THE DEVELOPMENT OF AN ANTHROPOMORPHIC MECHANICAL ARM

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Summary

The processing power of modern computers and the understanding of how the human brain works are two areas that are growing together, thus creating the impression that everyday science fiction can be turned into reality. Nowadays, there is a wide variety of studies to develop new technologies. Among the various innovations is the potential to handle computers or machines through human "thought" and the power to work out an action without being physically performed. This provides a matter of convenience but also includes accessibility.

To help the mobility-impaired, this research project explores some of the development possibilities of this new form of interaction. This is done by making a prosthesis of an anthropomorphic mechanical arm, which presents the opportunity of performing actions through brain stimuli and, at the same time, with a production cost infinitely lower than the current technologies on the market. With the development of this technology, there is the possibility of obtaining a more skillful interaction, capable of helping people with some disability to acquire a better quality of life. This work presents a proof of concept that contributed to the study carried out in the area.

Keywords: Brain-Computer Interface (BCI). Electromyography (EMG). 3D printing. Myo armband. Mechanical arm.

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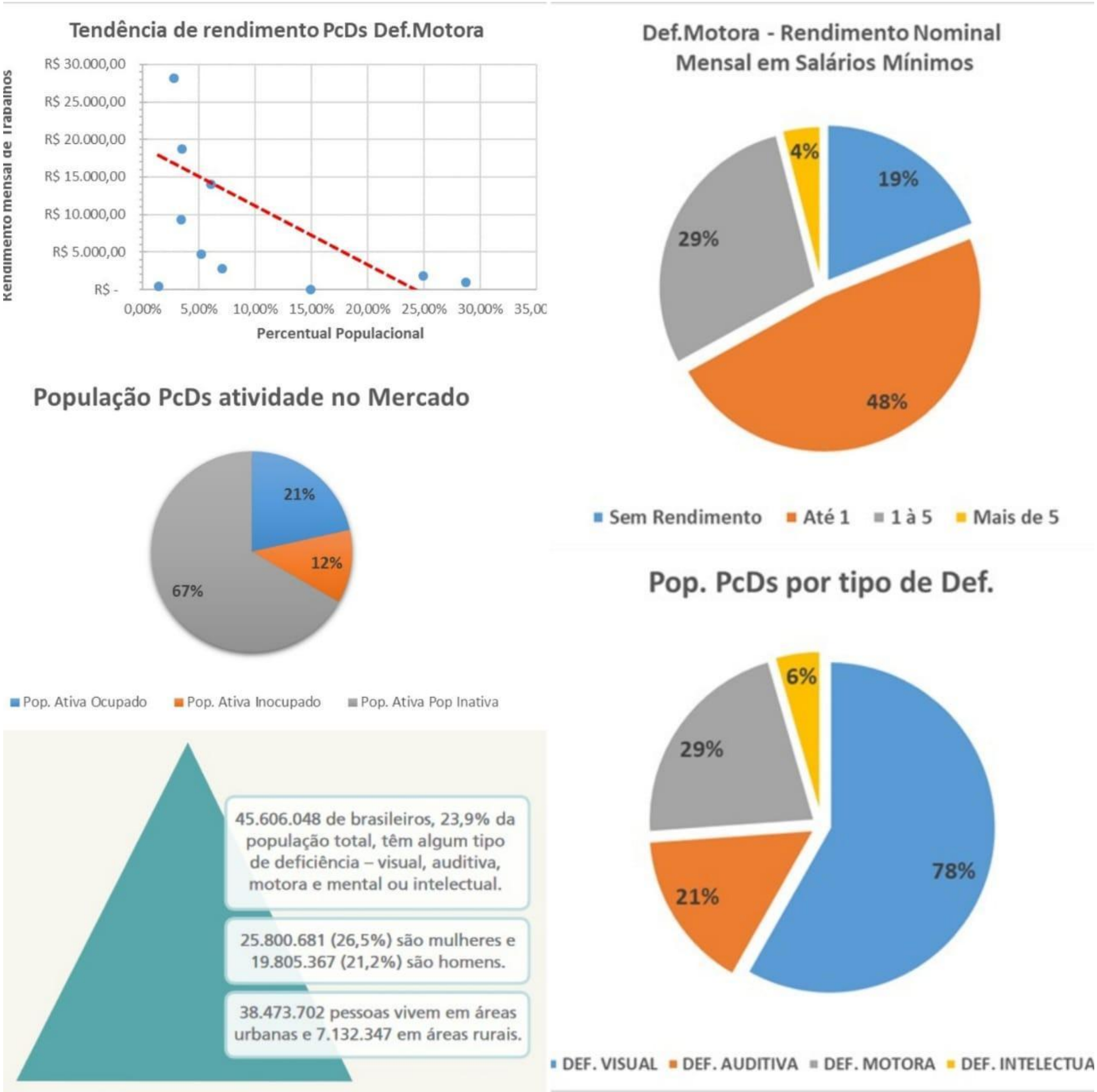
1. Introduction.

