Escola Superior de Propaganda e Marketing Information System Scientific Initiation Program

IAN DOS REIS E ARAGÃO

The Development of an Anthropomorphic Mechanical Arm

Sao Paulo
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Scientific Initiation Project for the High School Before Advertising and Marketing, under the guidance of Professor Doctor Humberto Sandmann.

Advisor: Prof.Dr.Humberto Sandmann

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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, 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.

Thus, to help people with motor disabilities, this research project explores the development possibilities arising from this new type of interaction. From the making of a prosthesis of an anthropomorphic mechanical arm that has the power to perform actions through brain stimuli and, at the same time, a production cost infinitely lower than the current technologies in the market. With the development of this technology, there is the possibility of obtaining a skillful interaction capable of helping these people acquire a better quality of life. Through the study carried out in the construction of a proof of concept, the result of this research was concluded satisfactorily, demonstrating the importance given to the search for new technologies and solutions aimed at benefiting a large number of people.

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

list of illustrations

summary

1. Introduction

1.1 Research Findings

The interface between humans and machines is constantly the object of intense research and innovation since there is the assumption that the more intuitive and friendly it is, the more productive the development of work using it will be. This research has emerged areas of study whose goal is to achieve high-level interaction between man and machine as a new frontier of implementation through the growth of neuroscience with the understanding of the nervous system. The formation of procedures for collecting signals from the brain has enabled new levels of interactions known as the Brain-Computer Interface (BCI).

Through new research models that present the potential to manipulate computers with nothing more than a thought, quickly human interaction. Without limitations, it became possible to break a barrier among several levels of relationship that existed between a man and a binary code. Not only for convenience but also to meet the need for the lack of existing communication possibilities due to their inadequacies.

Interacting with your environment is essential for health care and quality of life. BCI devices can provide an opportunity for those with neuromuscular impairments people with disabilities (PwDs). The remarkable possibility for a debilitated person to regain their movements and interact habitually with the environment around them again without being subjected to the demeanor of others. They were enabling a new hope to perform activities typically and giving them new self-esteem to perform an action that makes them enthusiastic, for not being limited anymore, granting a renewed possibility to the individual to do what they value, again.

Nowadays, there are countless prosthesis models with a significant impact on the life of debilitated individuals. A cosmetic model that allows some realism in aesthetic matters represents a change in reality for these people. A more technological model, using the technology provided by the BCI, can reestablish the confidence of these people to be able to correct the loss of their movements. However, the technology and materials strictly available on the market used to make these prostheses effectively increase the price, making them unaffordable.

Thus, a research project is proposed exploring the possibilities of neuroscience techniques in the BCI, developing an interaction capable of meeting the difficulties people encounter with special needs. In this solution, a model was developed, made with reusable, sustainable, and resistant materials. The goal is to produce a proof of concept (PoC), which in the future may originate a cheaper and more accessible product for a large part of the population. Besides the use of more attainable manufacturing for the prototype, along with the help of BCI techniques, acting on the collection of neuromotor signals coming from the brain. The prosthesis can mimic human movements, making it technologically comparable to the most modern ones on the market.

The following topics describe the motivational studies of the research project, the use of the BCI to make a change in the conventional ways of interacting with a computer by investigating the social impact of a more accessible prosthesis model for society, and the benefit obtained by using assistive technologies. Chapter two discusses how the development of a mechanical arm will be implemented in the research project. Chapter three presents the fundamentals necessary for understanding the techniques used during the electromyography investigation. Chapter four discusses the manufacturing process and development of the proposed project. Finally, chapter five discusses the conclusions of the research.

1.2 Brain-Computer Interface

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 turned into reality. Nowadays, there is a wide variety of studies to develop new technologies. It considered the potential to handle computers or machines through human "thought" and the power to work an action without being physically performed.

In addition to creating more fluent interactions for Human-Machine Interaction in the development of research in BCI. Many people have some physiological disability condition, in which the development of new BCI technologies can be considered a way to improve the quality of life of these individuals—enabling a broad scenario of implementation through the integration of a BCI system, such as, for example, a computer application or a neuroprosthesis, solely by human intentions through synapses.

The great stimulus of using the BCI interface is that it is directly connected with the functioning of the human body: every time we think, move, feel, or remember something, our neurons are inactivity. A work performed by small electrical signals can be captured by specific electrical devices when transmitted across the neural membrane. They can be detected, interpreted, and used by researchers, to interact with the machinery of a prosthesis; to "decode" macroscopic brain states in real-time, such as attention, motivation, learning, plasticity, memory, emotion, etc.; and to enable optimization in the performance of the brain, being able to rehabilitate lost neural mechanisms.

The development of such a device is a highly interdisciplinary research topic, bringing together scientific research from many different fields from psychology to neurophysiology, physics, engineering, mathematics, and computer science. Thus, it focuses mainly on data analysis and computer science to develop the BCI interaction. The device, the target of the research "A New Frontier for Human-Machine Interaction" (Myo), has exposed an excellent competence for development using BCI techniques, a core area in modern technological innovation research. This area innovates daily in academia, raising many technological advancements and medicine expectations.

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Given its employability, the area of study provided by BCI was subject to the first research conducted by the author at ESPM (REIS, 2017). To develop a form of control that could perform several ordinary functions by collecting nerve stimuli to demonstrate the power coming from this interaction. Providing remarkable results, explained in developing the scientific initiation project "Brain-Computer Interaction: A new frontier for Human-Machine Interaction." Nevertheless, the epilogue portrayed expressing the acquisition of knowledge and experience for teaching training obtained during the execution of the proposal.

In this research project, a breakthrough is proposed in the scope of multidisciplinary teaching presented by the area of study of BCI, intending to develop and explore the capable interaction of two distinct areas. Through an investigation that envisions the acquisition of signals in the nervous system to mimic them in a device created with the intention of people who possess physical weaknesses to recover, in a certain way, the restoration of lost movements. It is directing itself more and more toward complementing the two areas of education that, working with human interactions with machines, is interested in providing hope.

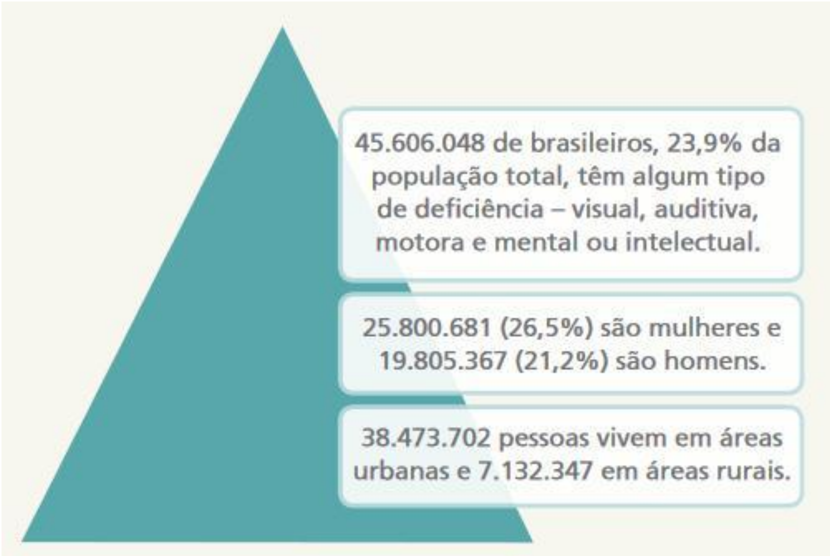
1.3 **Social integration**

Understanding the relevance of a BCI technology device to a debilitated person made it possible to survey information that can help understand how these people are organized globally, especially in Brazil. However, despite the magnitude of the issue, both awareness and scientific details on disability issues are lacking information. There is no consensus on definitions and little internationally comparable data on the incidence, distribution, and trends of disability. Few documents are compiling and analyzing how countries develop policies and responses to address the needs of people with disabilities.

The data on disability and its contextual factors are essential to building a complete picture of disability and functionality. Without information on how particular health problems in interaction with environmental barriers and facilitating elements affect people's daily lives, it is difficult to determine the scope of disability as a human rights and economic and social development priority. According to the 2010 Census by the Brazilian Institute of Statistical Geography (IBGE), almost 23.9% of the Brazilian population (45.6 million) comprises people who have some disability.

According to the World Report on Disability, published by the World Health Organization (WHO), more than one billion people worldwide live with some form of disability. Around 200 million experience considerable functional difficulties. This crucial international treaty has strengthened our understanding of disability.

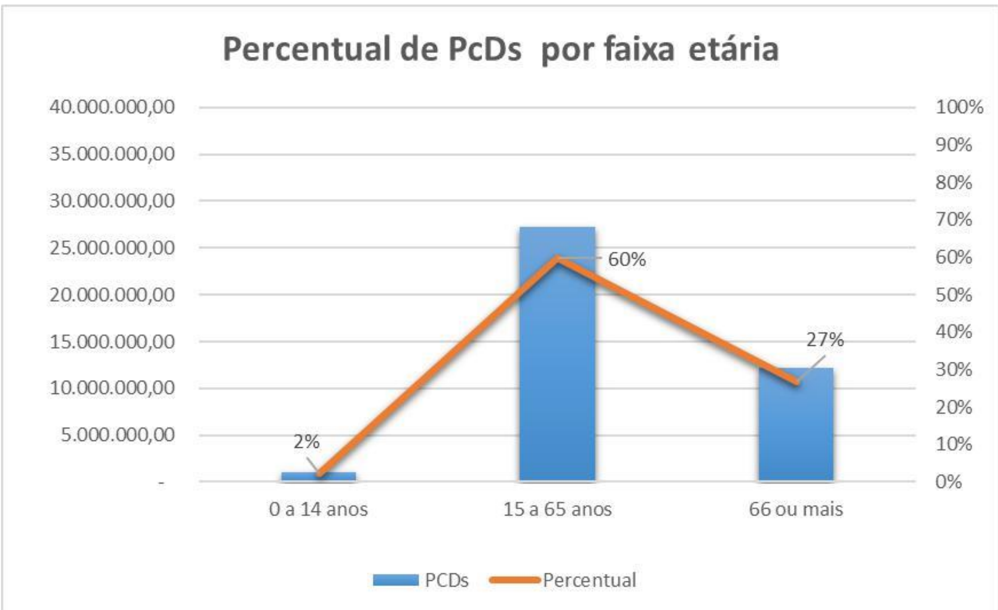
Figure 1 - Population with PwDs Brazil



The image is taken from the 2010 Census report published by IBGE.

The census data shows that disabilities affect people at any age; some people are born with them, others acquire them throughout their lives. The population contingent with at least one of the disabilities investigated reveals that its prevalence is relatively high in the Brazilian population. Many people with disabilities do not have equal access to health care, education, and employment opportunities, do not receive the services corresponding to the disability they need, and suffer exclusion from activities of daily living (IBGE, 2010).

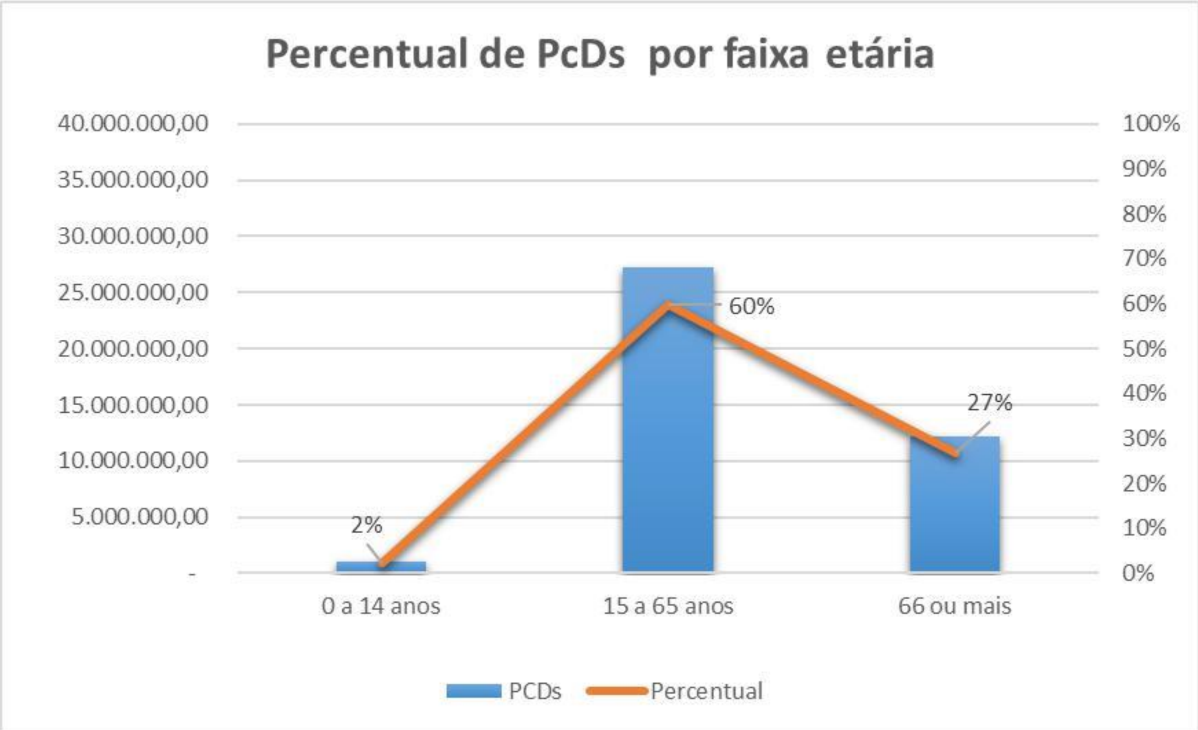
Figure 2 – Working-age population



Prepared by the author based on the 2010 Census

The segment of people with disabilities tends to be composed of older people than people without disabilities, reflecting the aging process of the Brazilian population with disabilities. It is predicted that the incidence will increase in the coming years due to the aging population, higher risk of disability in older people, and the global increase in chronic diseases such as diabetes, cardiovascular disease, cancer, and mental disorders (IBGE, 2010). According to the World Report on Disability, disability is part of the human condition. Almost all people will have a temporary or permanent disability at some point in their lives, and those who extend their lives into the aging phase will face increasing difficulties with the functionality of their bodies.

