving from the surroundings and from the very effectiveness with which it is executing the desired action, all of it thanks to the feedback provided by the sensory information.

The nervous system of a living organism is in charge of collecting information both about itself (proprioceptive, of its own state and condition) and its surroundings, analyzing it, elaborating it, saving it and, at the right time, generatingmotor commands through which the individual responds or adapts to changing situations. Each of these functions involves the activity of subsystems of nervous circuits or neural networks. An essential part, the most primitive one, is the one in charge ofcollecting information from the environment and from the body itself. The information in its original medium is in the form of physical variables, light, color, dampness, pressure, molecule concentration, etc, so that a virtual image of the outside and of oneself is generated. The part of the nervous system which captures these variables can be defined as an interface, and is formed by a set of highly specialized nerve cells which reside in the sensory organs (eyes, skin, nose), measure these variables and generate series of electric impulsesin different combinations. They are transducing cells; that is, cells which transform a type of energy into another by means of certain codes or transfer functions.In essence, this defines an interface. In the world of applications, interfaces have a similar role; they are devices which transform a type of signal into another with the aim of making it comprehensible within another system different to the one it started from. A computer screen, a microphone, the Wii, are interfaces which transform different signals (light, sound waves, position and movement) from or towards the nervous system.

Brain-machine interfaces

Nowadays,in a controlled way and under the strict supervision of the individual's environmental and physiological variables, it is now possible to establish more or less direct communication between the physical world and the brain using mechanical or electronic devices; that is to say, substituting the functionof the natural transducers. For that purpose brain-machine interfaces are needed, also known as brain-computer interfaces or BCIs, the latter being the most commonly used onestaking advantage of their great ease, in turn, to interact with another person; for example, a programmer or controller, or to execute a command on an external actuator.

In computer terminology, the main outputs generated by the nervous system are neuromuscular or hormonal. Ultimately, every output can turn into motion (the locomotor system to walk, the face muscles to speak, etc). A BCI provides the nervous system with new output types of artificial origin. In the words of a well-known researcher in the field (J. Wolpaw), a BCI is a system which measures the activity of the nervous systemand converts it into artificial output which replaces, restores, enhances, supplements or improves the natural output of the nervous system and thereby changes the ongoing interactions with the external or internal environment.

How they work

We distinguish between several stages in the use of a BCI, from when neural activity is read until output towards an actuator or an external device is generated. In the first stage the nervous activity is read, and the relevant information is retrieved. This information is essential and must contain specific characteristics which imply the intention of the user who is wearing the BCI, one way or another. Let's remember that brain activity has, among other functions, that of sending commands tothe body's effector organs. The aim, therefore, is to recognize brain signals which indicate, for example, that the user would like to move. In general, this processing is carried out by a computer or micro-computer dedicated to the recognition of specifictemporary patterns of thebrain electric potential (waves, rhythms, etc). Once the signals of interest have been detected which imply the user's intention, they have to be translated into commands understandable by the actuator or device which executes the desired action in the physical environment or in the subject's own body.

Types of brain-computer interfaces

Considering the placement of the interfaces, they can be classified as invasive or non-invasive. The former are implanted directly in the brain parenchyma and require complex intracerebral neurosurgery. These sorts of interfaces provide great quality with regards to reading brain activity, since they are located in the very place where it is generated inside the brain. Their main disadvantage is their limited biocompatibility. The organism has very effective mechanisms to recognize what is its own and what is not, and it is extraordinarily hostile to theforeign. The immune system is activated and tries to break down and metabolize the foreign materials, whether they are organic or inorganic, and when it cannot, it isolates them, generatingsurrounding layers of glial cells with which it tries to maintain neural activity in the nearby regions with their normal functions. It is a mechanism developed for situations of brain damage due to an accident (for example a stroke, or a head trauma) in which it is necessary to reabsorb a part of the dead tissue or isolate a region with abnormal or potentially dangerous activity (for example, a tumor), but which acts the same on foreign bodies. The materials implanted are attacked by the acidic medium, decompose and lose their function. This is one of the problems which is researched most intensely, since the viability of intracerebral interfaces depends on its solution. We have to bear in mind that an interface must be very long-lasting and as permanent as possible, since brain activity differs in microscopic displacements and replacement by a new probe will hardly be able to achieve the same positioning. As a consequence, the activity will be different and the parameters which have beenextracted from the first one will not be valid in the following ones, which implies a re-learning or re-calibration of the complete systemwhich can have different effectiveness on the actuator's control. Belonging to these types of interfaces are those which use intracerebral electrodes among their components.

