7th SEMIC |ESPM – São Paulo | October 2018 | ISSN 2358-2138

Brain-Computer Interface: A New Frontier for Human-Machine Interaction

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Summary

Several types of research in human-machine interfaces (HCI) seek improvements in the use of better techniques to facilitate the interactions between man and technology. In this context, a variety of interfaces interact directly with the human nervous system, integrating the study area of Brain-Computer Interface (BCI) and providing new possibilities for the development of the HCI area.

Through the study of the state-of-the-art in the BCI area, this work aimed at investigating the functionalities and comprehension of the treatment of biological signals: a) going through the capture and processing of muscle signals (EMG - Electromyography) mysteriously through the BCI device; b) developing an interaction from the signal processing done by Myo; c) preparing possible scenarios and architectures for an interaction; d) conjecturing a prototype to exemplify the potential of the interaction created.

At the end of the research, a greater insight into the study area of BCI interactions was obtained, in addition to the various multidisciplinary applications. It also allowed the prototyping of an application on Android, using human-machine exchange in the case of home automation. And finally, it was envisioned to continue the research, expanding to the study of signal processing and developing the application to other devices: e.g., prototyping a mechanical arm.

Keywords: Human-Machine Interaction. Brain-Computer Interface (BCI). Electromyography (EMG). Human-Computer Interface (HCI). Myo Armband.

Introduction

The interaction between humans and machines is the subject of constant research and innovation since there is the assumption that the more intuitive and friendly it is, the more productive the work development will be (Hewett et al., 2014). Over years of studies and tests, a new area was established to address this specific subject; this area is known as Human-Computer Interface (HCI) (Green; Paul, 2008).

In this context, the HCI study area proposes developing or improving the security, practical utility, and usability of the entire environment that uses or is affected by computer technology. Innovations in HCI generate new business models, such as, for example, the innovation of the mouse, which has enabled greater productivity at work.

Besides these forms of Human-Machine interaction, some techniques work with signals captured by the central nervous system by specific sensors. In this approach, biological signals are collected from the central nervous system and CNS and then processed; the devices that do this task are called Brain-Computer interfaces, BCI. With advances in neuroscience studies, these interfaces have significant enhancements that stand as a new frontier of implementation for HCI areas.

The eccentricity of the BCI area matches its way of apprehending biological signals from the nervous system; in a reducible way, the BCIs do the acquisition, pre-processing, and classification of physical signals so that high-level systems can execute their tasks with deterministic commands to machines. There are two ways to capture movements in the signal acquisition phase, using either invasive or evasive sensors.

The technique is said invasive when the capture sensors somehow invade the human body to obtain the signals; on the other hand, it is said evasively when the capture sensor accepts the signals through the surface of an area of interest. Additionally, the acquired signals are named about the site from which the signs are extracted.

> When signals are taken directly from the central nervous system (brain), these signals are signals from an electroencephalogram (EEG). When the signals are obtained from the cardiac system, these signals are signals from an electrocardiogram (ECG). When the signals are received from the

> somatic approach, coming basically from the muscles, these signals are signals from electromyography (EMG) (Mark F. Bear et al., 2002)

In this research, an investigation was developed that envisions the acquisition of signals from the biological system through BCI equipment. That through signal processing works with the signals captured from the bodily system, in a mysterious way in the forearm, for reasons of accessibility and practicality for the study.

Brain-Computer Interface (BCI)

The processing power of modern computers and our understanding of the human brain are two areas that are growing together, creating the impression that everyday science fiction can be transformed into reality. Nowadays, there is a wide variety of studies for developing new technologies, considering the potential to manipulate computers or machines through human "thought" and the power to work an action without that action being physically performed (Hewett et al., 2014).

> Studies of the encephalon are as old as science itself, but when researchers realized that the best approach to understanding the function of the encephalon came with interdisciplinarity, they were then able to produce a new perspective of study for the most complex organ of the human body (Mark F. Bear et al., 2002)

Thanks to Huxley's studies, neuroscientists have developed a new field of study, computational neuroscience. This area of neuroscience has as its objective the apprehension of brain functions in terms of information processing that are produced in the nervous system (Patricia S. Churchland et al., 1993).