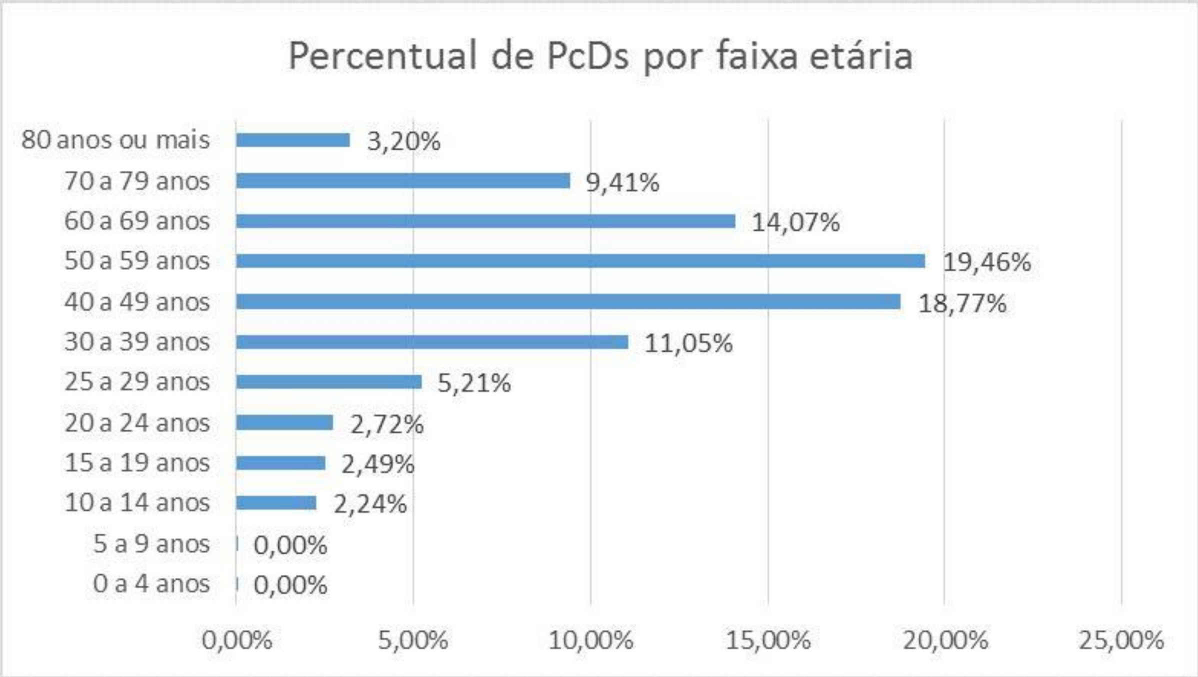
Figure 2 – Working-age population



Prepared by the author based on the 2010 Census

The segment of people with disabilities tends to be composed of older people than people without disabilities, reflecting the aging process of the Brazilian population with disabilities. It is predicted that in the coming years, the incidence will increase due to the aging of the people, the greater risk of disability to older people, as well as the global increase of chronic diseases such as diabetes, cardiovascular diseases, cancer, and mental disorders (IBGE, 2010). . According to the World Disability Report, disability is part of the human condition. Almost all people will have a temporary or permanent disability at some point in their lives. Those who prolong their lives in the aging phase will face increasing difficulties with the functionality of their bodies.

Figure 3 - Population by age group

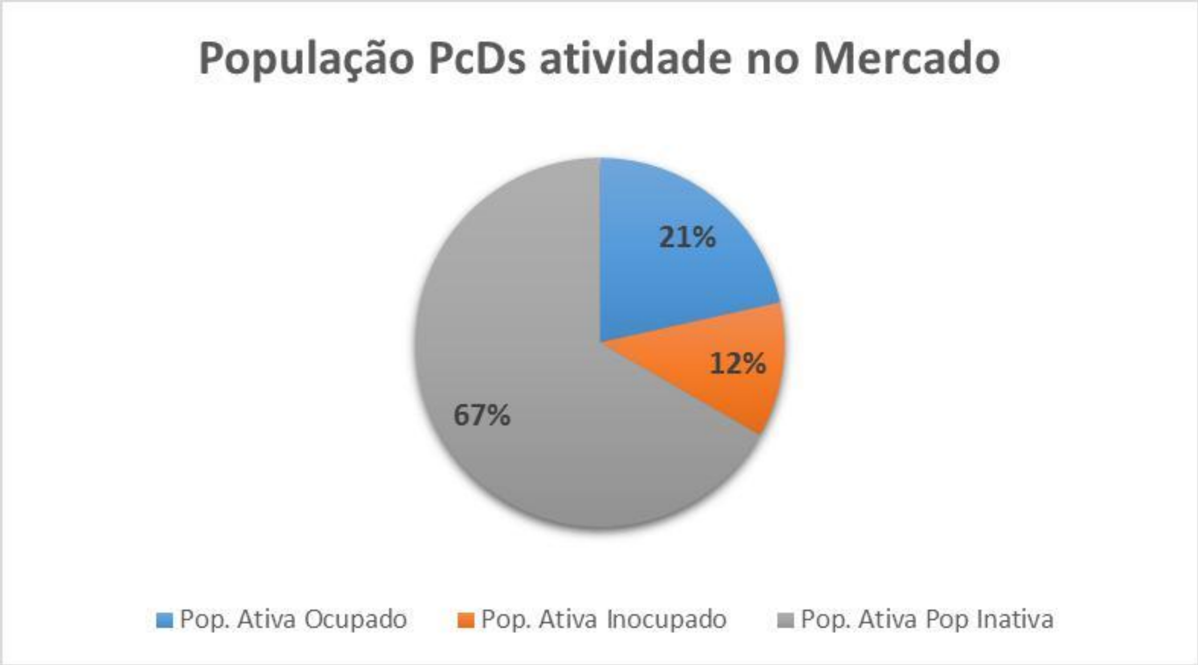


Prepared by the author based on the 2010 Census

Worldwide, people with disabilities have poorer health prospects, lower levels of education, lower economic participation, and higher poverty rates than people without disabilities. In part, this is because people with disabilities face barriers to accessing services that many of us took for granted long ago, such as health, education, employment, transportation, and information (WHO, 2011).

Thus, disability has an essential developmental issue with increasing evidence that people with disabilities experience worse socioeconomic outcomes and poverty than non-disabled people. Of the population age group considered to be of working age in the Brazilian labor market, 21% of the PcDs population is employed while 12% is idle. A significant factor responsible for part of the number of unemployed people is the lack of medical support.

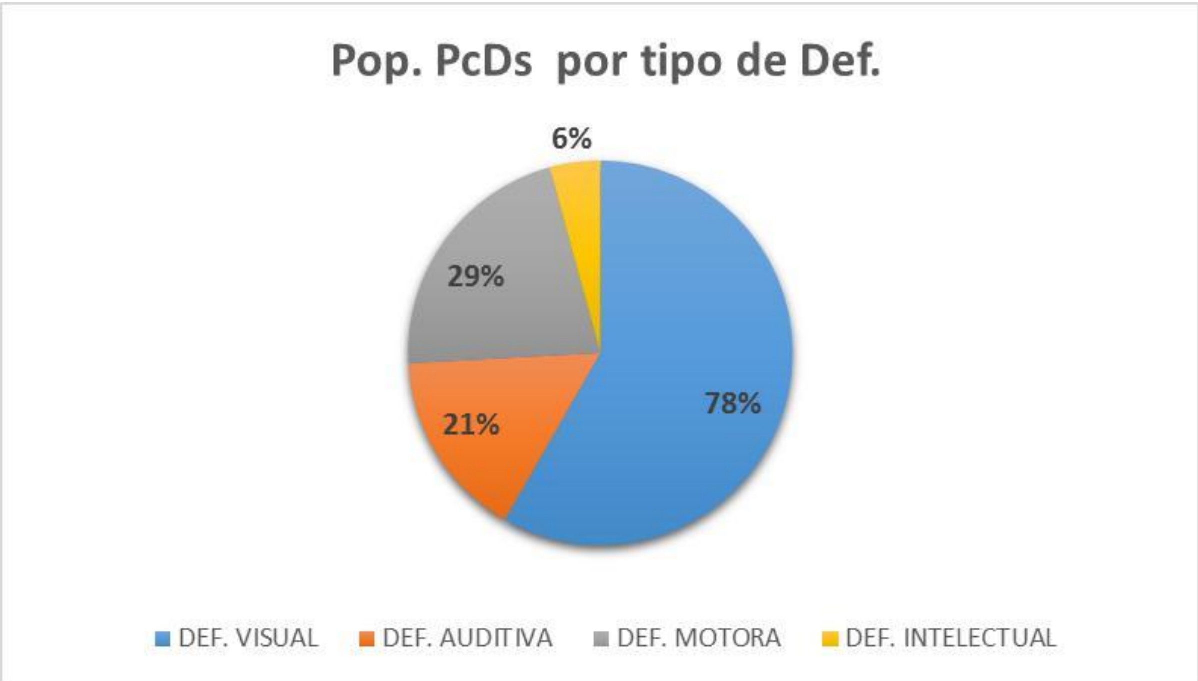
Figure 4 - Active market population



Prepared by the author based on the 2010 Census

Among the total number of people with PwDs in Brazil, 29% have physical or motor disabilities, 78% have problems seeing, 21% have a hearing impairment, and 6% have intellectual disabilities.

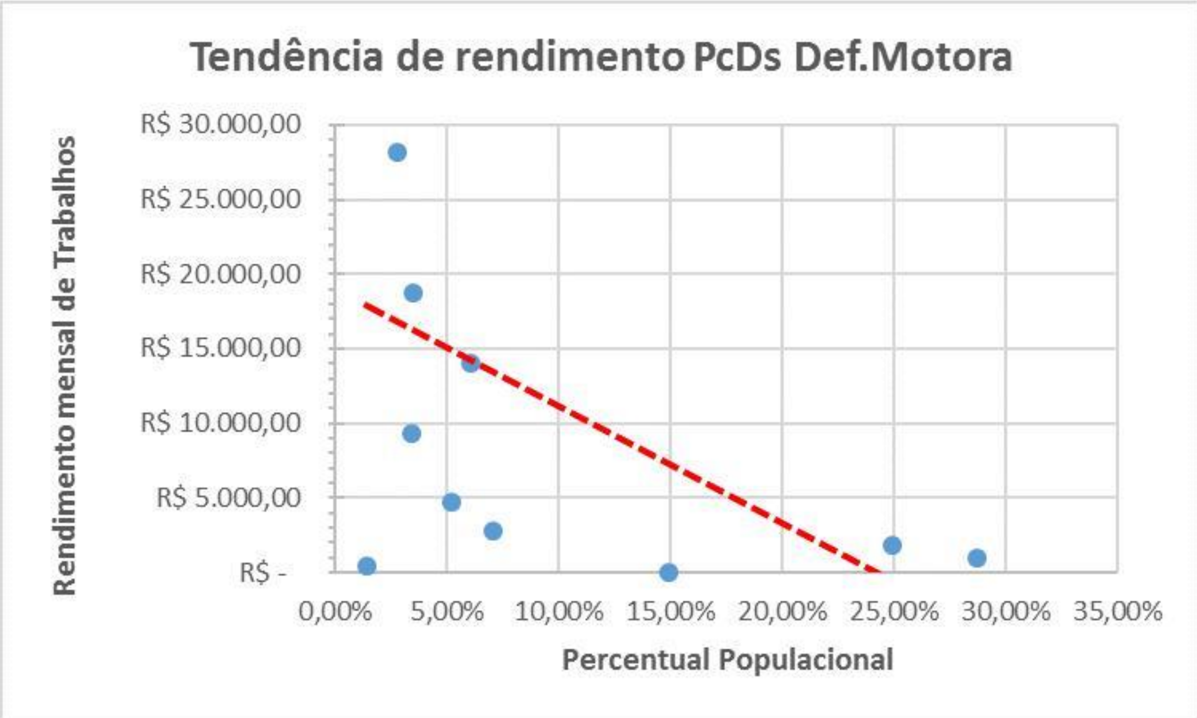
Figure 5 - Population by type of disability



Prepared by the author based on the 2010 Census

Since one of the research objectives is people with motor disabilities, the focus will now be analyzing this population. Among the second largest number of people with PwDs, more than 13.2 million people claimed to have some degree of motor disability, equivalent to 7% of Brazilians. More than 4.4 million people declared severe motor disability. Of these, more than 734.4 thousand said they could not walk or climb stairs at all, and more than 3.6 million said they had great difficulty in locomotion.

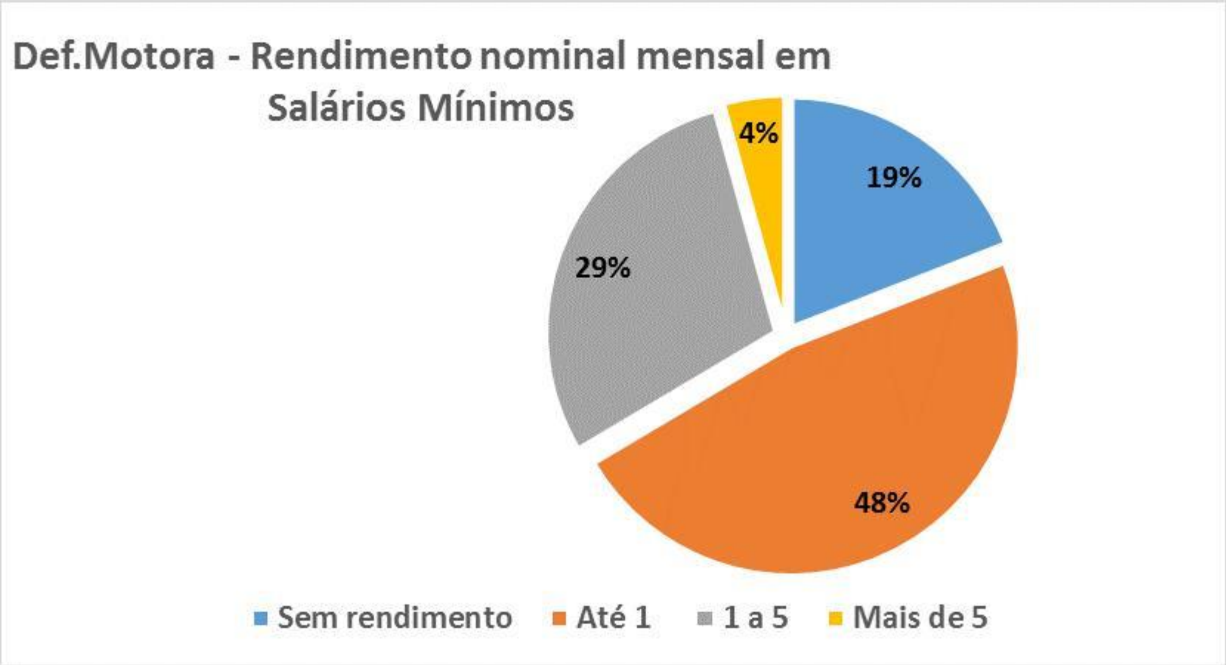
Figure 6 - Income trend of the population



Prepared by the author based on the 2010 Census

People with disabilities are more likely to be unemployed and generally earn less, even when employed. Both employment and income outcomes seem to worsen with the severity of the disability. Among employed people, it was observed that 53% of the population (approximately 7 million people) earn around 1/2 to 2 minimum wages (IBGE, 2010).

Figure 7 - Nominal income of the population



Prepared by the author based on the 2010 Census

It is more difficult for people with disabilities to benefit from development and lift themselves out of poverty due to discrimination in employment, limited access to transportation, lack of access to resources to promote self-employment and livelihood activities. People with disabilities may face extra costs resulting from disability, such as the costs associated with medical treatment or assistive devices, or the need for personal support and assistance, so they often require more resources to achieve the same results as non-disabled people (WHO, 2011).

1.4 Benefits of assistive technologies

An assistive technology device can be defined as "any item, piece of equipment, or product, whether commercially purchased or adapted or modified, used to increase, maintain or improve the functional capacity of persons with disabilities" (WHO, 2011).

In some countries, assistive devices are an integral part of health care and are provided by the national health care system. In others, assistive technologies are provided by governments through rehabilitation services, vocational rehabilitation or special education agencies, insurance companies, and philanthropic and non-governmental organizations.

Assistive technologies can transform the lives of PwDs; they are items that make social reintegration possible for these people. They provide a radical change through a change in the quality of life of PwDs. For people with disabilities resulting from brain injury in the UK, technologies such as personal digital assistants and simple posters were closely associated with independence (WHO, 2011).

In a study of deaf and hard-of-hearing Nigerians, the provision of hearing aids was associated with increased functionality, user participation, and satisfaction. Assistive devices were also noted to reduce disability and replace or complement support services, possibly reducing care costs (WHO, 2011).

In the United States, data collected over 15 years through a national long-term care survey showed that increased use of technology decreased disability reporting among people aged 65 and older. Another survey, also in the United States, showed that users of assistive technologies such as walking aids and personal care equipment reported less need for support services.

Assistive technology brings about a significant change in people's lives with PwDs. Thus, there are several assistive devices on the market. For example, there are several technological levels in the prosthetics market to promote human assistance, from a simple cosmetic device to one whose technology can replicate human movements. However, this high level of technology is absent in such a large market of disabled people. Due to high production costs, a bionic prosthesis is accessible to a small portion of the PwDs population. According to the Brazilian Association of Orthopedic Technique (Abotec), less than 3% of the Brazilian disabled people can access bionic technology (GARCIA, 2009).