The interface between humans and machines is constantly the subject of intense research and innovation since there is the assumption that the more intuitive and user-friendly it is, the more productive the development of work using it will be. As a result of these investigations, areas of study have emerged whose goal is to achieve a high-level interaction between man and machine, through the growth of neuroscience with the understanding of the nervous system and the formation of new procedures for collecting signals from the brain such as the Brain-Computer Interface (BCI). Additionally, the development of research in BCI makes it possible to search for more convenient ways and meet some needs in existing interactions due to their shortcomings.

Interacting with your environment is essential for health care and quality of life. For those with neuromuscular impairments, people with disabilities (PcDs), BCI devices can provide an opportunity for greater integration. The possibility for a debilitated person to restore their movements by interacting again with the environment around them without being subjected to the demeanor of others. According to the WHO report, this equipment provides new self-esteem for PwDs to perform activities, stimulating a breaking down of barriers and granting a new possibility for the individual to perform affectionate activities again (WHO, 2011).

Nowadays, there are numerous prosthesis models capable of causing significant changes in the lives of PwDs. A cosmetic model, simple, which allows some realism in aesthetic matters, causes a substantial shift in reality for these people. On the other hand, a more technological model, which uses applications from the BCI, can restore the confidence of PwDs in being able to regain their movements after their loss. However, the technology and the materials used in this equipment are restricted because they use expensive inputs to make these prostheses, effectively increasing their price making them inaccessible.

Figure 1 - Research of PwDs in Brazil



Prepared by the author based on the 2010 Census

Aiming to provide an improvement in the quality of life of these people, through a case study analyzing the WHO report of 2011 and the demographic census of IBGE of 2010, this research project made an analysis of the PwDs population in Brazil, illustrated by figure 1, seeking to apply accessible technologies in the development of an interaction that can suppress some difficulties encountered by PwDs people. Having as a goal the production of a proof of concept (PoC), which in the future may give rise to a cheaper and accessible product for much of the population, as shown in the research report results.

2. Methodologies

Seeking to exercise the presented research objective and explore the possibilities of research and techniques coming from the multidisciplinary educational scope of the BCI study area, this research project focused on developing an interaction capable of exploiting signal acquisition in the nervous system and the detection of macroscopic brain states in real-time to "decode" motor movement signals to interact with a prototype of a "prosthesis."

After investigations carried out in the research project "Brain-Computer Interaction: A New Frontier for Human-Machine Interaction" (Reis, Ian D. (2017)), working with studies using BCI techniques, it became evident that this relationship can create assistive technology through interactions that help health care use rehabilitation and support disabilities.