With the development of this new area of neuroscience, other ramifications of research have emerged, such as the simulation of biological neural behavior in computational algorithms, with the highlight of the contributions of two scientists:

1. Wilfrid Rall, neuroscientist considered to be one of the founders of computational neuroscience, for having initiated the biophysically realistic computational modeling of neurons and dendrites, using cable theory to build the first multicompartmental model of a dendrite (W. Rall, 1962), and the passive and active compartmental modeling of the neuron (W. Rall, 1964);

2. David Marr, a neuroscientist and psychologist who integrated findings from psychology, artificial intelligence (AI), and neurophysiology into new models of visual processing, focused on the interactions between neurons, suggesting computational approaches to studying how functional groups of

> neurons in the hippocampus and neocortex interact, store, process, and transmit information (Dawson; Michael, 1998).

With the advances in computational neuroscience, the neural models proposed by Wilfrid Rall, David Marr, and other neuroscientists sought to approximate the processing of computers to the "processing" done by the brain. Seeking a human computational mimicry very similar to that performed by the central nervous system (CNS).

Creating computer models that replicate the behavioral properties of the encephalon help neuroscientists understand how specific study features develop without the use of an invasive method (Mark F. Bear et al., 2002).

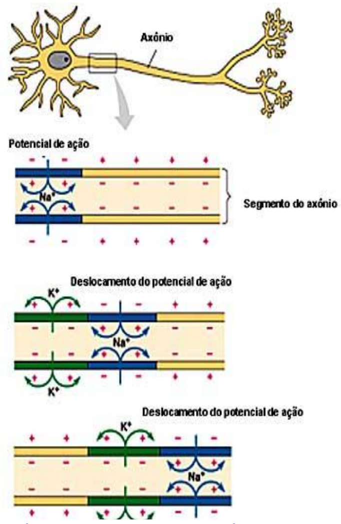

Figure 1 - Propagation of the nerve impulse, triggered by the action potential.

Source: Just Biology (goo.gl/PNCAij).

> The information provided by these models is commonly discussed as a "technological discipline that deals with parallel, distributed, and adaptive information processing systems autonomously developing information processing capabilities as responses to the information environment." (R. Hecht-Nielsen, 1990).

One of the applications of BCI is to enable people who have some muscle movement restriction to somehow ease their interaction restriction, for example. Thus, the development of BCI can be considered a way to improve the quality of life of these people, therefore existing a vast potential market.

The study of interaction with the somatic system (EMG)

Throughout history, in the search for understanding the functioning of the central nervous system (CNS), there were specialized cells for this system, which have the characteristic to receive and transmit electrical stimuli and are known as neurons. To carry out the study of the structure of nerve cells, researchers had to overcome several obstacles.

Neural systems are groupings of neurons that transmit information to other neural systems and also other systems in the body. These signals are transmitted by electrical impulses generated by the neurons, the electrical potentials, and chemical means between the neurons. There are two models of neurons capable of developing and conducting action potentials; they include both nerve cells and muscle cells, both have an excitable membrane.

> The chemical environment in which neurons exist is electrically conductive, so the electrons carried by the axon eventually leak into the saline extracellular environment. In the cytosol on the surface of the membrane, there is a negative electrical charge compared to the external account. This difference in electrical charge is called the resting potential. The action potential is simply the reversal of this condition, and for a millisecond, the electrical potential of the membrane becomes positive (Mark F. Bear et al., 2002)

From the discovery of the action potential, scientists began to develop techniques for capturing the stimuli transmitted by the neuron to monitor the electrical activity of the excitable membranes of the nervous system. Its main objective is to analyze the speed of electrical conduction and the state of the motor units to detect lesions of the peripheral nervous system and muscle localizing the lesion within the motor unit (MU) and quantify such lesions. The motor unit action potential (MUAP) is the temporal and spatial summation of the individual action potentials of all the fibers of a MU.

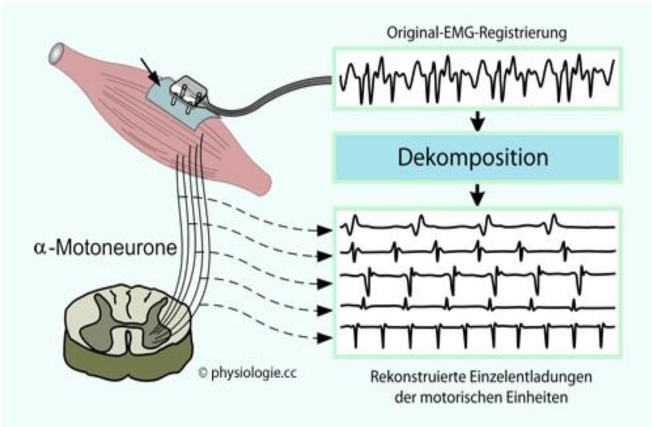

Figure 2 - Visualization of the EMG collection technique.