Nowadays, several companies and laboratories invest time and effort in studying more fluent man-machine interaction techniques. In this race to overcome existing limits, bionic devices have been created whose interaction capabilities are presented as a fantasy due to such technological capacity. Such interaction models have been well developed in terms of performance to maximize the use of human movements, being as simple, safe, and pleasant as possible.

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Recent studies done by WHO participants show that patients with access to brain-computer interface technology recover more quickly from severe neural traumas, enable physical support through technologies and machinery that act with the human body introduced in studies in the bionic area, in the prevention of neural diseases, in the transformation of people's quality of life, among other aspects.

This area innovates every day in the academic environment, forwarding many expectations in technological advancement for human relations with machines and the new era of health economics. Demanding emerging technologies to help outcomes, reduce costs, increase cost-effectiveness, and foster the creation of development that will potentially impact billions of patients worldwide.

The cost of rehabilitation can be a barrier for people with disabilities in Brazil and both high- and low-income countries. Even when funding from governments, insurance companies, or NGOs is available, it cannot cover a good portion of the expenses to make rehabilitation affordable.

People with disabilities have lower incomes and are often not employed in the labor market even though they are of working age, as shown in the market research. Therefore, these people are less likely to have health insurance covered by their occupation or private health insurance by their membership.

Because these people have financial limitations and inadequate public health coverage, their access to rehabilitation may also be limited, compromising their activity and participation in society, and comprising the disaggregation of PWD society. Lack of financial resources for assistive technologies is a significant obstacle for many.

Several devices perform these approaches. However, these arms are expensive to purchase. As presented in the market analysis, the great majority of the Brazilian population cannot acquire a conventional model, much less the most advanced one. The development of this technology

Figure 8 - Market for prostheses in Brazil

Próteses braço	Qualidade	Preço	Condições de Pagamento	Localização	Atendimento	Serviços aos clientes
Prótese de Silicone	Cosmético, prótese feita de silicone, plástico, produto personalizável, braço ou mão	R$ 450,00	Parcelado com desconto a acessibilidade	Brasil	Local	Personalizado
Prótese mecânica	Fechamento e abertura das mãos voluntária por sistema de molas, personalizada, feita de plástico, silicone e aço.	R$ 2.500,00	Parcelado com desconto a acessibilidade	Brasil	Local	Personalizado
Bebionic3	Mão biônica, com reconhecimento bioelétrico, feita de metal e fibra de carbono	R$ 92.000,00	Parcelado com descontos a planos de saúde	Importado Alemanha	Local Telefone E-mail	Especializado
iLimb	Mão biônica, com reconhecimento bioelétrico e controlada por celular, possui bluetooth, feita de fibra de carbono, metal e silicone.	R$ 285.000,00	Parcelado com descontos a planos de saúde	Importado EUA	Local Telefone E-mail	Especializado
Michelangelo	Mão biônica, com os melhores materiais possíveis de concepção, melhor reconhecimento bioelétrico	R$ 425.000,00	Parcelado com descontos a planos de saúde	Importado Alemanha	Local Telefone E-mail	Especializado

Prepared by the author based on third-party sources

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In this way, this research project enters this vast market in which better interactions have been operating for years, promoting a social impact by demonstrating new models of relationship and inclusion that will please in an accessible way and facilitate human beings' lives. Disability should not be seen as purely medical, nor as something strictly social, breaking down behavioral and environmental barriers that prevent full and effective participation in society on an equal basis.

2 The Anthropomorphic Mechanical Arm

2.1 Purposes for design

The development of research in BCI does not exist only to search for more convenient ways for man-machine interaction. Many people have some physiological disability condition. The result of BCI can be considered a way to improve the quality of life of these individuals. They enable an extensive implementation scenario by integrating a BCI system, such as a computer application or a neuroprosthesis, solely by human intentions as reflected by the appropriate brain signals.

The technique's primary motivation is to improve the interface of relationship with brain functioning. As mentioned earlier in chapter one, every time we think, move, feel, or remember something, neurons are active producing small electrical signals, capable of being picked up by specific electrical devices when transmitted across the neural membrane. They can be detected, interpreted, and used by researchers to interact with the machinery of a prosthesis; to "decode" macroscopic brain states in real-time, such as attention, motivation, learning, plasticity, memory, emotion, etc.; and to optimize and improve human performance by rehabilitating lost neural mechanisms.

The development of such a device is a highly interdisciplinary research project, bringing together scientific research from many different fields from psychology to neurophysiology, physics, engineering, mathematics, and computer science. Thus, it focuses mainly on data analysis and computer science to develop the BCI interaction. The device, the target of the research "A New Frontier for Human-Machine Interaction" (Myo), exposed an excellent competence for development using BCI techniques, a core area in technological innovation research in modern times. This area innovates daily in academia, raising many technological advancements and medicine expectations.

Given the employability of the area of study provided by BCI, it is subject to research to develop a form of control in which it is possible to perform various everyday functions by collecting nerve stimuli to demonstrate the power of this interaction. After completing previous research conducted at ESPM (REIS, 2017), new possibilities were raised to deepen the study and cover the analysis of the potential of BCI interaction. The target device of the research presented an extensive prospect of progress for this scope of study with neuroscience. Providing notorious results, explained in the development of the scientific initiation project of the previous period.

Thus, in this scientific initiation, an evolution was proposed in the scope of multi-disciplinary teaching offered by the BCI area of study. It enabled the development to explore an interaction capable of exploiting the potential of the human brain through an investigation that envisions the acquisition of signals in the nervous system to mimic them in a device created to encourage people who have physical weaknesses to recover, in a certain way, the restoration of lost movements—directing more and more the complementation of the two areas.

2.2 Design logic

Reaching the insight of the processes performed by the BCI device, worked on in the scientific initiation project, together with the understanding of the biological process that comes from the human body through the study of neuroscience. Studies were proposed to reach a new level of interaction capable of meeting the people's expectations who need support the most. Thus, some steps presented diverse relevance for the development of the proof of concept:

1) The collection stage alludes to the treatment of biological signals, in the conversion of the collected signals, the processing of movements in the brain, in the collection of the sample rate of the physical process—a fundamental step for developing new techniques to capture new gestures, becoming unprecedented functions for implementation.
2) The testing stage alludes to the techniques used by the device in the elaboration of algorithms that describe the gestures—being able to add then the understanding of the technique, its verification, and the reproduction. In other models or devices, for a better understanding of the technique used.
3) The expectation of applying bioelectricity techniques is to mimic human movements by improving a device capable of acting in the area.
4) Continuing the interaction from signal processing in a mobile application.
5) The stage of developing a copy capable of repaying the progress obtained in the form of a proof of concept.

2.3 The anthropomorphic conception

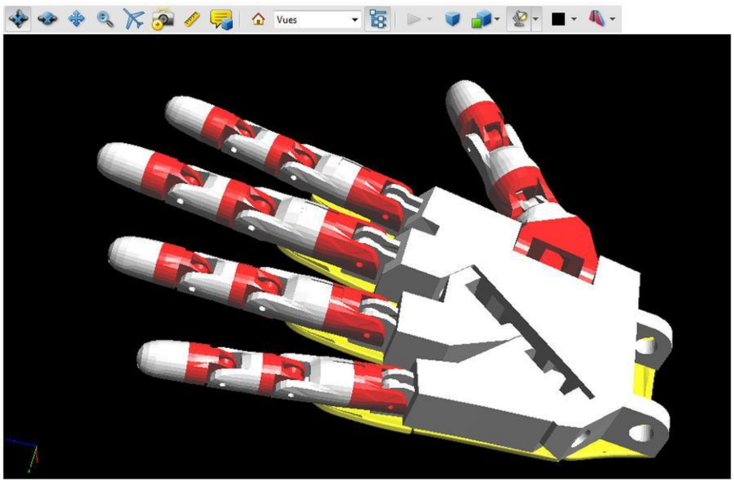
To realize a project of mimicking human movements and at the same time unveiling the medium of medical implications within the BCI. The proposal presents a development path in which it is possible to demonstrate a social impact through a robotic prototype of a human arm, in the expectation that this project can have a significant effect on people who need help, hope, and motivation to perform activities that are impossible due to their weaknesses.

Thus, to promote improvements through the aid provided by cybernetics and robotics, a study will be developed to design a cybernetic prototype capable of causing such an expressive repercussion. Currently, there is a sample repository developed and made available to encourage research in robotics and mechatronics, which is used by students in several parts of the world to obtain knowledge in the area.

For example, one of the companies responsible for making these samples available is the French company InMoov (http://inmoov.fr/). Using this sample as a basis, it is possible to demonstrate the applicability of the study performed in conjunction with the multidisciplinarity obtained by the science of medicine by proposing the minification of human movements for a real example. Therefore, the implementation of the anthropomorphic mechanical arm is essential.

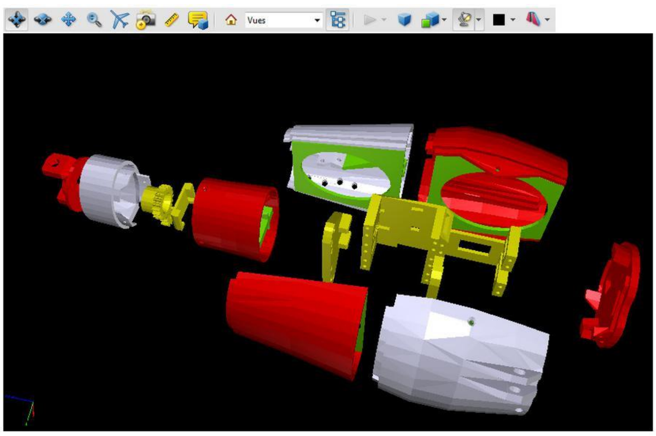
The 3D models presented in figures 8 and 9 represent the molds originated for the development and manufacturing of the anthropomorphic mechanical arm project:

Figure 9 - Prototype hand



The image is taken from the website: http://inmoov.fr.

Figure 10 - Prototype Arm



The image is taken from the website: http://inmoov.fr.

2.4 Scientific resolutions

After the investigations carried out in the research project "Brain-Computer Interaction: A New Frontier for Human-Machine Interaction." By performing and elaborating connections through the validity of BCI, it became evident that this relationship can offer assistive technology. Through the ability to assist the noble cause of health care as a means of rehabilitation to disabilities.

Given the broad scope of BCI, there are significant research possibilities in this area. Besides the minification of human movements by the arm. There is the possibility to achieve more implementation models exploring other options of studies such as the collection of signals directly from the brain or the improvement of a humanoid, integrated with the rest of the body of the project used in the arm, reaching paths for the development of a cyborg organism.

> For some disabled people, rehabilitation, or assistive technology, is essential to participate in academic life, the labor market, and civil life. To allow people with disabilities to achieve and maintain maximum independence, their most total physical, mental, social, and vocational ability, and full inclusion and participation in all aspects of life. In all cases, rehabilitation should help to empower the person with disabilities and their family" (WHO, 2011).

When suited to the user and their environment, assistive technologies have proven powerful tools for increasing independence and improving participation. Research in Uganda with people with reduced mobility found that assistive technologies for mobility created more possibilities for participation in the community, especially in education and employability (WHO, 2011).

The rehabilitation of disabled people has long lacked a unifying conceptual framework. Through actions such as those proposed in this research, it is possible to create enabling environments to develop support and rehabilitation services, ensure adequate social protection, create inclusion policies and programs for the benefit of people with disabilities and the community.

For example, with the objectives of this research completed, the barriers to the provision of current rehabilitation services will be addressed through a social awareness of the impact provided by the fruits of the project undertaken. Through a reflection on the living condition of these people and the impact of this change on the living situation of society as a whole. The assistive technology supply system causes the effect. Through the expansion and decentralization of the supply of services, increase in the use and availability of assistive device technology, and, mainly, the evolution of research programs in the area for the more significant benefit of society and health. They are accomplished by the conception of a mechanical arm accessible to the great majority of the PwDs population.

Thus, as plans resulting from the implementation of this research project, it is intended to have a proof of concept (PoC) for the project with the learnings obtained not only by the stages of development present in the execution plan. But mainly with the acquisition of knowledge acquired during the steps of the implementation process of this research. Since technology transforms and changes concomitantly with innovation researches that appear in the market. To realize a modern and current PoC for the time it will be delivered, thus, seeking a partnership with some agency or institution responsible for helping people with disabilities, for starting to implement the inaccurate prototype models. Employing a significant change for the people for whom this project is intended

2.5 Methodological structure

For the execution of the research project, it is indispensable to conduct bibliographic research to formulate the basis of the project and use the scientific process for the elaboration and effectuation of the project itself. Both methodologies were crucial to developing the final report since the scientific method is often used to understand the work better and for the project's construction to become more easily executable.

For the bibliographical research, inquiries are necessary to understand the work and the study techniques. In this way, the studies of the results, Neuroscience, unraveling the nervous system (Mark F. Bear), and the book Digital Signal Processing (John G. Proakis) are required. Documentation of the SDK and API reference scripts of the electronics used in the project. In addition to all the needed research, it is also crucial to have proof of the studies.

To conduct and prove these studies, a sample data collection of the experiment and the placement of a method is required to verify the analysis performed. The scientific process to be carried out consists of a few step-by-step steps for the construction of the final report:

1) Observation reflection, typically performed during experiments, is designed to test a particular hypothesis;

2) Replication, regardless of whether the observation is experimental or clinical, it is essential that it can be replicated before being accepted by other researchers;

3) Interpretation, at the moment, before believing that the observation is correct, an understanding is needed, which depends on the knowledge and perceived conceptions about the project. So interpretations do not always stand the test of time. Often great discoveries are made when old interpretations are reinterpreted in a new light of research.

4) Verification, a step to prove the observation made about the experiment, accepts that the statement made is a fact.

The observation step will be carried out with the study of signal processing. It was realizing a study of graphs and functions that generate the analysis of the nerve impulses, chapter 3.

The replication stage comes after the study of its development platform. A background in which several tests will be necessary to confirm the integration of the mechanical arm with the data collected by signal processing, chapter 4.

The interpretation step consists of developing software to test the observation made, that is, software that can interact with a simple system with the mechanical arm from the signal processing.

In the final verification stage, a reflection about the work was made, opening a discussion about the results obtained from the development of the scientific initiation project to conclude if it was possible to get the desired results and if it was possible to contribute to the universe of PcDs with motor disabilities. Also, about the learning obtained with the studies carried out by the initiation and what this made possible for the course of Information Systems, along with the possibilities for new studies formulated from this and if this was a good choice as an area of research.

3 Fundamentals of Electromyography

The innovation of the BCI area is its way of capturing bioelectric signals from the nervous system (SN), interpreting them, classifying them, and transforming them into deterministic commands for machines. There are several techniques for capturing bioelectric signals. These techniques differ concerning the area from which the signals are extracted. Hence: 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) (BEAR; CONNORS; PARADISO, 2002).

In this scientific initiation, bioelectrical analysis is used to apply in biomechanics. In this area, the register of the electromyography activity allows us to investigate which muscles are used in a specific movement. In the sense of serving as an indicator tool of phenomena such as the level of muscle activation during the execution of the campaign, the intensity and duration of the muscle request, and the identification of inferences regarding muscle fatigue and noise in the signal collection. The signals collected in the electromyography analysis used in this paper are captured from the bodily system, the forearm, for accessibility and practicality of study. A section on electrostatics through the survey using bioelectrical analysis introduces some of the terms in this chapter in the text's appendix.

3.1 Anatomy and physiology of muscle bioelectrical signals

EMG is a valuable technique to study human movement, evaluate neuromuscular physiology mechanisms, and diagnose 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. However, there are many potential pitfalls in using EMG as a tool.