Another type of interface called semi-invasive requiresminor surgery, and has fewer biocompatibility problems in general. The activity-reading devices are electrodes which register the activity of the cortexand are placed under the cranial bone, over thedura mater membrane which protects the brain. The activity they register is called the electrocorticogram (ECoG), from which characteristic fluctuations are extracted by means of mathematical algorithmsthat inform of the activation of a specific region of the cerebral cortex.

Finally, non-invasive interfaces include those which use external electrodes, on the skin of the skull (electroencephalography, or EEG), or brain imaging techniques such asfunctional magnetic resonance (fMRI) or magnetoencephalography. The last two require highly-expensive large-scale devices and their use is restricted to very specific situations, in general related to theclinical diagnosis of a brain pathology.

Current applications of BCIs

A BCI equips the user that the brain activity is registered in with new abilities and can have different applications controlling a huge variety of physical or virtual devices.Depending on the device controlled by the interface, we can handle avatars in a video game, robots as an articulated arm to handle objects, humanoid robots, text generators as a speller, drones, exoskeletons to help people's mobility, prostheses in the case of patients with amputated limbs, or electrodes to stimulate a brain region for the purpose of helping patients to move around who have lost that capacity due to some disease (for example, Parkinson's).

In general, any type of software or hardware can be handled for which a valid control interface is developed.Thus, the applications which we can currently find in the commercial environment and in the research field aim to replace, restore, enhance, complement or improve the natural capacities of the nervous system.

Future applications

Thanks to technological advances, nowadays the diagnosis of certain brain pathologies can be made by means of an EEG to discriminate between normal and abnormal activity, andothers are even treated through electrostimulationof brain nuclei with electrodes implanted in the brain. Modulating brain activity has become a primary objective for Neurorehabilitation. Not only does one seek toredirect abnormal brain activity, but also to reactivate damaged circuits, and even redesign them through activity imposed by external devices, such as powerful magnets. The brain interfaces will make it possible to read the brain activity, analyze it, catalogue it andact upon it in order to correct it whenever necessary. Nowadays commercial devices are being used which contain magnetsto relieve the pain associated with migraine attacks. Will magnetic stimulation replace the "aspirin"?It is undoubtedly one of the most promising fields.

Fiction shows us a great variety of possibilities mediated by BCIs. Prostheses can be replaced by highly varied devices which act on the surroundings. In fact, Science has already managed to materialize some of those fantasieswhose mere possibility has intrigued and even frightened people from all walks of life for centuries, such as telepathy and other non-existent psychic powers. Any interaction with the outside medium requires a transduction of the brain activity to another type of energy. The brain has no such capacity, but a BCI interface does, and executes it with the same ease as a tiny remote control is able to turn on the TV, launch a missile, or unlock a car door. Electronic miniaturization and the command of electromagnetic waves have made possible what a few years ago was an object of mockery for some and a concern for others.

Through interfaces it has already been possible for two rat brains to communicate with one another. How long will it take us to do so between human brains? Or to use electronic extensions of the brain to enhance our capacity? Will we use brain interfaces to control the feared devices which use artificial intelligence? Where will the boundaries lie of what an individual is in the near future?

Sources of information

- Brain-Computer interfaces. Principles and practice. J.R.Wolpaw. Oxford University Press
- https://www.youtube.com/watch?v=aHRJQjJcMNw
- https://www.slideshare.net/vijayrocks123/brain-computerinterfaces-ppt
- https://www.slideshare.net/asertseminar/bci-32898921?next_slideshow=1