For the execution of the research project, it was indispensable to carry out bibliographic research to formulate the basis of the project and use the scientific process for the elaboration and effectuation of the project itself. In this way, it was required the study of the works; "Neuroscience, unraveling the nervous system" (Mark F. Bear) and "Digital Signal Processing" (John G. Proakis); along with the documentation of the SDK (Software Development Kit) and reference scripts of APIs (Application Programming Interface), of the electronics used in the project, as well as, a sample data collection of the experiment for the placement of a method and the proof of the study carried out.

In the project, insight was gained into the processes used to operate using the BCI and an understanding of the biological process that comes from the human body through neuroscience. The flowchart shown in figure 2 highlights some of the fundamental steps for developing the PoC presented in this report.

[1] After the investigations carried out in the previous research project, it became apparent that this relationship can offer assistive technology. The device, the target of Myo's research, exposed a great competence for development using BCI techniques. This area innovates daily in academia, forwarding many expectations in technological advancement and medicine. Given the employability, the research has given rise to development by collecting nerve stimuli to demonstrate the power coming from this interaction. After completing the investigation, new possibilities were raised to further the study and cover the analysis of the potential of BCI interaction (Reis, Ian D. (2017)).

Figure 2 - Flowchart of the development of the research project

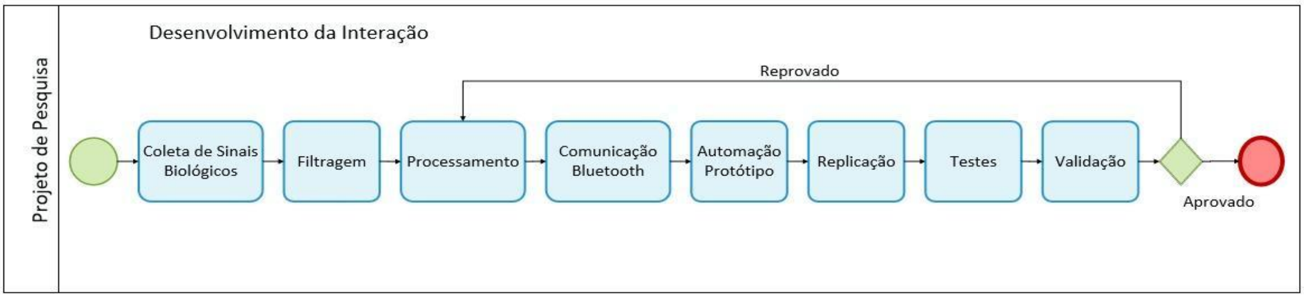


Figure prepared by the author

The stages of **Collection** and **Filtering**, allusive to the treatment of biological signals in the conversion of the collected signals to the collection of the biological process sample rate; **Processing** and **Communication**, allusive to the techniques used by the created application elaborating algorithms for understanding the signal processing and communication with the developed prototype; **Automation**, development of an exemplar capable of replicating the obtained advance in the form of a proof of concept; **Replication**, regardless of whether the observation is experimental or clinical, it is essential that it can be replicated before being accepted by other researchers; **Testing**, at the time before believing that the observation is correct, an interpretation is required which depends on the knowledge and conceptions perceived about the project; **Validation**, step to prove the observation made regarding the study of signal processing, the tests and experiments to develop the prototype the development of a software capable of making a simple interpretation from the signal processing.

3. Processing and acquisition of biological signals

The use of techniques from the BCI study area matches seizing bioelectric signals from the nervous system (SN) for their interpretation, classification, and transformation into deterministic commands for machines. There are several techniques to capture bioelectric signals. They diverge concerning the area from which the signals are extracted: 1) when the signals are captured directly from the central nervous system (brain), these signals are signals from an electroencephalogram (EEG); 2) when the signals are obtained from the cardiac system, these signals are signals from an electrocardiogram (ECG); 3) when the signals are obtained from the somatic system, coming basically from the muscles, these signals are signals from electromyography (EMG) (Mark F. Bear et al. (2002)).