Figure 11 - Architectural and anatomical characteristics of muscle fibers

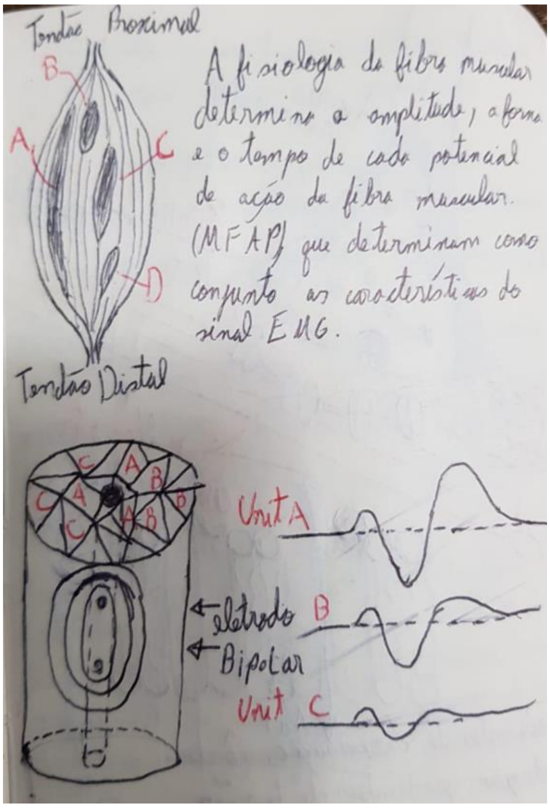


Image created by the author

Although researchers often evaluate electromyography using traditional signal processing techniques, the EMG signal has physiological origins in individual or group muscle fibers. The anatomical characteristics of the individual fibers, the architectural features of the entire muscle, and the physiological sources of the action potentials are critical to understanding how to record, analyze, and interpret the EMG signal (KAMEN; GABRIEL, 2010).

Since electromyography works with the acquisition of bioelectrical signals from muscles, the salient anatomical features of these organs directly affect electromyographic movement. Variations in muscle fiber length, fiber type composition, muscle partitioning, and variations in sensory receptor distribution are anatomical and architectural features that differ among the various muscles of the human body and even between individuals. These features are essential to ensure adequate EMG recording and interpretation.

3.1.1 Anatomy and physiology

A 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. The transverse tubular system (T-tubules) interrupts the membrane at regular intervals. The T-tubules serve as important structures for transporting the action potential deep across myofibrils to activate all portions fully.

The muscle fiber. Differences in ionic concentrations produce voltage gradients across the sarcolemma. These voltage gradients are responsible for the resting membrane potential in slow and fast-twitch muscle fibers.

Figure 12 – The production of an action potential in the muscle fiber

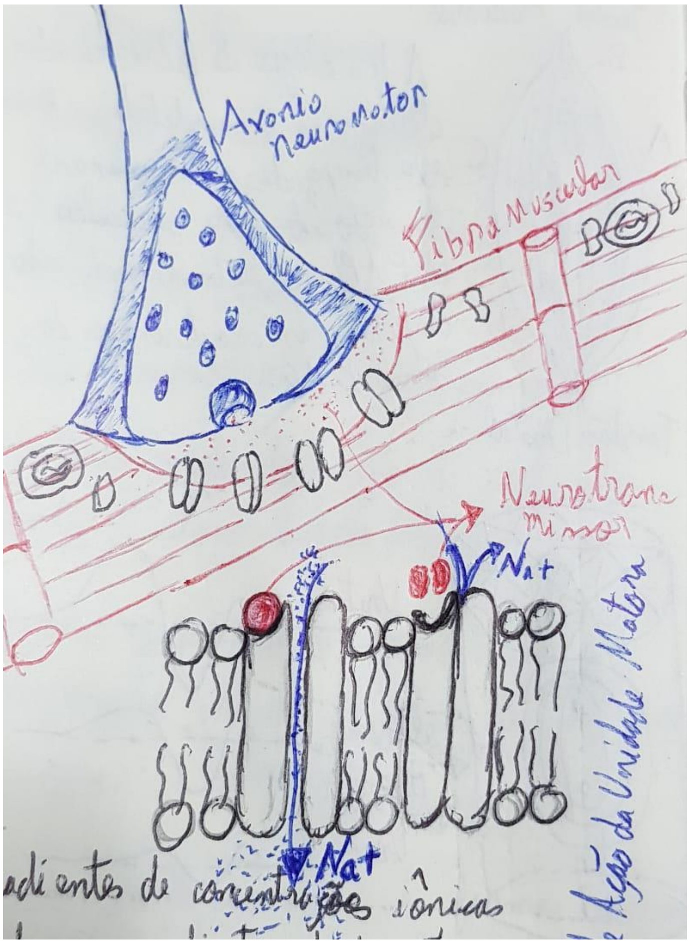


Image created by the author

Muscle fibers are excitable tissues. Under resting conditions, there is a voltage gradient across the muscle fiber membrane such that the inside of the fiber is about -90mV relative to the outside. Through the motor units connected in the muscle fibers, the electrical message to initiate muscle contraction is transmitted through the T-tubules of the muscle fiber, causing the membrane to depolarize. When the muscle fiber is depolarized by about +10mV or more, the membrane potential reacts in a stereotyped and predictable way, producing a Muscle Fiber Action Potential (MPAP) response.

3.1.2 Action potential

The physiology of the muscle fiber determines the amplitude, shape, and timing of each PAFM, which determines the characteristics of the EMG signal as a whole. Specific phases of the action potential have been defined, and some EMG characteristics have been interpreted using these phases:

Figure 13 - Action potential

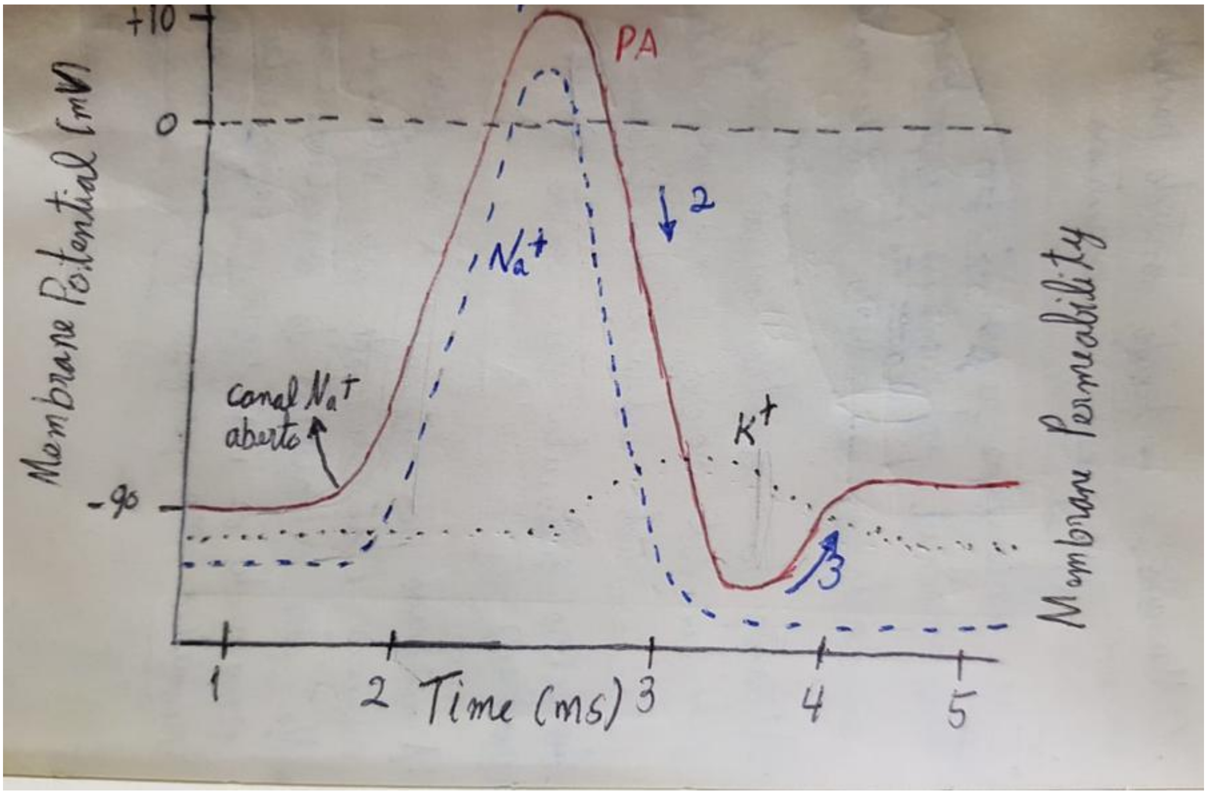


Image created by the author

- The permeability of Na+ and K+ increases the polarity reversal of the cell by about ten mV positive, and their flow eventually results in the membrane potential returning to its resting state.

  Terminal wave

- Produced by the termination of the action potential at the muscle-tendon

  junction. Post-potential (after-wave) - Limits the frequency of PAFMs.

- It reflects the negative phase of the muscle fiber action potential due to the repolarization of the T-tubule system, making it difficult to quantify the duration of FAP. Thus, high pass filtering the EMG signal at high frequencies will depress the after-wave appearance.

As the action potential is propagated along with the muscle fiber, it proceeds at a rate measured as the Conduction Velocity (VC). This conduction velocity of the muscle fiber is affected by ionic concentrations, temperature, muscle fiber length and diameter, fiber type, fatigue, various neuromuscular pathologies, and other factors such as hypoxia and age. The temperature of the muscle fiber can affect the VC and frequency characteristics of the action potential and ultimately influence the frequency characteristics of the EMG signal.

3.1.3 Motor unit

The Motor Unit (MU) is the fundamental control unit in the neuromuscular system. We cannot activate a single fiber since motor units are composed of a single motoneuron and several muscle fibers. Instead, we start groups of muscle fibers through the motor unit. Muscles vary in the number and organization of motor units. The characteristics of the motor unit can differ considerably, including fiber type, motor unit organization, and fiber groups.

Figure 14 - Motor units producing action potentials

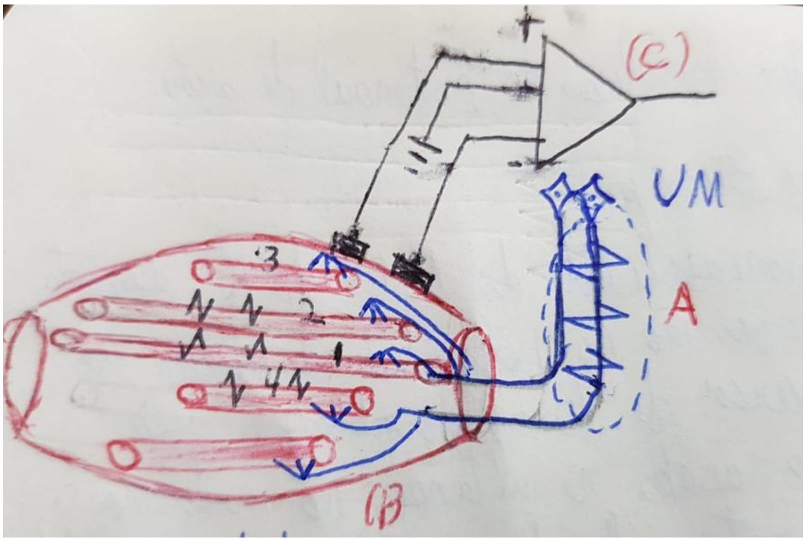


Image created by the author

Since multiple muscle fibers are innervated by a single motoneuron, the firing of one motoneuron results in the nearly simultaneous discharge of many muscle fibers, the PAUM recording process begins with the generation of PAs in the motoneuron. The summed activity of all these muscle fibers culminates in generating a motor unit action potential (MAP). The temporal and spatial sum of the PAUMs of each motor unit, recorded by the electrodes and amplifiers placed in the muscle, gives rise to the EMG analysis. The amplitude of the PAUM is determined by the recording site of the PA in the muscle fiber, both temporally (firing rate), spatially (characteristics of the muscle fiber membrane), and the location that the electrodes are distributed.

The difficulty of determining which MUs should be involved in a specific movement requires the nervous system to activate the motor units in a logical and organized manner. The size principle determines the order of motor unit activation. Small motor units are activated at low forces, and larger motor units are activated as force requirements increase. The process of starting motor units electrically is termed recruitment, and MUs are deactivated (or withdrawn from recruitment) in the opposite order, the smaller motor units remaining active at lower muscle forces. The MUs vary the frequency of action potentials (firing rate) in rate coding. Non-linear firing patterns, such as double firing, can cause significant changes in muscle force. Pairs of MUs can also fire simultaneously by synchronizing motor units.

In the frequency domain, the changes occurring in the spectrum of the action potential in the electromyographic signal already makes it possible to identify and quantify the median or average signal frequency of a given movement, even though the changes in recruitment, pickups of the motor units of different users are so sensitive. Therefore, once the electromyographic signal has a static function in the distribution of frequencies in the intervals of interest provided by pre-programmed movements, it becomes possible to capture the action potentials and translate them into a machine code.

3.2 Bioelectricity

The basic unit used for representing the EMG analysis is the Volt, a unit introduced by physics concepts in electrostatics. Although it is a concept commonly used to study electrical circuits, it becomes possible to interpret the bioelectrical phenomena that occur in the human body. Therefore, it is essential to understand some electrical concepts to register the electromyographic analysis, its instrumentation, and the methods used to process the signal resulting from the biophysical understanding of the signal.

3.2.1 Electric potential

An electric charge is placed somewhere in space creates a state of electric tension in its general vicinity, called an electric field. If another, much smaller amount is placed in the electric field, the first charge exerts an electrostatic force on the second due to the area. The magnitude of the electric field in that space is then the force per unit charge proportional to the distance between them (Appendix A.1).

The electric field is a force that electric charges generate around them. It is a vectorial quantity, i.e., it has a module, direction, and direction in which the approaching electric charges (electrons, protons, or ions) are subject to forces of interaction, either of attraction or repulsion. Determining this force between the two charges as a function of distance, moving in one direction relative to the other at different points in space, is equivalent to mapping the electric field around the static charge (Appendix A.2).

Because these forces are moving, a charge within the electric field requires work (force applied over a distance) to the amount. Electric potential energy is a position-dependent ability to do work. The relationship between electric potential energy and work gives rise to the definition of the Volt as a unit of measurement. Still, the force between the two charges is the basis of the description (Appendix A.3).

The concepts developed so far help calculate the difference in electrical potential in the muscle fiber represented as a dipole (a system consisting of two charges separated by a distance) during the depolarization and repolarization phases of the action potential. Thus, electromyographic recordings require a minimum of two electrodes since the difference in electrical potential between two points in the muscle is being measured. Since the charges associated with the muscle action potential are of the order of nano-coulombs (nC), the resulting difference in electrical potential can be obtained in microvolts (mV or ten 6V) or millivolts (mV = 10 3V). It is also more common to refer to the difference in electrical potential between the two electrodes as electrical muscle activity, measured in microvolts or millivolts.

3.2.2 Volumetric conduction

One of the most fundamental topics of EMG analysis is used to record the muscle fiber action potential (FMAP) through a medium of cellular fluids and tissue. Volumetric Conduction transmission electric or magnetic fields through biological tissue to measurement sensors from an electric current source. The conductivity distribution of the different tissues through which the fields are transmitted to the electrode explains how the size and shape of the resulting potential depend on the location of the recording (BROWN, 1984).