Source: Adapted from De Luca et al. 1982[a] (goo.gl/xBZpLi).

Electromyography (EMG) is the technique that monitors these membranes, representing the measurement of the action potentials of the sarcoma as a voltage effect as a function of time (W. Rall, 1964). Therefore, EMG is an algebraic summation of the electrical potentials generated in the muscle fibers, during different categories of contraction, detected under the working area of electrodes applied to an area of the human body.

In EMG signal acquisition, the amplitude of the PAUM is derived from several factors such as the firing rate, characteristics of the muscle fiber membrane, muscle fiber diameter, the distance between the active muscle fiber and the EMG signal detection site, the surface area of the electrode pickup, and the extent to which the electrodes are distributed over the muscle, i.e., the location of electrode placement.

After data acquisition, necessary procedures are required for signal processing. The EMG signal captured in the human body is analog (a continuous movement in time), converted to a digital signal to record it. In EMG, when the noise frequency differs from the direction of interest, its use makes it possible to clean the movement. The collected signal, or raw signal, is subjected to a specific and valuable filtering process since it minimizes the probability of noise in the treated signal.

The first filter passed is called the Band Stop filter, in which the signals collected at frequencies close to 60Hz (frequency in electrical average) are removed. Another filter used is the band delimiter called the "bandpass filter" (Band Pass) that delimits the frequency spectrum to the desired amplitude, for example, 20-250Hz, the natural operating band of neurons.

Once the signal has been obtained and processed, it quantifies the density of the collected signal spectrum. Two commonly used ways to get this value are the integral of the EMG signal (iEMG) and the RMS. The EMG is calculated by an integral area in the frequency spectrum filled by an iEMG signal. Another treatment implemented is the fast Fourier transform (FFT) algorithm, which can generate the median and average frequency values since it has a high accuracy for muscle fatigue analyses.

Electromyography has numerous applications, notably in clinical medicine, for the diagnosis of neuromuscular diseases; in rehabilitation, for the re-education of muscle action (electromyographic biofeedback); in anatomy, to reveal muscle action in specific movements; and in biomechanics, to serve as a tool to indicate certain phenomena.

In the development of this research, the EMG is used with the application in biomechanics. In this area, the recording of electromyographic activity allows us to investigate which muscles are used in a specific movement. Thus, being a tool that indicates phenomena such as the level of muscle activation during the execution of the action and the intensity and duration of the muscle request allows inferences regarding muscle fatigue and those who do not have the whole arm.

The Interaction Framework

One of the most exciting areas for technology development in recent years has been gesture-based device interaction. It allows users to interact with computers without touching any input object, such as a keyboard or mouse. There are no doubt several devices that perform these approaches. However, not all technologies can be accurate, faithful (precise) to human movements.

Thalmic Labs, a company started by three engineering graduates from the University of Waterloo, has developed an armband called Myo that uses innovative technology. The bracelet estimates human gestures from impulses captured in the forearm, such as "closing your hand," and transforms them into machine code. A device implemented using BCI interaction studies and analysis of EMG interaction with the human body.

The Myo armband captures the electrical activity of muscles through a set of electromyography (EMG) sensors that work with a mesh of electrodes with high-density multichannel, allowing a more accurate capture of muscle contractions, combined with a gyroscope, accelerometer, and magnetometer to recognize gestures and arm movement to interact with an interface or machine.

Table 1 - The features available for each SDK

SDK	gestures	IMU	EMG	Application	Platform
keyboard mapper	Yea	No	No	No	Windows/OSX
Myo Script	Yea	Yea	No	No	Windows/OSX
Platform SDK	Yea	Yea	Yea	Yea	Windows/OSX
unity	Yea	Yea	No	Yea	Windows/OSX
Android SDK	Yea	Yea	No	Yea	android
iOS SDK	Yea	Yea	Yea	Yea	iOS

In addition, Myo brings with it numerous development possibilities through the Software Development Kit (SDK) made available by the scientists at Thalmic Labs (Thalmic Labs, 2015). Through these SDKs, any developer can venture out to create interactions using the device.

