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BIOMECHANICS IN THE FOURTH INDUSTRIAL REVOLUTION: developing a special mechanized prosthesis

BIOMECÂNICA NA QUARTA REVOLUÇÃO INDUSTRIAL: desenvolvendo uma prótese mecanizada especial

BIOMECÁNICA EN LA CUARTA REVOLUCIÓN INDUSTRIAL: desarrollo de una prótesis mecanizada especial

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ABSTRACT

Background of the study: The theme of the Fourth Industrial Revolution, and specifically the fields of Biomechanics and Kinesiology has been an important, robust and timely segment, both in academic literature, as well as in technical and even business literature.

Literature revision: From classical thinkers to contemporary researchers, this theme has been explored, providing contributions to different literatures, notably in the fields of health, industry and sport.

Objective: To develop the compaction of all components of the prosthesis such as protobord plates, Arduino plate, obtaining the technology intended for the optimal functioning of the organ, for the comfort and well-being of the wearer.

Materials and methods: The compaction of all components was developed as plates suitable for Biomechanics and Kinesiology, servo motors and microcontrollers that were used for the prosthesis operation, via 3D printer.

Results: The prosthesis was manufactured in a 3D printer with PLA filament, showing good resistance, allowing great durability of the material. The 3D project was developed by parts and printed individually and all programming of movements and voice command was developed on Arduino Uno® platform and servo motors. Subsequently transferred to Arduino Nano® reducing the size of the components and electronic circuits located in the forearm.

Contributions to knowledge: The work made it possible to contribute to the advancement of technological knowledge in this area.

Practical Contributions: The prosthesis has demonstrated its biomechanical and kinesiological viability, allowing the development of new technologies for industry and new businesses, as well as contributing to the well-being and comfort of people.

Keywords: Biomechanics and Kinesiology. 3D printing. Mechanical prosthesis. Amputation.

RESUMO

Fundamento do estudo: O tema da Quarta Revolução Industrial, e especificamente os campos da Biomecânica e Cinesiologia vem sendo um segmento importante, robusto e oportuno, tanto na literatura acadêmica, como na literatura técnica e até de negócios.

Revisão da literatura: Desde os pensadores clássicos até os pesquisadores contemporâneos, este tema vem sendo explorado, proporcionando contribuições às diversas literaturas, notadamente nos campos da saúde, da indústria e do esporte.

Objetivo: Desenvolver a compactação de todos os componentes da prótese como placas protobord, placa Arduíno, obtendo a tecnologia destinada ao funcionamento ótimo do órgão, para conforto e bem-estar do portador.

Materiais e métodos: Desenvolveu-se a compactação de todos os componentes como placas adequadas à Biomecânica e Cinesiologia, servos motores e microcontroladores que foram utilizados para a funcionamento da prótese, via impressora 3D.

Resultados: A prótese foi fabricada em impressora 3D com filamento PLA demonstrando boa resistência, possibilitando grande durabilidade do material. O projeto 3D foi desenvolvido por partes e impresso individualmente e toda programação dos movimentos e comando de voz foi desenvolvida em plataforma Arduino Uno® e servos motores. Posteriormente transferida para Arduino Nano® reduzindo o tamanho dos componentes e circuitos eletrônicos localizados no antebraço.

Contribuições ao conhecimento: O trabalho permitiu contribuir ao avanço do conhecimento tecnológico nesta área.

Contribuições Práticas: A prótese demonstrou sua viabilidade biomecânica e cinesiológica, permitindo o desenvolvimento de novas tecnologias para a indústria e novos negócios, bem como contribuindo ao bem-estar e conforto de pessoas.

Palavras chaves: Biomecânica e Cinesiologia. Impressão 3D. Prótese mecânica. Amputação.

RESUMEN

Antecedentes del estudio: El tema de la Cuarta Revolución Industrial, y específicamente los campos de la Biomecánica y Kinesiología, ha sido un segmento importante, robusto y oportuno, tanto en la literatura académica, como en la literatura técnica e incluso empresarial.

Revisión de la literatura: desde pensadores clásicos hasta investigadores contemporáneos, este tema ha sido explorado, proporcionando contribuciones a diversas literaturas, especialmente en los campos de la salud, la industria y el deporte.

Objetivo: Desarrollar la compactación de todos los componentes de la prótesis, como placas protobord, placa Arduino, obteniendo la tecnología orientada al óptimo funcionamiento del órgano, para la comodidad y bienestar del portador.