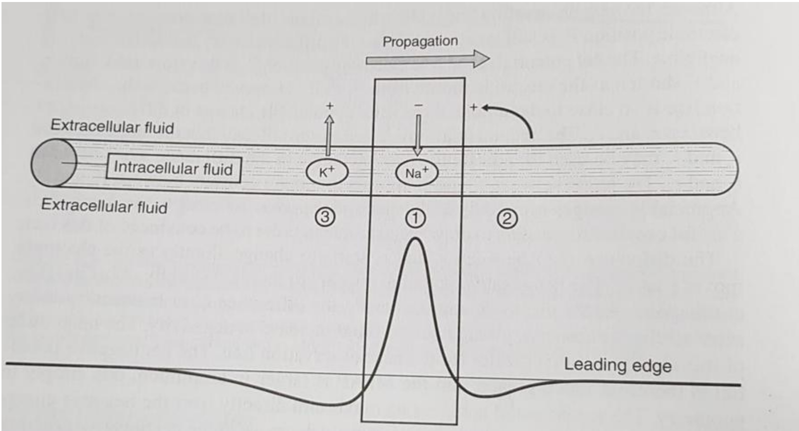
> The term "volumetric conduction" refers to the complex effects of measuring electrical potentials at a distance from their source generators. Near-field prospects refer to those recorded in relative proximity to the detector. In contrast, far-field potentials are recorded at a considerable distance, as is more common in evoked potentials. A direct and direct model of volume conduction can be worked out to help better understand how volume conduction effects can affect the shape of a recorded action potential (SEWARD, 2007).

Conductive volume effects substantially impact all motor and sensory nerve conduction waveforms. The recording configuration of the sensory studies (i.e., whether they are bipolar or referential) also affects the size and morphology of the recorded signals. In addition, the composite motor action potential represents a composite of near and far-field activity. The morphology of both the spontaneous discharges and the motor unit potentials assessed during EMG analysis is partly caused by the complex effects of volume conduction (SEWARD, 2007).

The PAFM travels at a constant velocity, and the muscle fiber maintains its shape as it propagates while traveling to the electrode. Thus, treating the continuous depolarization and repolarization phases as stationary phases concerning the electrode positioned on top of the muscle fiber. After all, since physical events link positive and negative charges to an electrochemical event arising from the AP, changes in the shape of the PAFM are represented immediately along with the muscle fiber. The closest direction dominates the net potential, being recorded by the electrode and corresponding to the amplitude of the PAFM in microvolts (KAMEN; GABRIEL, 2010).

As presented previously in topic 3.1.2, the action potential is recorded through three phases, the prominent peak, the terminal wave, and the post-potential. These three phases are directly related to three stages of different electronegativities, a Tripole (+ - +) (DUMITRU, 2000; GEDDES; BAKER., 1968b). To understand how differences arise in the PAFM format, the Tripole consists of three equal and opposite phases. The net potential is determined by the radial distances between each charge and the electrode.

Figure 15 - Process of registration of PA phases



The image is taken from the book Essentials of Electromyography.

The first depolarization point occurs when Na+ ions penetrate the muscle fiber and leave relatively strong negativity in the extracellular space. Due to the significant peak provided by the ions, this negativity left behind is referred to as a current reductant, so the electrode collecting data from the depolarization event registers a negative potential.

However, the current reductant is so strong that it attracts positive ions from the membrane area before the depolarization event. Thus, the site promotes a weak current source, providing the positive ions attracted to the current reducer. The electrode placed in front of the depolarization event would now register a slight positivity in the potential (Appendix A.5).

Eventually, the positive ion leaves the forward membrane area, and the charge difference across the membrane decreases, leading to passive depolarization of the muscle fiber. The momentum mediated by the positive ion (K +) channel outside the muscle fiber gives the repolarization event and strong current. Again, the electrode placed directly over the repolarization event would register an immense positivity.

Thus, as the PAFM propagates along with the muscle fiber toward the electrode, the initial edge (weak current source) is detected first, followed by the depolarization phase (current sink) and then the repolarization phase (stable current source).

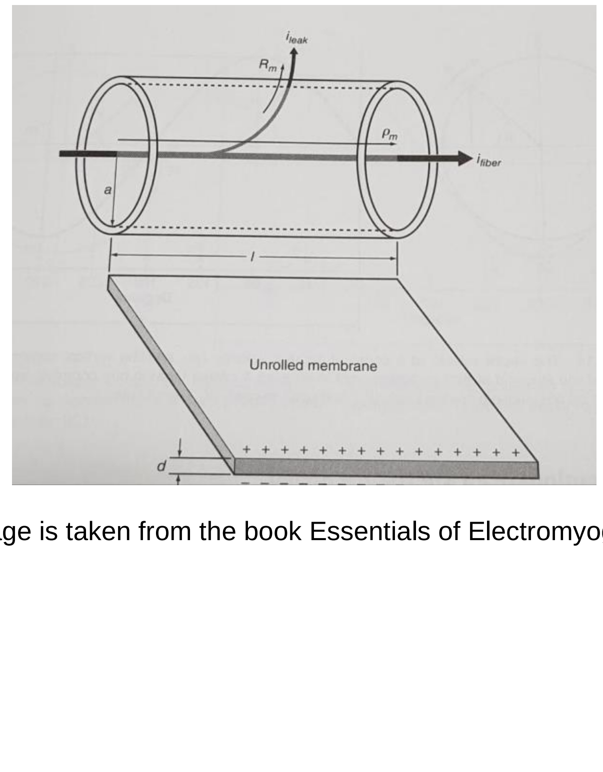
The concepts involved in volume conduction extend to recording motor unit action potentials (PAUMs), but the single fiber is used to understand the basic principles. And the PAUM is also triphasic because it is the linear sum of all the activation of a large number of motor units is given simultaneously. The triphasic waveform is still apparent in the depolarization and repolarization of the recruited motor units. The evoked potential is logically called a full action potential (or M-wave). It is also called a composite muscle action potential (PACM) due to the linear sum of all constituent PAUMs. The large number of muscle fibers involved in the evoked response results in an electrical potential that is several millivolts in magnitude.

3.2.3 The muscle fiber as an electrical circuit

In electrophysiology and biophysics, muscle fibers are represented as electrical cables with porous insulation, such that the current can leak into the surrounding area. Thus, the muscle fiber is a long cylindrical tube of conducting fluid (mycoplasma) surrounded by a membrane. The electrical potential depends on the resistance to current flow in the axial and radial directions and the muscle fiber.

Incorporating a resistor and a capacitor in the same circuit has critical physio-logical and physical applications for EMG. For example, the relationship between the electromotive force, the current flow through the resistor to the capacitor, and the resulting potential across the plates form the basics for understanding the physical properties of muscle fibers. In addition, it is essential for signal processing concepts related to filtering the electromyographic signal (Appendix A.8).

Figure 16 - The concept of the electrical circuit in the muscle fiber



The image is taken from the book Essentials of Electromyography.

> The resistance (R) to axial current flow (ii f Ibra) depends on the resistivity of the myoplasm (rm). The opposition to the radial flow of leakage current (leak) depends on the resistance per unit area of the membrane (Rm). The membrane also has a capacitive function because charges of opposite signs exit both sides, negative on the inside and positive on the outside. Analogous to the situation with the plate capacitor, the cost per unit area divided by the potential difference is the membrane capacitance per unit area (Cm) (KAMEN; GABRIEL, 2010).

The electromyographic signal is finally fed to an amplifier that boosts the relatively small voltage to a level that can be measured. An electrical circuit changes the frequency content of the incoming electromyographic signal to minimize (filter out) noise from the surrounding environment or other sources before it is stored in the computer for later analysis. The electrical circuit is also essential for understanding the physical properties of nerves and muscle fibers related to current flow and electrical potential.

3.3 EMG analyze and

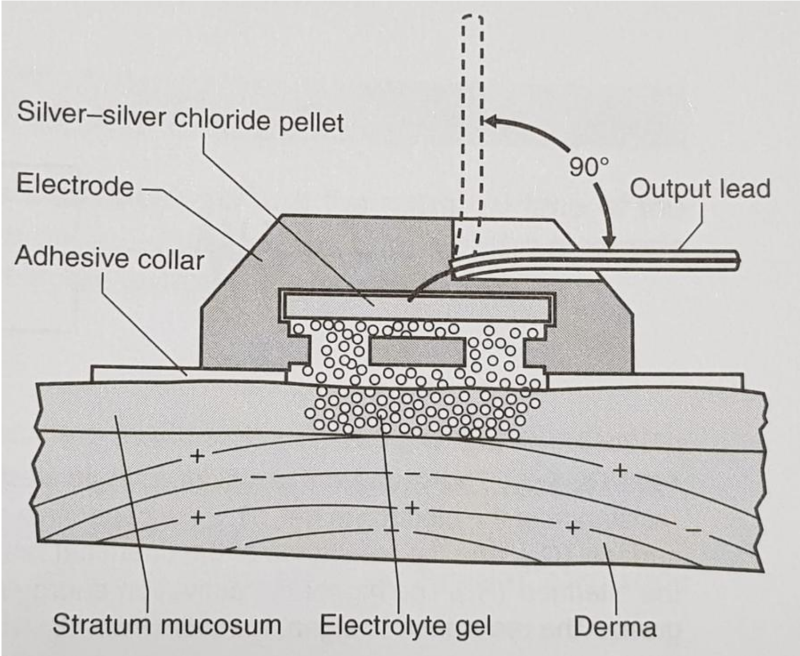
After introducing the basic concepts of bioelectricity to understand the action potential phenomenon here, a deeper understanding of EMG instrumentation can be obtained, which is best understood from the point of view of electrical circuits. After all, in a typical experimental EMG, signals are collected by electrodes, sent to an amplifier, and converted to an analog-to-digital signal. This topic and sub-topics will explain the collections by the types of electrodes and the importance of the amplifier in the conversion process to a digital signal.

3.3.1 Electrodes

There are two basic types of electrodes, surface and invasive. Surface electrodes are placed on the skin directly over the muscle, while invasive electrodes are inserted through the skin directly into the power. Both electrodes are made of conductive metals and perform the same function.

The essential function is to convert the electrical potential generated by the muscle into an electrical signal that is conducted through wires to the amplifier, a process called signal transduction. As explained in Section 3.2.2, the action potential of the muscle fiber generates extracellular currents that extend from the membrane to the electrode on the surface of the skin tissue. As the potential propagates along with the muscle fiber, the electrical currents from electrochemical phenomena flow through the extracellular fluids. Resulting in electrical currents at the electrode, conducted by capacitive conductance across the electrolyte-metal interface at the electrode contacts.

Figure 17 - Surface electrode



The image is taken from the book Essentials of Electromyography.

The tiny currents in the electrode conductors are then detected by the amplifier and increased to a large enough magnitude to be recorded. Therefore, the electrode is a device that converts the ionic potentials generated by the muscles into electronic potentials that can be measured by the amplifier (LOEB; GANS., 1986).

Surface and internal recordings are the two primary recordings of electrical muscle activity. Both methodologies are associated with different recording electrodes, each with advantages and disadvantages. The physical properties of electrodes have severe consequences for the determination of muscle activity because they can induce a frequency-dependent voltage drop, which means that they can alter the amplitude and frequency content of the EMG signal. Thus, electrodes can also filter (GEDDES; BAKER., 1968b).

The general advantage of all surface electrodes is that they are non-invasive and easy to apply. However, their use is limited to superficial muscles that are large enough to support mounting the electrode on the skin surface. It is difficult to isolate the activity of just one muscle using surface EMG detection. The entire limb can be seen as a volume of conductive tissue. Electrical activity from muscles anywhere within the limb volume can be conducted through the intermediate tissue to reach the electrode at some distance on the skin surface (DUMITRU, 2000).

3.3.1.1 Surface Electrodes (Passive)

Surface electrodes consist of a single conductive metal plate, either square or circular. Before the electrode is applied to the skin, the skin is lightly scrubbed with an electrolytic gel to remove oils and layers of dead skin that contain only low levels of electrolytes needed for conduction. The electrolyte gel is then applied to the surface of the electrode and rubbed into the skin so that it is absorbed into the stratum musculus to make contact with the dermis, where it can serve to decrease the recording resistance through the skin (KAMEN; GABRIEL, 2010). The second primary function of the electrolyte gel is to maintain a conductive path between the metal surface and the skin, forming an electrolyte bridge. This constitutes the electrode-electrolyte interface.

> The electrochemical reaction between the electrolyte gel and the metal surface of the electrode stabilizes (i.e., reaches equilibrium), and a potential difference creates a likely electric layer. Thus, the gel outside the electrode surface obtains a potential difference from the surrounding medium. The potential difference between the electrolyte on the electrode surface and the surrounding medium is the half-cell potential (COOPER, 1963).

A common design feature of most surface electrodes includes an engraving surface embedded away from the skin. This type of electrode is also known as a floating electrode. The metal recording surface is usually embedded within a plastic housing, and the entire unit is attached to the skin surface with two collars of electrode adhesive (GEDDES; BAKER., 1968a). The floating electrode belongs to the general class of so-called passive electrodes because no additional electronic components are associated with the unit itself. The electrolyte gel is the only signal transduction mechanism.

3.3.1.2 Surface Electrodes (Active)

Active electrodes incorporate a preamplifier inside the small cabinet that houses the metal recording surface. The metal recording surface then makes direct contact with the skin. The magnitude of the EMG signal is increased "on" the skin surface by an amplifier unit. As long as the skin is immaculate so that the natural electrolytes present in the dermis can conduct the signal, an electrolytic gel is not needed to facilitate signal transduction.

The complex electrochemical interaction between the metal recording surface and the electrolytic gel is eliminated (ROY et al., 2007). However, the additional advantage of active electrodes is that the resulting EMG signal intensity is significant compared to the surrounding environmental noise (JOHNSON et al., 1977). Both the size and configuration of the active electrodes are necessarily fixed to accommodate the physical dimensions of the preamplification unit. Therefore, active electrodes are more restrictive than passive electrodes concerning the size and location of the muscle that can be recorded.

3.3.1.3 Electrode configuration

The electrode configuration for electromyography refers to the number of recording surfaces and their arrangement relative to the muscle, tendon, and bone surfaces. The two most common electrode configurations for surface electrodes are monopolar and bipolar arrangements. In both cases, there are two sensing surfaces and a ground electrode. More complex electrode configurations can be seen as a natural extension of the bipolar case.

To realize a monopolar configuration: the first electrode is placed as the active signal recording point (G1); the second is used as the signal reference (G2) to determine the potential difference used by the amplifiers; the third ground electrode (G3) is used as the ground. Thus, G1 is placed in the muscle, G2 is in an electrically neutral location such as a tendon, and finally, G3 is placed on a bone surface. If evoked potentials are recorded, the ground is usually between the stimulator and G1. Electrodes in this configuration are called monopolar because only one electrode is used to record muscle activity (KAMEN; GABRIEL, 2010).

Bipolar recordings are defined similarly for surface and dwell EMG. A bipolar setup has G1 and G2 electrodes placed over the muscle. The signals from electrodes G1 and G2 are fed into an amplifier that inverts the G2 input. The ground is placed in a neutral location, such as a bony prominence, usually near G1 and G2. This basic configuration takes full advantage of amplifier circuitry designed to minimize unwanted EMF interference signals in the surrounding environment. The amplifier achieves this by subtracting G2 from G1.

> The practical impact is that a bipolar detection system acts as a comb filter allowing some frequencies in the EMG signal to pass through, but not others. If the inter-electrode distance and muscle conduction velocity are known, the frequencies present in the EMG signal can be calculated (LINDSTROM; MAGNUSSON, 1977).

3.3.1.4 Selectivity

Selectivity refers to recording significant muscle activity from a local volume of the tissue rather than cross-talk from neighboring muscle fibers. Electrode distance is the main factor affecting regional selectivity for surface EMG recordings. Selectivity cannot be improved by decreasing the surface area of the electrode, which only increases impedance and results in more significant noise contamination in the signal.

> The interelectrode distance for surface electrodes is an important consideration, as it affects both the amplitude and frequency content of the EMG signal. And it should be noted that the opposite is true for shorter inter-electrode distances, resulting in lower amplitude EMG signals with high-frequency components (KAMEN; GABRIEL, 2010).