To help understand and design how to utilize the capabilities of each development kit, by exploring the features of each SDK made available, it is possible to determine what their basic functionalities are. Each SDK offered has its operations and capabilities, so they may differ and may not present all available features. Thus, table 1 illustrates the development possibilities, in their current versions, for the creation of interaction using the bracelet.

The architectures, or frameworks, serve as the basis of the bracelet communication for the project. They are models or concepts of information used to explicitly detail the system of collecting and sending data, control, and execution. And, as a matter of good development practices used in software engineering, to choose a good implementation technique, it is necessary to know a problem in-depth to obtain the best solution. In this case, this problem is to define the best architecture for the development.

As shown in table 1, there are two platforms targeted by the Myo SDKs. The first is the computer platform, Mac (OSX) or Windows, and the second is the mobile Android or iOS platform. Although these two platforms are the focus of the bracelet development, it was possible to identify some alternatives to add to the research framework through studies and research in the area. The Raspberry Pi and the Arduino platforms are worth mentioning among these tools.

Using active methodologies for an analysis of the software structure, it was inferred that, by obtaining knowledge about the advantages and disadvantages of each framework, it is possible to get an adequate level of solution for this research development. In the same way, achieving a solid understanding of the implementation of each interface served to guide the implementation of the research. Following this logic, the characteristics of each control interface shown were explored to choose the best implementation architecture.

Table 2 - Capabilities of the worked and researched Frameworks.

Capabilities	Tiered Architectures			
	Raspberry Pi	**Computer**	**android**	**mobile**
Mobility	Medium	None	High	High
Development Support	Short	High	High	None
Development Capacity	High	High	High	Medium
IoT Integration	High	Medium	High	High
Usability	Medium	Short	High	Medium
objective	Adequate	not suitable	Most appropriate	Adequate

After raising the positive and negative points about each framework, it was necessary to choose one to develop the human-machine interaction. Undoubtedly, they all presented some advantages for a form of use that would significantly benefit the interaction created. However, to choose one to perform the development focused on using an IoT device, the most interesting architecture to explore in this area is the one provided by the Mobile platform, the last column of Table 2.

Connecting Myo to a mobile device interferes directly with people's daily lives, which brings a great advantage for interaction. After all, having a smartphone nowadays has become essential to establish the basic needs of human communication and increase the level of technological interactions and possibilities through the device, besides being able to represent the potential of a computer in the palm of your hand and using the advantage of the mobile device being present in the daily life of many.

Thus, both Myo and the mobile platform are free to bring the most significant mobility to the user. With the choice of the working framework to conceive the interaction, the focus is given on how the communication between the interfaces occurs to perform the data processing. The platform serves as the communication bridge, interpreting the bracelet data through the Myo SDK. The HCI habitually uses the other side of the communication as a means of interaction with the user, a prototype developed through the Arduino platform. Ready to execute an action according to the information sent by the mobile device.

The BCI Device

The Myo armband is a device that presents much of its power through the transformation of user interaction, using signal processing techniques to create a BCI interaction. Undoubtedly, the way this transformation occurs is intriguing; as simple as it may seem, this interaction is highly complex, requiring a lot of techniques to accomplish.

As much as how individuals practice the same gesture, for example, a fist may appear identical under a microscopic eye; there is more complexity and variety than the human eye can see when noticing a gesture. To reduce the impacts of signal behavior, scientists use a large amount of collected electromyographic data to maintain the algorithm used to identify a motion and minimize differences in EMG interpretation.

Figure 3 - Identifying a gesture using Myo

Source: Thalmic Labs (https://goo.gl/gxaspJ).

In addition to understanding human gestures by collecting and processing EMG signals, Myo uses a combination of spatial sensors to measure the movements performed by the user's arm accurately. It uses an inertial measurement unit (IMU) to determine the bracelet's spatial position relative to the earth. With such a characteristic, the minification of the movements is elaborated through a graphic interface created to illustrate and increase the immersion of the experience produced by the bracelet to the user.