Materiales y métodos: Se desarrolló la compactación de todos los componentes, como placas aptas para Biomecánica y Kinesiología, servomotores y microcontroladores que se utilizaron para el funcionamiento de la prótesis, vía impresora 3D.

Resultados: La prótesis se fabricó en una impresora 3D con filamento PLA, presentando buena resistencia, permitiendo una gran durabilidad del material. El proyecto 3D se desarrolló en partes e imprimió individualmente y toda la programación de los movimientos y el comando de voz se desarrolló en la plataforma Arduino Uno® y los servomotores. Posteriormente trasladado a Arduino Nano® reduciendo el tamaño de los componentes y circuitos electrónicos ubicados en el antebrazo.

Aportes al conocimiento: El trabajo nos permitió contribuir al avance del conocimiento tecnológico en esta área.

Aportes Prácticos: La prótesis demostró su viabilidad biomecánica y kinesiológica, permitiendo el desarrollo de nuevas tecnologías para la industria y nuevos negocios, además de contribuir al bienestar y comodidad de las personas.

Palabras clave: Biomecánica y Kinesiología. Impresión 3d. Prótesis Mecánica. Amputación.

1 INTRODUCTION: Contextualizing the state of the art of the subject and the purpose of the project

The Fourth Industrial Revolution, also known as Industry 4.0, represents a milestone of fundamental importance in the history of human society. In the most diverse scenarios, its foundations and impacts are already intensely manifested, at all borders, in the lives of organizations, governments and people (Schwab and Davis, 2018). In this context, it is natural that scientific and technical publications, meeting the demands on the contemporaneity, opportunity, importance, pertinence and robustness of contents from different literatures have been exploring this theme in a consistent way, even though it can still be considered as emerging. With these purposes, the studies are aimed both at the advancement of the frontiers of knowledge and at the practical applicability of new technologies, seeking to offer solutions for institutions and people. Thus, purposes and processes, integrating their objectives, strategies, structures and results, converge to the densification of knowledge on the most diverse themes.

One of the most evident frontiers in the densification of the Fourth Industrial Revolution is the field of health (OECD, 2020), with its contributions regarding the applicability of Artificial Intelligence as a way to achieve cutting-edge diagnoses, treatments and procedures. Thus, both the drug industry and the surgical and diagnostic equipment industry have provided significant improvements in the quality of life and health of people, especially in the more developed world, as can be seen (World Economic Forum, 2018). Due to the irradiation of the economy and the technological applicability of this new era in development, the benefits will certainly reach the poorest societies in the poorest regions of the contemporary world in the medium term (Hidalgo, Klinger, Barabási & Hausmann, 2007). In this spectrum, the advances in science and technologies in the segments of Biomechanics and Kinesiology have been highlighted.

Biomechanics can be defined as one of the primary tools for the study and analysis of movements, showing then how to achieve them in the best possible way and achieving a good relationship between metabolic and mechanical expenses. For this purpose, biomechanics has been reinvented and studied by scientific multidisciplines, which have been adding a vast amount of new procedures and techniques for the storage, measurement and processing of useful data for the analysis of movements. Through it, it is possible to analyze, describe and model the biological systems of each human being in order to explain how the different forms of movement occur, starting from the two main kinematic and dynamic parameters.

Kinesiology, on the other hand, means the study of movement and can be defined as knowledge of the bone, muscular and anatomical structures of the body. Thus, it can easily be linked to the movements performed by the human being. This area of study seeks mainly to understand how movements occur from a great careful analysis of anatomical structures, with the main focus on skeletal bones and muscles so that through this could understand the cause and effect of each movement and know the specificity of each muscle and what its contraction will trigger in order to indicate the acceptable limit of stress that muscles and structures are able to withstand, thus, has great medical importance in helping to prescribe activities that will benefit muscle strengthening.

Regarding limb surgery, which has existed since the beginning of human history, amputation has always caused serious impacts, not only on the physical nature of the subjects, but also on the emotional state, due to limitations in locomotion, differences in perceptions and social acceptance and restrictions in the field of professional practice (Simsek, Ozturk & Nahya, 2017).

Amputation is the removal of an extremity of the body through surgery or accident. Thus, extremity amputations have been reported since the dawn of human history, being one of the first surgical procedures to be performed, mainly highlighting the amputation of upper limbs and featuring a large number of hand and forearm removals of individuals. for which they required amputation. The hand is one of the most important members of the human body, as it performs various daily functions, including manipulation, perception and exploration, thus being responsible for a large part of man's daily activities (Sono, 2012).