A general rule of thumb is that electrodes can detect "significant" electrical activity from a spherical volume of muscle tissue with a radius equal to the distance between electrodes (P.A. et al., 1978). This is called the electrode capture area—detection volume. The detection volume is the same regardless of muscle size for a fixed inter-electrode distance.

3.3.2 Amplifiers

The EMG values can vary greatly depending on factors already presented so far, such as muscle size, type of concentration, and other differences in methodology and collection techniques. Maximum isometric concentrations can generate amplitudes in the potential, peak-to-peak (P-P), of 5mV for surface EMG. However, these recorded voltages are still relatively small and require unique instrumentation to record them (WINTER, 2005).

Thus, to improve the signal acquisition to be sent to an oscilloscope or a computer, the main point of an amplifier is to increase the magnitude of the signal collected with a high level of fidelity. An amplifier comprises essential components such as differential gain, input impedance, common-mode rejection ratio, and the amplifier's frequency response to the acquired signals.

The differential amplifier can be considered two separate amplifiers connected to a common ground and output. Its primary purpose is to subtract the common-mode (noise signal) and amplify the difference (biological signal). It may seem counter-intuitive at first, but the key is that G1 and G2 do not detect the same physical movement. A sign present in both electrodes simultaneously is called common-mode (60Hz) and will be present in the baseline of both and is considered noise. The EMG signal at G2 is delayed concerning G1 by the titer (Dt) taken to propagate along with the muscle between the two recording surfaces. The G2 input is invoked so that the positive and negative common-mode components cancel each other out, leaving behind only the biological difference signal in the original. The difference signal is then multiplied by some magnitude set by the amplifier. However, the total extent of the amplifier depends on some resistive and capacitive elements within the device's electrical circuit. After all, the amplifier and the muscle form one circuit when connected by electrodes and their associated wire connectors. Unfortunately, the amplifier draws current into the circuit by combining the two to measure the voltage. This decreases the potential difference between the recording electrodes, and ultimately the voltage recorded by the amplifier is less than the actual magnitude. The effect is formally known as circuit loading. A certain amount of voltage is lost across the electrode due to its intrinsic impedance properties to complicate matters further.

Therefore, the original magnitude of the muscle's electrical activity is reduced even before it reaches the amplifier.

This is due to the capacitive coupling between the amplifier and the input conductors and any electromagnetic radiation. Electrostatic induction of energy is generated in the body from wires near collection or electrical equipment and is the principal source of electromagnetic radiation. Power line noise is present in both electrodes simultaneously. And it is easily observed as the frequency component in the baseline of the surface EMG (sEMG) signal when the muscle is relaxed, recorded as 60Hz noise.

Remembering that impedance (Z) is a form of frequency-dependent resistance to alternating current flow, amplifiers can alter the original frequency content of the input signal before the computer digitizes it via the analog circuitry present in it. The amplifier works as a filter for the collected signal by changing the frequency content. The motion before the computer digitizes it is called an anti-aliasing filter (reduction of signal jaggies).

3.4 Quantization of the signal

The computer interface involves converting the analog EMG signal into a digital waveform. Then, a computer program can be written to process the digital signal in a meaningful way that allows its measurement. The computer interface can correct the interpretation of the signal through good filtering, matching an oscilloscope. Since if the data has been collected correctly, errors in post-processing can be fixed. However, if the EMG signal has not been digitally sampled at the correct rate or if its vertical resolution has not been set correctly, the errors will not be as easily corrected, and the data may have to be collected again.

The process starts with the analog EMG signal being sent from the amplifier to the computer, where it is digitized. The computer uses the internal clock to send a command that opens a sample and holds a circuit for the signal. A capacitor in the board circuit is then used to hold the analog signal while the computer assigns it a digital value while the course is open. Software in the computer is then used to control and specify a sampling frequency for the signal used to sample the analog signal. The sampling rate is given in Hertz (samples per second). Thus, digital conversion has several levels of representation for the analog signal, featuring graphics obtained at a higher or lower sampling rate.

The process of assigning a digital value to an analog signal is called quantization. Through the analog-to-digital (A/D) conversation board, a digital voltage value is given, in which this process divides a defined voltage range into different levels (resolution). The computer then uses the binary system to represent the voltage range in a base-2 numbering system. The base two system constitutes 1 or 0 as a single binary digit or bit for short. Thus, the resolution of A/D boards is ultimately determined by a factor of 2n, where "n" is the number of bits.

The signals are then amplified to maximize the voltage range of the A/D card. If the amplification is too small, the waveform can be represented by only a few voltage levels. The extreme values will not receive any voltage value with amplification, so the maximums and minimums are lost. Optimal resolution of the waveform can be obtained by selecting an amplification level such that the waveform occupies an average of the A/D voltage range.

4 Interaction Development

From the understanding of the signal collection and its treatment, the construction stage of the mechanical arm begins. It consists of three assembly stages: the printing of parts, preparation and acquisition of equipment, and finally, the assembly and testing stage. Besides the composition of the mechanical arm, an application was built to serve as an interface for the user to receive feedback from the Myo device and automation of the component.

4.1 Assembly of the anthropomorphic mechanical arm

During the development of this scientific initiation, the design process of the mechanical arm was the most time-consuming part of the project. After all, unlike the last scientific initiation project presented, this is a more experimental work. Needing more time spent prototyping the project because it is a more technical experiment, and thus, much more skillful work in manipulating the parts and conception of the arm was required. This required a lot of rework and printing until the arm's assembly reached an ideal quality point. In this way, the project was divided into three major stages. The printing of the parts using a 3D printer, the preparation of the details for the assembly stage, the acquisition of equipment, and finally, the composition of the arm. Each step presented its challenges and peculiarities, portrayed in the following subtopics.

4.1.1 Printing the parts

To print the parts used in the project, a 3D printer was used to produce the necessary components for assembling the arm mechanisms. These machines manipulate inputs, usually plastic, with making objects worked on in 3D modeling programs, as illustrated in Figure 18. They allow anyone to create, experiment, and share solutions, even without much prior knowledge. They were enabling the creation of a cheaper solution for previously inaccessible technologies such as the arm developed in this project.

Figure 18 – Makerbot Replicator+ 3D Printer

The image is taken from the website: makerbot.com.

This was one of the steps that demanded a lot of time supervising each printing set since each piece has individual characteristics for its production. Among these particularities are the density of the part, the type of filling, the use of supports, and the preparation of the printing base. Since this is one of the first works using a 3D printer, it was necessary to study and learn how to prepare each part so that its structure is well manufactured at ESPM and the use of the printer equipment.

Much dedication and time were required during the first assembly stage for printing the parts used in the arm. After all, each component is unique and has its printing particularities. Intermittently, during the project's development, time was needed for learning and testing how to handle the 3D printer. Table 1 shows the estimated costs for each print of the printed objects per material cost and production time.

Table 1 - List of material and time expenses for printing each part of the arm

Objeto	Impressões	Gramas	Lb	Tempo Estimado
Palma e Polegar	Print1	89.2	0.2	7:06:00
Dedos	Print2	48.54	0.11	4:24:00
Antebraço Superior	Print3	74.29	0.16	6:03:00
Antebraço Inferior	Print4	102.16	0.23	8:28:00
Parafusos e Suportes	Print5	48.01	0.11	3:37:00
Engrenagens	Print6	102.27	0.23	7:41:00
Pulso	Print7	85.59	0.19	6:51:00
Total		**550.06**	**1.23**	**20:10:00**

Table prepared by the author

For 3D printing, the plastic filament polylactic acid (PLA) was used, enabling the construction of rigid parts with certain flexibility. It is a polymer consisting of lactic acid molecules, with properties similar to those of polyethylene terephthalate (PET) used to manufacture containers and biodegradable. It degrades quickly in water and carbon dioxide. The printing process has been divided into production sets, which have structural characteristics in common for their manufacture. Figure 19 illustrates some examples of these groups cited in Table 1.

Figure 19 - Examples of printing

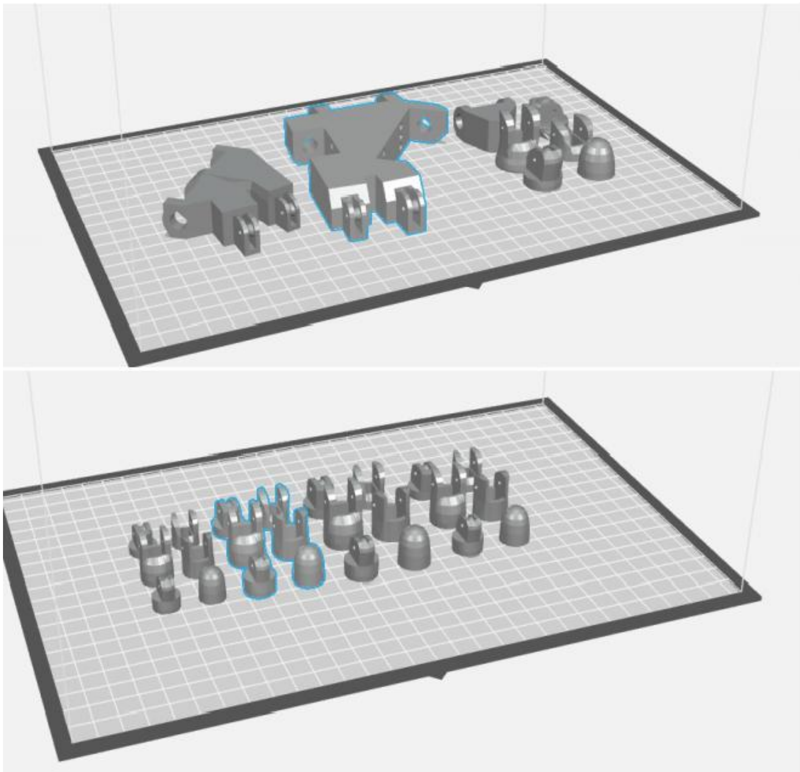


Image created by the author

Some parts presented defects or problems caused by a lack of experience with the printing techniques during the printing process. This caused several reprints until an adequate prototype fabrication level was reached. Another obstacle that prolonged the printing stage was eventual problems with the printer. Since it is a shared printer with other students and many did not present the proper printing process, it broke down considerably, making it impossible to produce parts for an extended period. Production of features for a long period. Despite these problems with the arms manufacturing process, the pieces were printed correctly after a few runs.1

1 Some considerations during the production stage are the sizes of the objects, such as width, height, depth, and proportion, so that they would not present defects when the machine produces the parts. Ensuring the best quality and finish possible at the arm handling and assembly stage.

Figure 20 – The printing process and its challenges

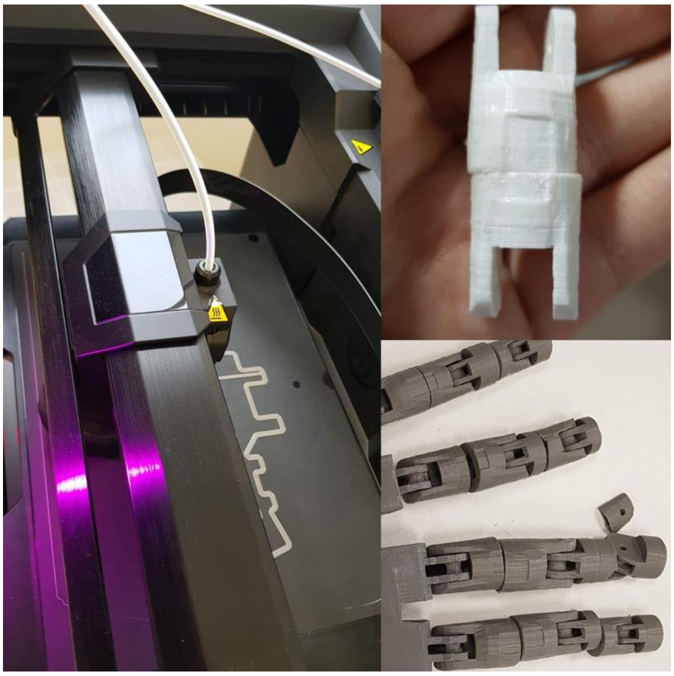


Image created by the author

After the printing process of the parts used in the assembly of the arm, the next step in producing the component is continued, starting with the seizure of the features and the search for new materials needed in the mechanical construction used in the prototype described in the following topic.

4.1.2 Picking up parts

With most of the parts printed, the next step was to separate and find materials needed to assemble the arm, such as some tools, screws, springs, glue, and other not easy tools. The project also presented eventual needs to change equipment that was inadequate for the task and new demands. Electronic equipment was purchased for the prototype's automation besides the inputs and instruments used in the assembly process.

The first challenge of this process refers to the acquisition of screws compatible with the printed parts, from the hole opening diameter length to the type and head of the screw. Without suitable screws, the assembly of the arm becomes irregular and directly hurts the integrity of the arm's operation, which can occasionally lead to the deterioration of its operation. Thus, the most significant setback in this step was the shortage of compatible parts for the mechanisms. It provides a fatigue apprehension of equipment that would fit the project's needs.

The second challenge consists of integrating and articulating the project to create tendons controlled by the prosthesis' motors. To build this mechanism, it was necessary to find and acquire a line with good resistance and flexibility to sustain

Motor torque concerning the force required to perform the finger movements. In the case of the prototype, the material that best suited the circuit created was a hundred-pound braided fishing line. With a suitable material to support the motor's performance, there is still a lack of representation of the tension present in the tendons to keep the position of the fingers stable as they relax. Thus, to create the proper pressure to the arm strands, the implementation of springs was used to tense the line as the motors rotate. [2]

For the automation of the arm, high voltage and torque motors capable of giving proper movement to the mechanical fingers of the project were purchased. Together with the engines, an Arduino was acquired, capable of controlling the various servos compactly and efficiently.

Figure 21 - Challenges for assembly

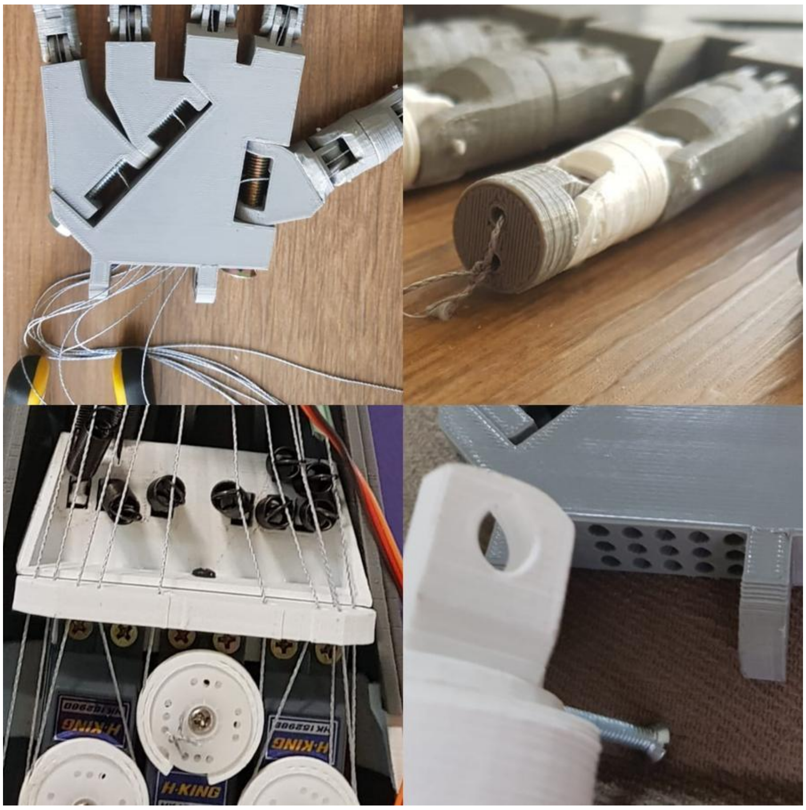


Image created by the author

After acquiring the necessary materials to enable the arm's automation, the assembly of the prototype begins. The steps involved in this process are described in the next topic.