In this scientific initiation, EMG signal collection techniques were used, through which it is possible to investigate which muscles are used in a particular muscle movement. Thus, acting as an indicator tool of phenomena in the level of muscle activation during the execution of the action by detecting the intensity and duration of muscle request in identifying inferences regarding muscle fatigue and noise in the signal collection (Gary Kamen; David A. Gabriel, 2010). The signals collected in the analysis of electromyography used in this work are captured from the somatic system, forearm, for accessibility and practicality of study.

EMG is a valuable technique for studying the mechanics of human movement and evaluating the mechanisms involving neuromuscular physiology, and diagnosing neuromuscular disorders. The study and analysis of the electromyography signal allow the identification of events that occur over time with specific frequency patterns, recording the electrical potentials generated in the muscle fibers from the stimulation of motor units.

> Muscle is a tissue constantly bathed in an ionic medium. The voltage gradient arises from the different concentrations of sodium (Na+), potassium (K+) and chloride (Cl-), and other anions across the membrane. Like all living cells, muscle surrounds itself with a sarcolemma membrane. Differences in ionic concentrations in the muscle produce voltage gradients across the sarcolemma. These voltage gradients are responsible for the resting membrane potential that varies in slow and fast-twitch muscle fibers (Mark F. Bear et al. (2002)).

The motor units are connected to muscle fibers that, under resting conditions, present a voltage gradient such that the inside of the thread is negative relative to the outside. The electrical message to initiate muscle contraction is transmitted through the motor units connected to the muscle fibers, causing the membrane to depolarize. When the muscle fiber is depolarized positively, the membrane potential reacts in a stereotyped and predictable manner, producing a response called the Muscle Fiber Action Potential (MPAP) (Gary Kamen; David A. Gabriel, 2010).

To record the muscle fiber action potential (PAFM) through a medium of cellular fluids and tissue, one of the most fundamental topics of EMG analysis is used; by using concepts commonly used to study electrical circuits, it is possible to interpret the bioelectricity phenomena occurring in the human body:

> Volumetric Conduction transmission electric or magnetic fields from an electric current source through biological tissue to measurement sensors (electrodes). The electromyographic signal is then fed to an amplifier that amplifies the muscle fiber voltage to a level that can be measured and converted to an analog-to-digital signal, giving rise to the signal transduction process. An electrical circuit changes the frequency content of the input electromyographic signal to minimize (filter out) noise from the surrounding environment or other sources before it is stored in the computer for later analysis (Brown, W.F., 1984).

With the acquired signals, a computational interface promotes the conversion of the analog EMG signal into a digital waveform. In this way, an algorithm can be written to process the digital signal meaningfully, allowing its measurement. For more information about the EMG signal collection, analysis, treatment, and quantization process, check out the full report of this research project available at the ESPM library (Reis, Ian D., 2019).

4. Interface Development

The development of this PoC can be broken down into five stages:

- the printing and making of parts and gears
- the assembly and preparation of the electronic components for automation
- the assembly and testing stage of the arm prototype
- the building of an application as a feedback interface
- the testing stage, verifying the functioning of the proof of concept

4.1. Mechanical arm assembly

In order to manufacture the parts used in the project, a 3D printer was used to produce the components needed to assemble the arm mechanisms. These machines manipulate inputs, usually plastic, to make objects worked on in 3D modeling programs. They allow anyone to create, experiment, and share solutions, even without much prior knowledge, enabling the creation of a cheaper solution for previously inaccessible technologies such as the arm developed in this project.

In the printing process, some parts presented defects or problems during the printing process caused by printing errors. The problems extended over a long testing period until an adequate fabrication level was reached. With most of the parts printed, the next step in the assembly process was separating and purchasing new supplies, replacing inadequate or defective equipment, and new demands. In addition to the inputs and instruments used in the assembly process, electronic equipment was acquired to automate the prototype with the help of ESPM.