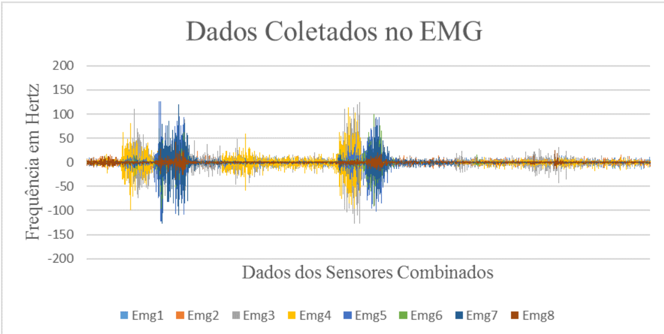

Figure 4 - Illustration of the acquisition of the 8 EMG channels over time by the device.

Finally, the bracelet can perform a wireless communication to transmit collected data to an intermediate interface, which will complete the processing of these data. This transmission is done through wireless communication technology, Bluetooth, more specifically Bluetooth Smart.

> Technology was created to work worldwide, so it was necessary to adopt an open radio frequency that is accepted almost anywhere on the planet. Bluetooth enables the exchange of data over short distances (Kevin Townsend, 2014).

The Myo armband has electromyographic (EMG) sensors that capture the electrical signals coming from the human body to perform biological signal processing. More specifically, in 8 separate sensor modules to read the muscle activities and estimate the gesture that the user performed. Through the biomechanics used by the BCI device, the record of the electromyographic activity allows the investigation of which muscles are used in a given movement, the level of muscle activation during the execution of an action, the intensity, and duration of the muscular solicitation, inferring how the device detects a pose by deciphering the EMG collection.

An inertial measurement unit (IMU) works by detecting linear acceleration using accelerometers and rotation rate using one or more gyroscopes. The accelerometers measure acceleration along specified axes, while the gyroscopes measure acceleration about the axes. Some IMU modules also include a magnetometer commonly used as a heading reference. Typical configurations contain one accelerometer, gyroscope, and magnetometer per axis for each of the three axes of the device: roll (Φ), pitch (θ), and yaw (ψ) (Sparkfun, 2017). Using this unit, it is possible to realize a spatial representation of the bracelet and, consequently, the motion of the user's arm while performing a movement.

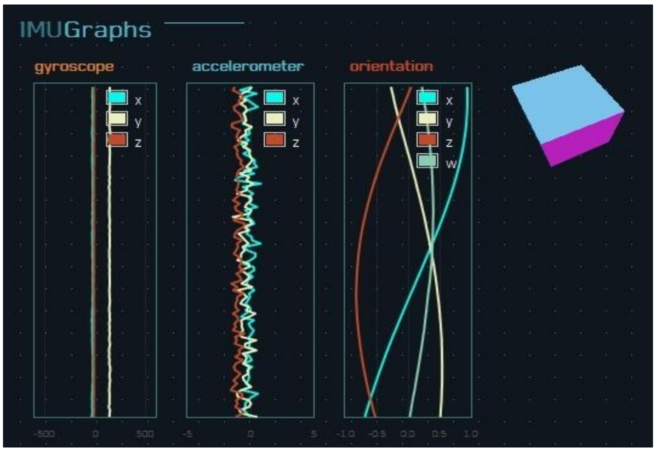

Figure 5 - Illustration of the data collection responsible for the spatial representation of the bracelet (cube) through the IMU.

All the signals collected by the bracelet are sent through wireless communication to a mobile device. The data are processed and translated into commands to operate another device, usually an electromechanical system. The data is processed over changes in both the action potential spectrum in the EMG signal and its spatial motion through a Quaternion. There are numerous possibilities for connecting to the Myo, giving a wide range of options for working on human-machine interaction in this scientific initiation.

With the result of integrating the bracelet data, a graphical interface was developed to present the collected data and thus assist in decision making. These represented interactions end up generating a high level of communication with the device, breaking the barrier of an exchange. In the next section, this range of possibilities is explored, justifying the choice of developing the interaction itself with the device.

The Result of the Interaction System

This project started by doing something simple in response to a pose to demonstrate the capability of the BCI interaction provided by Myo. For this, a prototype was built through the Arduino platform, despite having implemented and evaluated other alternatives (Table 2), to light a led corresponding to a gesture captured by Myo. As simple as this process may seem, it is essential for automation because it demonstrates knowledge of the whole process, and new functionalities could be obtained in the future.