[2] Besides the materials mentioned above, some essential inputs were also necessary for producing the work. Even though it is not required to highlight these items, they were fundamental for the assembly. Mainly in terms of tools to manipulate the pieces and make them ready for the arm. After all, in addition to the printing process of the parts, they need a finish to ensure better functionality.

4.1.3 Arm Assembly

The mechanical arm was started with all parts printed, machined, and purchased. The first step in the prototype assembly process is the construction of the forearm.

Figure 22 - First stage

Image created by the author

This part is classified as the foundation of the project for allocating all the electronics, fundamental for the construction of the hand movements, the muscular tensioning system made by the springs, and the "muscular" support structure for all the weight and mechanisms of the arm.

Figure 23 - Forearm components

Image created by the Author

During the process of assembling the forearm, most of the inputs were attached with due care not to hinder

Any tensioning or torque procedure of the motors, being necessary enough caution with the positioning of the springs so that they are following the respective tendons and motors. Through this first construction step, the foundation of the "muscular" activity performed by the forearm is established through its electronic components. The idea of a "muscular" movement is made possible through the distension of the wires in the movement of torque motors to the tip of each finger, thus simulating the movements of relaxation and pressure similar to the biological hand.

Figure 24 - Components of the mechanical hand

Image created by the author

With the forearm components ready, the next step was to assemble the hand members. The mechanical hand consists of small gears responsible for creating movements of the fingers. The project's kits allow ninety degrees of freedom for the exercise of each finger, which is enough to open and close the hand. However, what enables the mechanical action in the "muscular" movement of the prototype are the lines (tendons) that connect each of the gears present in hand to the rotation movement of the motors current in the forearm.

Figure 25 - Degrees of freedom of the fingers

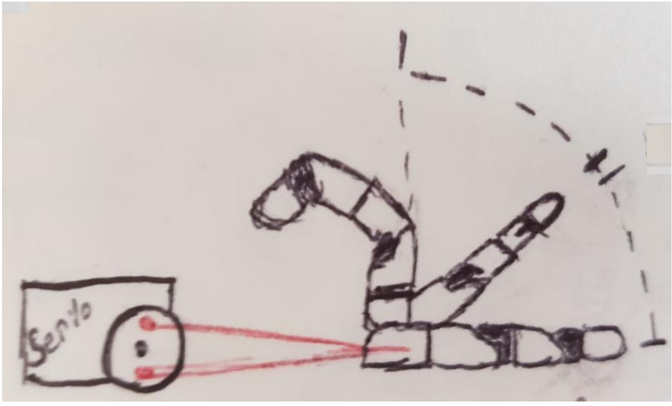


Image created by the author

The next stage of building the arm components consists of the carpal members and the wrist of the prototype. Although these parts do not constitute the main movement of the arm, they still represent essential degrees of freedom in the activity of the "musculature" of the project. They are responsible for the rotation and connection of all the parts involved in the movement of the hand. The equipment present in this region is a motor to compose the wrist process and another support for the tendon tensioning mechanism. These components coordinate the movement caused in the forearm with the activity that occurs in hand, subject to much of the friction and resistance of the prototype. In such a way that, without the aid of the parts present in this region, the arm activity and its mechanisms can cause a rupture among the hand parts.

Figure 26 - Arm assembly process

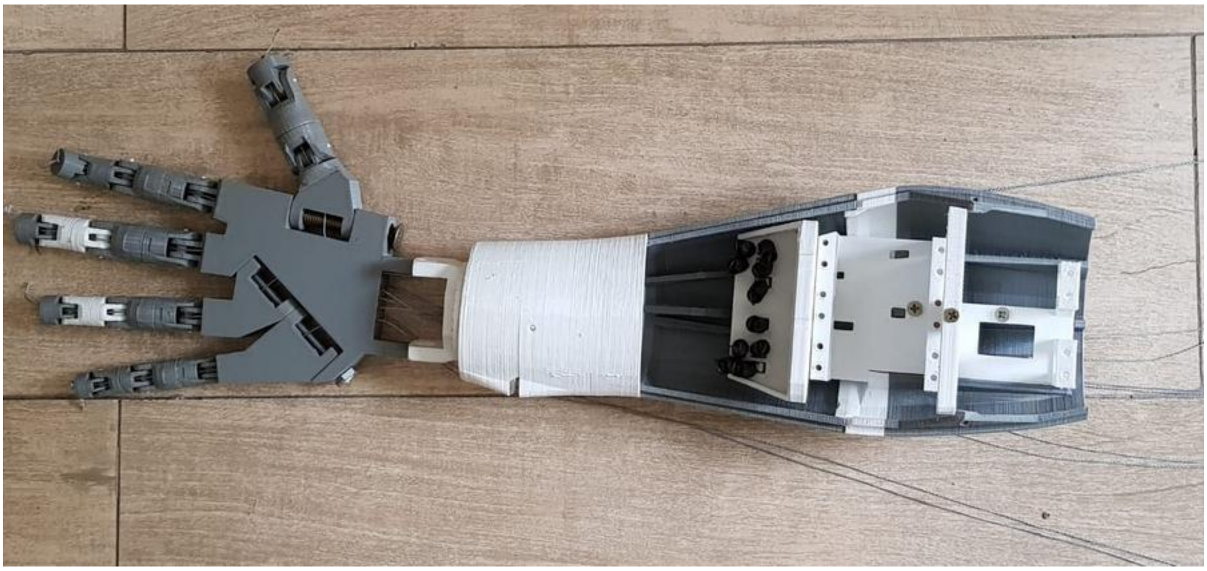


Image created by the author

Finally, finalizing the arm assembly process, more attention was given to the composition and functioning of each component present in the project's frame, not only because these parts present a higher degree of complexity for the project's assembly because they have a delicate movement. Thus, for the pieces to enjoy less friction in the mechanical movements, it was necessary to re-finish the printed parts, replace some inputs used in the organization of the arm, and reprint some parts to obtain a more refined movement.

Besides the inconveniences involved at the end of the assembly process, the most challenging process was present in the framing of the tendons. After all, if these were not well allocated within each gear designed to create the displacement and connection of the parts, this would mean a re-assembly process of the mechanical arm.

Figure 27 - The Anthropomorphic Mechanical Arm

Image created by the author

In other words, because each of the components present in the design assembly is connected by the tendons, the maintenance possibilities in the prototype become limited. If any of the lines break, it becomes challenging to repair the prototype because all of them are attached to each of the mechanisms. The friction provided on the lines by the printed parts, which maintains the design's tension, also hinders the possibility of prolonged operation of the prototype. These problems and others are highlighted in the concluding chapter of this project as possible solutions for future developments. All of the issues reported were obtained during experiments and tests during the assembly process. Although not all the tests performed are described, the focus of this report was on the assembly of the equipment.

4.2 The development of the mechanical arm interaction

During the development of the interaction created during the scientific initiation Brain-Computer Interaction, it was not feasible to achieve all the objectives idealized until then. Since, at that time, there was already the interest in developing the mechanical arm in future research. Since then, due to the good and the search for new resources for the production of the component, the realization of this project allowed a deepening in the ideas already studied and contemplated. To perfect and consolidate the progress in the research preceding this work.

4.2.1 The BCI Interaction

Myo is a device that presents much of its power through the transformation of user interaction, using signal processing techniques to create a Brain-Computer Interface (BCI) interaction. A device used to measure the electrical potential generated during muscle contractions allows users to interact with a machine through more natural and intuitive interaction. An extensive set of electrodes can perform more accurate muscle contractions because it is a bracelet. It is making a selective record, as presented in chapter 3.

Figure 28 – The Myo bracelet

The image is taken from the website: learn.adafruit.com/myo.

From the selectivity of the bracelet, it can record muscle activity significantly from a local volume of tissue instead of a cross-talk of neighboring muscle fibers. That is because it is an electrode array occupying the entire surroundings of the muscle. By effectively spacing the radial distance between the muscle fiber and the sensing surface, it can perform a (volumetric) analysis of an entire muscle array when recording a movement.

However, the bracelet can only collect the volumetric conductance of the muscle. To process this data and transform it into an analysis, it is necessary to transmit the information to another device, which will take care of the signal registration (quantization). In this way, the transmission is done through Bluetooth Low Energy (BLE) wireless communication technology, which allows devices to interconnect fast and straightforwardly, proposed to provide considerably reduced energy consumption and costs. From the communication created with the bracelet, it becomes possible to develop a graphic interface to perform the EMG analysis:

Figure 29 - Application developed to acquire EMG data

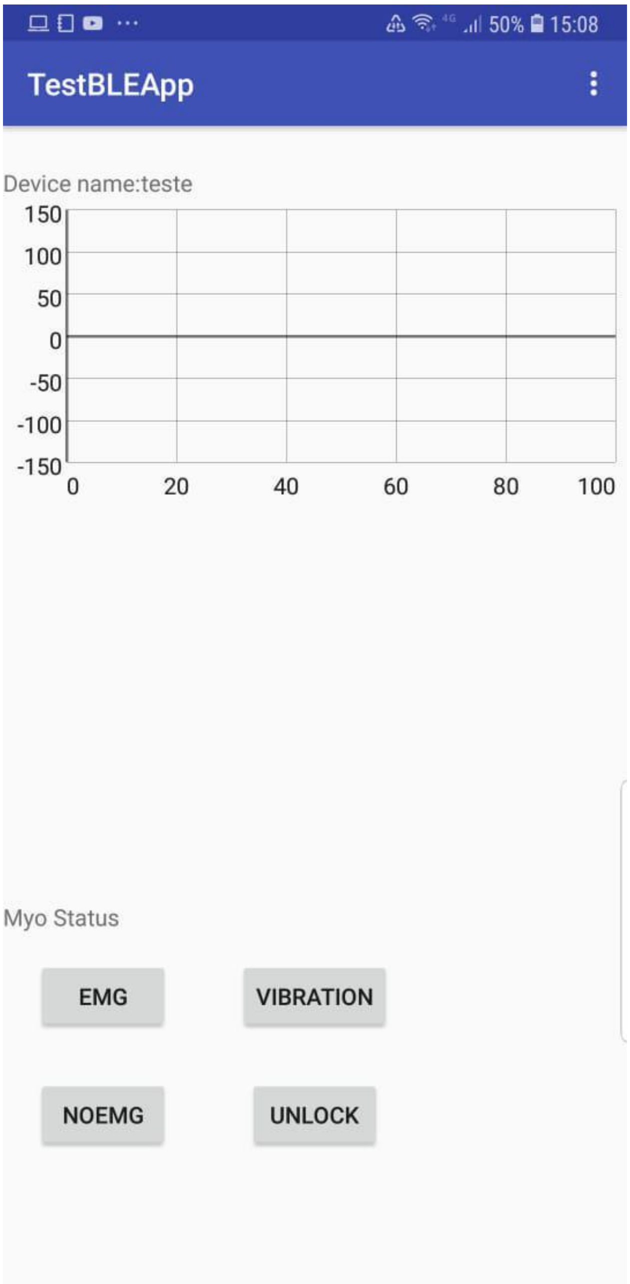


Image created by the author

4.2.2 Development

The first step in developing interaction with a BLE device is to establish communication with it, more specifically, to connect to the services available from the device by acting as a GATT (generic attribute name) client.

To connect to the GATT service provider in the device, it is necessary to use an actuating method to ascertain a stable connection between devices. This profile is a general specification for sending and receiving small data, known as "characteristics," on the link established by the machines.

With the connection established between the appliances, the client created connects to the server hosted by the BLE device returning a GATT connection snapshot used to conduct operations between the service clients to deliver results such as connection status and any other procedures and characteristics of the GATT client.

Figure 30 - Features and services provided by the device

```
//ID Servicos
private static final String MYO_CONTROL_ID = [redacted];
private static final String MYO_EMG_DATA_ID = [redacted];

//Caracteristicas ID
private static final String MYO_INFO_ID = [redacted];
private static final String FIRMWARE_ID = [redacted];
private static final String COMMAND_ID  = [redacted];
private static final String EMG_0_ID    = [redacted];

/** Characteristics ID - EMG Sample 1 */
private static final String EMG_1_ID = [redacted]
/** Characteristics ID - EMG Sample 2 */
private static final String EMG_2_ID = "[redacted]";
/** Characteristics ID - EMG Sample 3 */
private static final String EMG_3_ID = "[redacted]";
```

Image created by the author

Services the appliance uses divide data into logical entities to contain specific parts of their code in features. That is, a service can have one or more characteristics. Thus, each service provided is distinguished from others by a unique numeric ID called UUID (Universal Unique Identifier), 16 bits for officially adopted BLE services or 128 bits for custom services.

Like services, a given feature is distinguished utilizing a predefined 16-bit or 128-bit UUID (official or custom). Besides using characteristics in the communication service, descriptors facilitate the devices' reading of the data traffic.

Descriptors are defined attributes that describe a characteristic value. For example, a descriptor can specify a human-readable description, an acceptable range for a distinctive weight, or a specific unit of measurement.

It is common for BLE applications to be notified when a specific characteristic changes on the device. When notifications are enabled for a feature, a callback is triggered if the element changes on the remote machine:

Figure 31 - EMG reading

```
//SETBYTEREADER
ByteReader emg_br = new ByteReader();
emg_br.setByteData(emg_data);

final String callback_msg = String.format("emg %5d,%5d,%5d,%5d,%5d,%5d,%5d,%5d\n" +
                    "    %5d,%5d,%5d,%5d,%5d,%5d,%5d,%5d",
        emg_br.getByte(), emg_br.getByte(), emg_br.getByte(), emg_br.getByte(),
        emg_br.getByte(), emg_br.getByte(), emg_br.getByte(), emg_br.getByte(),
        emg_br.getByte(), emg_br.getByte(), emg_br.getByte(), emg_br.getByte(),
        emg_br.getByte(), emg_br.getByte(), emg_br.getByte(), emg_br.getByte());


//COMECA A LEITURA DO EMG_0_ID
emg_br = new ByteReader();
emg_br.setByteData(emg_data);
for (int emgInputIndex = 0; emgInputIndex < 16; emgInputIndex++) {
    emgDatas[emgInputIndex] = emg_br.getByte();
}

   mHandler.post(new Runnable() {
               @Override
               public void run() {
                   dataView.setText(callback_msg);

                   for (int inputIndex = 0; inputIndex < 8; inputIndex++) {
                       dataList1[inputIndex][0] = emgDatas[0 + inputIndex];
                       dataList2[inputIndex][0] = emgDatas[7 + inputIndex];


                   }
```

Image created by the author

From the algorithm shown in Figure 31, it is possible to read the EMG characteristic provided by the device service. When there is a change in the isometric concentration patterns in the muscle, initiating muscle activity, the device begins to record the action, and the client developed by the application is triggered to read the muscle activity. To facilitate this reading, a descriptor (call-back_msg) was designed to provide a readable description corresponding to the literature described in Chapter 3.

Figure 32 - Mapped communication

```
//Define o BLE Callback
@Override
public void onLeScan(BluetoothDevice device, int rssi, byte[] scanRecord) {
        if(deviceName.equals(device.getName())){
            mBluetoothAdapter.stopLeScan( callback: this);


            //Tenta conectar GATT
            HashMap<String, View> views = new HashMap<~>();
            //Seta GraphView
           // views.put("graph", graph);

            showDevice.setText(deviceName.toString());

            mSeries = new LineGraphSeries<>();
            graph.addSeries(mSeries);


            mMyoCallback = new MyoGattCallback(mHandler, emgDataText, views, mSeries);
            mBluetoothGatt = device.connectGatt( context: this,  autoConnect: false, mMyoCallI
            mMyoCallback.setBluetoothGatt(mBluetoothGatt);

        }
}
```

Image created by the author

With the communication mapped to the peripheral device, the method shown in figure 32 defines the reading of information collected by the features. Through the descriptor's data matrix, a series was developed for reading the data provided by the device. This series originates the graph shown in Figure 29, allowing an analysis of the signal collected by the user used in the experiment.