During the forearm assembly process, there was the procedure of tensioning and angulating the motors to suit the positioning of the springs, providing asymmetry in the system's operation, as a result of numerous tests and rework on the arm's frame. In this process, the prototype's "muscular" activity was established by automating the electronic components.

The idea of a "muscular" movement of the mechanical arm is conceived through the harmonious activity of the system, given by the distension of the wires in the movement of the torque motors to the connecting tip of the gear of each finger. Thus, it became possible to simulate the relaxation and tension movements similar to a human hand. The mechanical hand consists of small gears responsible for creating the movements of the fingers; these gears enable a degree of freedom so that the activity of each finger is enough to replicate the opening and closing movements of the mechanical hand.

On the other hand, the parts at the end of the prototype's forearm activate the movements responsible for creating the degrees of freedom in charge of simulating a "muscular" activity, similar to the rotation of the body of a human hand, so that it remains in tune with the movement of the mechanical hand performed by the motors connected to the tendon tensioning support in the entire region of the forearm.

The lines (tendons) present in each of the arm's gears enable the mechanical simulation in the "muscular" movement of the prototype are the lines (tendons) present in each of the arm's gears. The training and rotation of the motors current in the forearm provide an alarming level of friction to the resistance of the mechanical components of the arm, in such a way that too much movement of the arm can cause a rupture among the parts of the hand because they present a very delicate movement.

During assembling and operating the arm, some inconveniences were present in the tendon frame. Some of the mechanisms created for the displacement of the threads and the connection of the parts were not properly cared for, leaving some burrs that were harmful to the integrity of the lines.

Because this adversity was presented in an advanced stage of the prototype mechanisms assembly, a correction for this problem would mean reassembling and remodeling the prototype of the mechanical arm. Something for a PoC is not feasible; after all, the developed prototype already represents a good development for the project's operation.

Another aggravating factor to the maintenance of the prototype is the component connections present to the tendons. If any of the lines break, it becomes incredibly challenging to repair the prototype due to the intrinsic connection of the system created. This may occur due to the friction provided by the rotation of the motors in the movement of the tendons by the design gears, which may impair the possibility of prolonged operation of the prototype. Thus, for future works, projects, or product production, rework will be necessary for the better functioning of the system.

4.2. The BCI Interaction

With the construction of the mechanical arm completed, we began the development of the automation responsible for controlling the mechanisms of the arm. For this, a BCI device was used to measure the electrical potential generated by the phenomena corresponding to muscle activity, as explained in section 3. This device allows the user to interact intuitively with the PoC through a refined capture of muscle contractions selectively aiming to identify a gesture of human movement mechanics.

From the selectivity of the device, it is possible to meaningfully record muscle activity from a local volume of the tissue rather than the crosstalk of neighboring muscle fibers. It effectively addresses muscle study in the (volumetric) analysis of an entire muscle set when recording a movement.

The development of this project produced an interface through a creative artifact to work directly with the signals obtained by the device. The developed artifact provides direct communication with the BCI device, aiming to improve the algorithm of the device's services without using the traditional means of an API (Application Programming Interface) and an SDK (Software Development Kit). This technique, employed in the development of the interface, was a low-level communication with the device (getting closer to machine language) to extract the essentials and improve the study of the electromyographic analysis by facilitating the. As a result, the investigation carried out in developing the software more refined signal processing analysis, contributing to a better understanding of signal collection and acquisition. Thus, the interface developed ended up reaching its level of completeness from the results obtained in the development of the project, as illustrated in figure 3. However, the goal of deepening the creation of BCI interaction came from retention in the investigation of the area when it became necessary to employ new research methods to advance the study of techniques and formulations to understand the EMG.

Among these methods and studies are Artificial Intelligence research employed in Deep Learning and Machine Learning. Two areas of study worthy of future work or in an eventual master's degree improving the researcher's knowledge in BCI for new developments are highlighted in the conclusion section of the article.