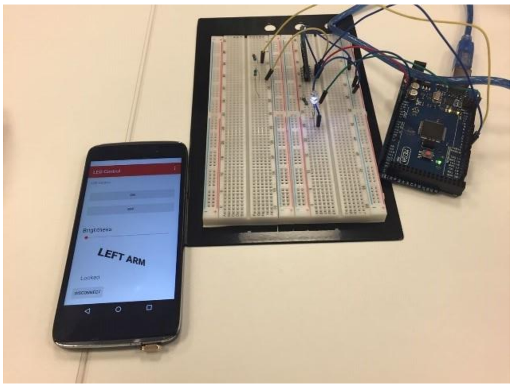

Figura 1 - Protótipo desenvolvido para testes da interação.

> Arduino is used in thousands of different projects and applications thanks to its ease of performance development. From building low-cost scientific instruments to testing the principles of chemistry and physics to introductory courses in programming and robotics and making it a vital tool for learning new things (Arduino, 2017).

The primary purpose of Arduino in a system is to facilitate prototyping, implementing, or emulating the control of interactive services, at the household, commercial or mobile level. With it, it is possible to send or receive information from almost any electronic system, making it applicable in various situations, such as: identifying the approach of a person, varying the light intensity of the enclosure, opening the windows of an office according to the sunlight energy and ambient temperature, among others.

Using the Arduino, a prototype was elaborated to act on Myo's interaction at the domestic level, focused only on the automation of a lamp. This automation, eliminating the usual interaction with a switch performing it with just a gesture, brings a new level of control and convenience to people's lives. Figure 6 illustrates one of the prototypes of the integrated system.

The interaction and studies with the Myo device evolved gradually throughout the project. Thus, near the end of the project, it was possible to implement an IoT module to exemplify the practiced development capability, assimilating it to a natural experiment for communicating a BCI interaction. Thus, the module conceived and presented in this project served as the basis for a proof of concept prepared in the discipline of the Information Systems course, which offered greater completeness of functionality in a real scenario.

In Figure 7, the application installed in the mobile device - in the center - processes the signals acquired by Myo - on the left - and then transmits an execution command to the Arduino - on the right. The Arduino, as soon as it receives the order to be executed, turns off or on the led on the central board. This simple example elucidates the entire operation of the proposed system, allowing the execution of actions by recognizing user gestures in a simple led automation.

I was using an IoT prototype and having an assertion in the discipline interdisciplinary project of the Information Systems course. The possibility of associating the two projects to assemble the learning in a single plan contemplating integrating a BCI interaction using the IoT created in the interdisciplinary subject.

Thus, the module conceived and presented in this project served as the basis for a proof of concept developed in the discipline of Information Systems, giving greater completeness and functionality in a real scenario. Since the project succeeded in a product with added value for the Startup OnHouse, organized by the group to which the initiating student is a member.

Figure 7 - Flowchart of the developed interaction.

Final considerations

This scientific initiation work aimed to study the interactions between man and machines. Investigating from the fundamentals that provided the conception of current technologies to the state-of-the-art, which offered new contributions to Human-Machine Interaction.

Through the learning obtained, areas of study such as HCI have established an understanding of new business models, searching for more fluent techniques and interactions. Such as the deepening of the size of study provided by BCI for developing a form of control in which it could perform new functions through the analysis of neuroscience and collection models for nervous stimuli in the human body.

As a result of this study: the integration of a system involving different development platforms was developed; the development of a Bluetooth communication model to integrate them; the encouragement of multidisciplinary teaching, which expanded the scope of traditional computer science knowledge, through neuroscience; the development of know-how using the BCI device worked; the design of internet of things (IoT) module; which in turn promoted changes to the composition of the work. Opportunities for learning in the neuroscience scope awaken numerous research possibilities for the continuity of academic training in this multidisciplinary and new business model.

Still, it is expected to obtain more significant contributions from a new investigation using other BCI devices through a new research proposal and acquisition of new equipment, which has already been submitted and approved. This area innovates every day in academia, raising many expectations for technological and medical advances. Thus, there is an exceptional research opportunity for Human-Machine Interaction, imminent in the study's progress using the techniques learned with the armband.

Thus, the possibilities occasioned by the evolution of the study provided plans for future work to evolve and advance the multidisciplinary teaching scope proposed by the BCI field of study. It is reaching the discernment of the processes performed by the processing of neural signals, with the understanding of the biological process that comes from the human body—directing itself more and more towards the complementation of the two teaching areas that work on human interactions with machines.

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