The features are the main point of interaction with the BLE peripheral essential for data communication between devices. But besides being employed in reading the information, they can also be used to send data back to the BLE peripheral as it is also possible to write data to a feature. The implementation of the interface (figure 32) uses four inputs to send control commands written into a custom characteristic, a UART (Universal Asynchronous Receiver-Transmitter) type service to control content parameters made available by the peripheral as well as trigger device functions.

Figure 33 - Device control input

```
//Sets the EMG streaming mode for a Myo
public byte[] sendEmgOnly() {
    byte command_data = (byte) 0x01;
    byte payload_data = (byte) 3;
    byte emg_mode = (byte) 0x02;
    byte imu_mode = (byte) 0x00;
    byte class_mode = (byte) 0x00;
    send_bytes_data =
            new byte[]{command_data, payload_data, emg_mode, imu_mode, class_mode};

    return send_bytes_data;
}
```

Image created by the author

The algorithm shown in figure 33 illustrates the manipulation of a feature to send an EMG content control command to trigger the device's collection function, which eliminates noise caused by the device amplifier when collecting the signal.

4.2.3 Results of the created interaction

Although this interaction remembers its predecessor, the interface developed for this work reached a high level of complexity and further development over time. Since, from the results obtained at the end of the previous research, it became conclusive that through the exclusive use of the Myo development platform, it would not be possible to reach the full potential of the BCI interaction.

Thus, to overcome certain limitations in using this device, a workaround was produced to work directly with the signals obtained by the bracelet. The workaround developed is demonstrated in the previous topic. From direct communication with the device, we can search for its specific services instead of using an API (Application Programming Interface) made available by the creators of the bracelet for software development Myo. This development technique is a high-level communication with the device (closer to machine language) to extract the essentials of electromyographic analysis.

As a result, the investigation on developing this application is a more refined analysis of signal processing, contributing to a better understanding of signal collection and acquisition. Through the designed interface, illustrated in figure 34, the signal processing techniques described in chapter 3 are used to treat the signals obtained in direct communication with the device, which has the raw data from the signal collection—facilitating the comparison between evidence of muscle behavior for analysis.

Figure 34 - EMG Analysis

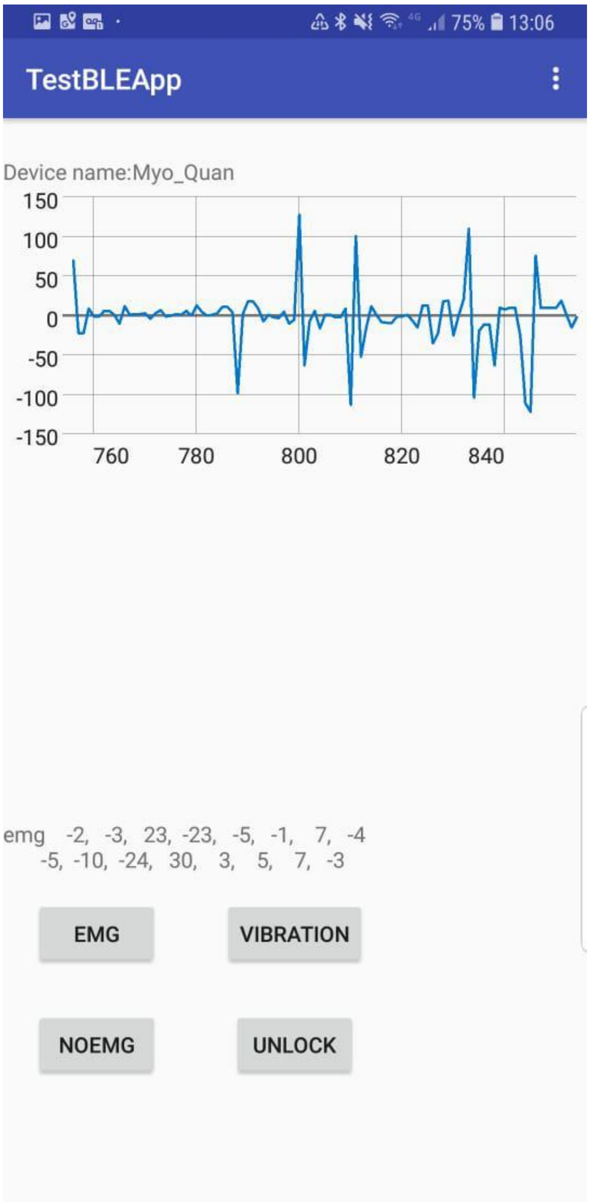


Image created by the author

However, there has been a lack in the study of signal processing. Since this analysis depends on numerous techniques and formulations, its learning requires more effort and time to process the complexity given EMG analysis. What will be better employed by using Deep Learning and Machine Learning methods, techniques from another significant area of study coming from Artificial Intelligence? This would significantly prolong the study of this scientific initiation and would be better elaborated in the author's possible future master's degree. Thus, the device's library was used to identify the data obtained in the electromyographic collection to supply this need. Future possibilities and challenges encountered during the development of this project are better highlighted in the concluding chapter of the work.

5 Conclusion

Through the study carried out in constructing a proof of concept in this project, we conclude the development of this scientific initiation. Contemplating the elaboration and refinement of the learning obtained and discussing the development results presented in the previous chapter, portraying the problems and challenges encountered in the research. Finally, offering some final considerations of the project developed and possibilities for future studies in the area.

5.1 From practice to experience denoted

To finish with the development of this scientific initiation project satisfactorily and to discuss the knowledge obtained, the worked proposal, the developed interaction, the impressions about the subject, finally, to approach new work possibilities. The possibilities occasioned by finishing the work marked the fascinating study on BCI Interaction, neuroscience studies, and development.

This area of study also comes to competence that encourages a multidisciplinary endeavor to expand the traditional scope of knowledge of computer science by way of medicine. The development capacity involving these subjects provides 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 different areas.

Thus, through the study of electromyography, one can see an advance in understanding the behavior and treatment of noise to work in the analysis of synaptic signals obtained from the human body. It investigated the techniques used in signal processing that provide the study design of current technologies. Through the learning obtained about neuromuscular behavior, in the formation and collection of a nerve stimulus during muscle activation, this work enabled the imagination of a new business model in seeking to meet a physical need tending to maintain or improve the functional capacity of people with disabilities to gestate and interact with the environment through the study area of BCI techniques and more fluent interactions.

To achieve a high-level interaction between the user and a mechanical prosthesis, more intuitive and friendly for a more productive interaction seeking to replicate the potential of computer manipulation through "thinking" (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. Opening surprising learning in the scope of neuroscience, which awakened research possibilities for the continuity of future academic training, is this chapter's third topic.

On the other hand, obstacles have arisen in achieving a high-level interaction through the multidisciplinary knowledge scope of the area, seen in the certainty in the search and use of new techniques and solutions for the development of the exchange. This area innovates daily in the academic environment forwarding new exceptional competencies fundamental to the study's progress. Thus, the study contemplated in this work possibility an opportunity to evolve this competence and continue advancing within the multidisciplinary teaching among many expectations at the forefront of technological research and medicine along with the evolution of new studies done by the researcher in the area.

5.2 Final considerations

During the development of the scientific initiation project, specific information was ascertained regarding the construction of the arm and the development of the application, as reported in the subtopics of chapter 4. We are providing some extenuation with the finalization of the work. This topic discusses mitigations for the possible rigors arising from constructing 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 became unrepairable. Each of the mechanisms present in it is connected so that an imminent deterioration of the arm will render the entire instrument created uselessly. Of course, because this is only a PoC, it allows future improvements to the prototype to design a better model according to eventual market needs. Thus, as identified, certain drawbacks in the mechanical part limited the project's performance, making the movement scarce, limiting the arrangement between the developed devices, and the failure to establish new gestures for robotic automation. However, because it was a proof of concept, the results of the automation worked on in this report were satisfactory.

Unfortunately, Myo had its sales and support terminated regarding the BCI device development at the end of last year. This dramatically hinders its use in new projects. Despite being a product for commercial use in various business presentations such as lectures, events, and fairs, it gave incredible support for developers to create functions for medical use and automation. It showed that the development possibilities of this product have contributed to numerous studies in BCI. So here, too, there is room for contribution in searching for new devices.

Given the discontinuity of the bracelet, for future studies, the stage of the study of collection and treatment of the biological signal should be re-built using other devices available on the market. Fortunately, some free hardware platforms like Arduino are developing new solutions and prototyping possibilities for the area, being

Something to watch out for. Technology moves the world, and inevitably the search for new knowledge will give rise to study possibilities without being tied to it.

5.3 Future works

This particular work had two rather striking characteristics, often as distinct in the eyes of a researcher. The most obvious is the search for knowledge, the scientific side, and the need, giving a more commercial opportunity to the issue. Thus, this research has not only served to motivate research in BCI but has enabled the formation of an entrepreneurial aspiration. New technologies seek to solve supply and supply issues and adversities encountered in everyday life.

The importance of searching for new technologies and solutions showed how the proposed study would directly benefit many people in resolving this project. Even though it is only a study in the extensive area of medicine and information technology, this desire for applicability in actual actions remains strong and eventual new possibilities for learning and knowledge in the area and the search for further research. Through recent investments in the study presented, it will be possible to improve the development of this PoC and eventually turn it into a product ready for commercial use aiming to solve the problem discussed in the presentation of this project.

Concerning possible research continuations, the study performed in this work still has great potential for evolution. However, to continue the research progress in the scope of the BCI, a deepening in artificial intelligence is primordial, aiming to incorporate its techniques in the treatment and signal processing methodologies. Thus, soon it is intended to start a graduate project to remedy difficulties encountered so far as to continue the search for new studies and research.

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Attachments

ANNEX A - Electrostatics

A.1 Electric load

A unit coulomb is a specific number of elementary charges. One coulomb of negative charge equals 6.25*10-18 electrons. Likewise, one coulomb of positive control represents 6.25*10-18 protons. Considering the magnitude of the two leaders and the radial distance between them allows conversion between electrical and mechanical units and concepts. The force between two tasks (Q) and the radial distance between the two charges (r) and the constant of proportionality so they can be expressed in the more familiar unit of newtons (k=9.0*109 Nm2/ C2):

$$F = kQQr2 \quad \text{(TO 1)}$$

A.2 Electric fields

When an electric charge is placed somewhere in space, it creates a state of electric tension in its general vicinity, called the electric field (E). If another much smaller charge is placed in the electric field, the first charge activates an electrostatic force on the second due to the area. The magnitude of the electric field (E) is then the force per unit charge at that particular point and is highly dependent on the radial distance between the two accounts.

$$E = F = q \quad \text{(A.2)}$$

A.3 Electric potential energy

The potential energy depends on its location within the electric field.
There must always be a reference point where the potential energy is zero. The difference in electric potential power between two points is measured in volts (V), the fundamental measurement unit for amplitude in EMG. The amount of work (W) is done on the charge by the electric field when it is moved from position A to B within the electric area. Trigonometry must be used to find the force vector component in the same direction as the displacement.

$$W = Fdcos(q\ ) \quad \text{(A.3)}$$

The magnitude of the electric potential energy at the second position (B) is equal to the negative value of the work done by the electric field. The normalized potential difference equals the negative value of work per unit charge required to take up the amount between these two points. The normalized definition of the electric potential difference in joules per coulomb gives a new volt (V) unit.

A.4 Capacitance

Any conductive material can be thought of as a reservoir or source of electrical charge. The electric account will flow if a conductive wire is connected to the pool. An item that can store electrical charge is called a capacitor. The capacitors connected in parallel receive a direct order from the battery, equal to the capacitor's total amount. The potential difference between the three capacitors when fully charged is similar to that of the storm.

A battery is an electrochemical device that maintains a potential difference (V) between two terminals. The negative terminal (cathode) is the low potential collector, and the positive terminal (anode) is the high potential source. The potential difference between the two terminals results in an electric field within the conductive wire that causes the flow of electrons when the switch is closed to complete the circuit. The potential difference at the terminal is the electromotive force of the battery. The unit of measurement is still volts.

Since the charge between the capacitors connected in series must be induced, each plate has the same order. If the mission remains the same, but the area over which it is distributed increases, the overall electric potential will decrease.

Each capacitor represents an additional surface area to distribute the same charge for a series arrangement. Consequently, there is a successive decrease in the electrical potential associated with each capacitor in the series. The sum of the potential differences between the three capacitors is equal to the potential difference supplied by the battery. The capacitance ratio can be used to replace V.

$$C = Q = V \tag{A.4}$$

A.5 Electric current

Electric current (i) flows like charges across a defined surface area. Negative charges moving to the left are equivalent to positive charges moving to the right, in the direction of the electric field (E). By convention, the direction of flow of the electric current is designated as the direction in which the positive charges are free to move. The amount of payment (DQ) passing through the area (S) in a given time interval (Dt) is the average current. However, the rate at which the charge flows vary in time, so the instantaneous current must be defined as the limit of the differential.

$$i = DQ/Dt \tag{A.5}$$

A.6 Resistance

The amount of charge flowing (i) per unit area (S) is referred to as current density (J). The current ratio is based on the number of carriers moving through a conductor section. If the current is divided by the cross-sectional area of the conductor, then the current density is J = i / A, where the units are amperes (A) per square meter (m2).

When the potential difference is constant as supplied by a battery, the current density is proportional to JE's electric field. The reciprocal conductivity is the resistivity (r) of the material to the flow of charges.

The relationship between potential difference and current density reveals the different factors governing charge flow: DV=ilsA, where (1 / s) is the resistivity of the material to charge flow (i.e., current, i) which is also governed by the length (l) and cross-sectional area (A) of the wires. All three factors together describe the resistance (R) of the conductor:

$$R = (l{=}sA) \tag{A.6}$$

Substituting resistance (R) for the potential difference gives the most friendly relationship with Ohm's law: =V = is. If the resistance is constant, then the conductor will obey Ohm's law, in which the flow of charges is directly proportional to the potential difference applied to the conductor. The resistance of a conductor is given by. The resistance unit is volts per ampere: one volt per one ampere is defined as one ohm (W).

$$R=DV/i \tag{A.7}$$

. The resistance unit is volts per ampere: one volt per ampere is defined as one ohm (W).

A.7 Electricity

To maintain a constant flow of current (i), the rate at which the battery works on the loads to increase their potential energy across the terminals must equal the rate at which the loads perform work on the resistor and lose potential energy. The speed at which work is done is called energy, and the rate at which electrical energy is supplied to the circuit by the source (battery) is also called power. The unit of energy is watts (W).

If several resistors are connected in series, the charges experience a potential drop across each resistor. The sum of each potential drop must equal the total voltage driving the directions through the resistor (conservation of energy).

Since the same amount of current must also pass through each resistor in succession, the same potential difference is applied to each resistor.

The potential difference between the resistors in parallel is equal to that applied by the battery. However, the current from the source splits into different branches—the division results in less current entering each resistor than leaving the battery. Since the charge must be conserved, the branch's current entering must be the same as that going the department.

A.8 Resistors and Capacitors in a Circuit

When the switch is closed in an RC circuit, the amount of charge q (t) and current i (t) on the capacitor plates as a function of time is based on reaching static equilibrium between the potential difference across the battery and the capacitor (e=Vc).

$$qt = Ce(1 \text{ and } 1RC) \tag{A.8}$$

If a fully charged capacitor is discharged through a resistor, the capacitor serves as a non-renewable source. The equation that describes both the charge q (t) and the current i (t) on the capacitor plates as a function of time is based on the absence of a battery (e = 0).

$$qt = Qe\ tRC \tag{A.9}$$