Figure 3 - Proof of Concept

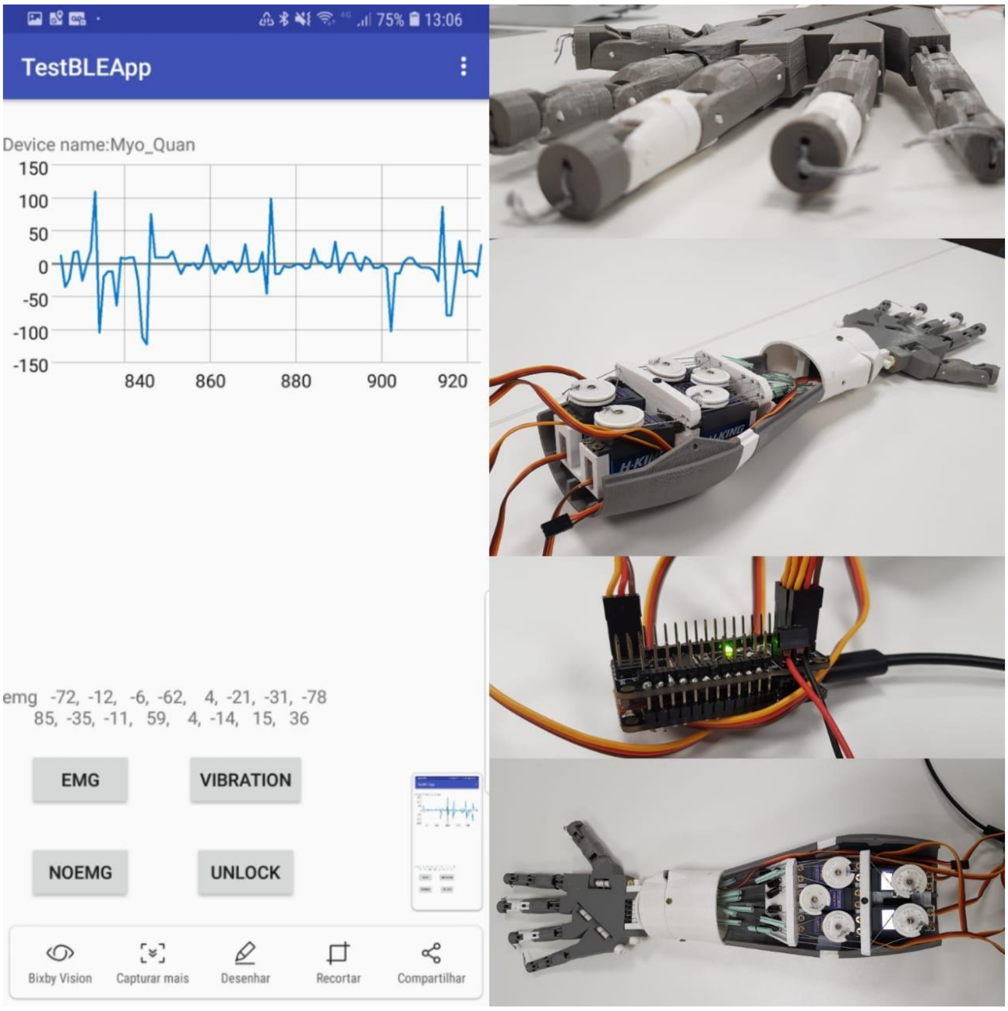


Figure prepared by the author

5. Conclusion

During the development of the interaction created in the scientific initiation Brain-Computer Interaction (Reis, Ian D., 2017), it was not feasible to achieve all the objectives envisioned for the investigation. Once, the interest in deepening the knowledge obtained applied in that research gave rise to the realization of this research project, enabling an improvement in the study of BCI interaction and consolidating the development of the study. Thus, through the survey carried out in constructing the proof of concept (PoC) in this project, results obtained by the project's development are discussed, portraying the problems and challenges during the journey, and presenting the final considerations of these two research periods, along with possibilities for future studies in the area.

5.1. From practice to experience denoted

The study of BCI interaction techniques provides a competence that encourages a multidisciplinary effort, expanding the scope of traditional computer science knowledge through medicine. The development capacity involving these subjects was supplied in the practical preparation for the assimilation of a proof of concept that can awaken the clarity and consensus of an understanding exploring the communication of such distinct areas.

Through a deeper study of electromyography done in this study, a breakthrough could be noted in understanding the behavior and treatment of noise to analyze synaptic signals obtained in the human body. It investigated the techniques used in signal processing that provide the study of current technologies in the learning obtained about neuromuscular behavior and the formation and collection of a nerve stimulus during muscle activation.

Thus, this work enabled the construction of a proof of concept, seeking to meet a physical need to maintain or improve the functional capacity of people with gestural disabilities and interacting with the environment through the study area of BCI techniques and more fluent interactions.

With this goal in mind, achieving a high-level interaction between the user and a mechanical prosthesis is more intuitive, friendly, and productive, seeking to replicate the potential of computer manipulation through a "thought" (logical reasoning). The know-how for the development using the BCI device employed promoted changes for the composition of a work confronting the traditional way of implementing a system. Creating a fantastic learning opportunity in the neuroscience field awakened research possibilities for the continuity of future academic formation.

On the other hand, obstacles have arisen in achieving high-level interaction through the area's multidisciplinary knowledge scope, seen in the certainty in the search for and use of new techniques and solutions to develop the exchange. Likewise, innovations arise in the use of new processes that lead to further studies and competencies of fundamental actions for the development of the work.

Finally, the study contemplated in this work provides an opportunity to develop this competence and continue advancing within the multidisciplinary teaching among many expectations at the forefront of technological and medical examinations and the evolution of new studies done by the researcher in the area.

5.2. Final considerations

During the scientific initiation project development, some limitations were noticed concerning the arm's construction and the application's development, as reported in section 4. Thus, providing some extenuation with the completion of the work. This section discusses mitigations for further studies arising from this proof of concept.

From the results obtained in tests performed during assembly and operation tests of the components used in the arm, some adversities found in the developed prototype were verified. Due to the inherent junction of the parts in the assembly cycle, the prototype had its operation threatened.

Each of the mechanisms present in it is connected so that an imminent deterioration of the arm will invalidate the entire instrument created. Of course, because this is only a PoC, it opens the possibility of future improvements to the prototype to design a better model to supply the market's needs.

Thus, as was identified, certain drawbacks in the mechanical part limited the project's performance, making the movement scarce and shortening the lifetime of the direction of the developed mechanisms. However, the automation results were satisfactory to demonstrate the idea and research in a proof of concept.

5.3. Future works

This particular work had two rather striking characteristics, often treated differently in the eyes of a researcher. Usually, the most noticeable is the search for knowledge, the scientific side, such as the search for a need. Nevertheless, this search can originate in the solution of a problem, which can create a product for the market. This research did not end with investigating BCI techniques, but it allowed us to glimpse the search for a solution that could overcome adversities found in day-to-day life through new technologies.

The importance given to the search for new technologies and solutions showed how the proposed study would directly benefit many people in this study. This desire for applicability in real situations remains firm, along with the eventual possibilities of learning and knowledge in the area as to the search for new research. Through recent studies in this area, new researchers can improve the development of this study and eventually turn it into a product ready for commercial use to solve the problem discussed in the presentation of this research.

Regarding the possible continuation of research, the study carried out in this work still has great potential for evolution. However, to continue the research progress in the scope of the BCI, it is essential to deepen the area of artificial intelligence, aiming to incorporate techniques and methodologies for the treatment and processing of signals. Thus, a post-graduate or master's project can be started.

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