Of the 55 thousand amputation procedures that take place per year in Brazil, there is a predominance in the Southeast, Northeast and South regions, which together account for 88.13% of this total. For this reason, there is a great demand for upper and lower limb prostheses. The use of prostheses is of paramount importance, as the amputation of a limb is directly associated with a person's psychological factor. This situation includes factors such as self-esteem, social inclusion, and relationships associated with work and daily activities (Simsek, Ozturk & Nahya, 2017).

The purpose of this report is to present a project that relates the proposal of SDG 10 (Sustainable Development Goals), which assumes as a premise the social inequality aggravated by the amputation of upper limbs. Thus, it is intended that the product developed and presented in this work should be widely used. In short, it consists of a mechanized system programmed to perform all basic hand movements, such as opening, closing, picking up and dropping objects.

The prosthesis was produced with PLA filament (lactic polyacid) and flexible polymers for the joints, enabling fidelity in hand movements. The 3D project seeks a proximity between the hand prosthesis and the non-amputated limb. The 3D printing of the prototype and the use of the Arduino platform for the movement mechanism provides the production of prostheses with 25% of the cost of prostheses found on the market today.

In this context, the general objective of this work is established, which is to produce and offer a product from the compaction of all components, such as Protobord Board, Arduino Board, servo motors and microcontrollers, which will be used for the operation of the limb prosthesis higher. Specifically, it is intended: 1) that the components, even being smaller, are effective for carrying out daily activities, and that all of them will be attached to the inner part of the forearm, helping to maintain the weight of the original limb; 2) that the cost of the product is widely accessible, resulting in a low sale price and great insertion in the market for various uses in society; and 3) that can be used by people of any age group, ranging from children to adults and seniors who have suffered from accidents, diabetes or who were born with any bodily characteristics.

The justifications for the development of a work with this purpose can be of two natures. The first is its academic importance. In the context of the Fourth Industrial Revolution, there is a significant turmoil in the production and publication of scientific and technological articles, reports and free thoughts, on almost all shades involving the contributions and risks of new discoveries and inventions. Notably in the fields of Engineering, and especially Mechanical, Electrical and Systems Engineering, as well as in its broad subspecialties, such as Robotics, Artificial Intelligence, New Materials, etc., applied to orthopedic conditions, contributions have been profuse. However, despite the researchers' efforts, there are significant conceptual, taxonomic, applicability and results differences in the most diverse works published (Wang, Lin, Yao, Wong & Zhu, 2018).

The second justification is technological and social in nature. It is known that one of the most common accidents in industries that present risks to their employees is related to limb amputation (Contuflex, 2020). Thus, this project can be of great acceptance to customers, companies and health ministries and departments, as it is intended that the product be manufactured with a minimum cost, thus providing the economic reach of the entire society. In this way, even if an employee has an accident that results in amputation, the company may be able to sustain the treatment, instead of trying to retire the employee due to disability. This, in turn, would also help the country's social security system, as more people would be able to return to work after the accident and would not feel left out of society (Costa, 2020).

2) LITERATURE CONTRIBUTIONS TO THE PROJECT DEVELOPMENT

2.1 About the Fourth Industrial Revolution and its contributions to health

The Fourth Industrial Revolution, or Industry 4.0, has been offering intense analytical content to academia and technical-executive publications, almost all over the world. An explanation provided by Bauman (2001) about everything that has been happening in recent years is that institutions and people are boldly entering the nursery of uncertainty where changes in seminal courses occur that create new environments. According to him, there is a major shift from the “Solid” to the “Liquid” phase, gradually forcing social organizations to continuously migrate to this medium of technology, information and advancement.

The Fourth Industrial Revolution has established different panoramas in knowledge and even pre-theories, increasingly bringing machine and man together, technology and everyday life, innovation and health, bringing radical changes in short periods of time. There are three factors named by Schwab and Davis (2018) as the pillars of this revolution, namely: the convergence of technologies in the digital, physical and biological world. Analyzing them separately, it appears that in the digital world there are no barriers, events that happen in a specific city are no longer there covering the world in a short time, thus, Giddens (2002) describes the modern or digital world as a huge machine of power that can only be controlled to a limited extent. The physical world, on the other hand, has to deal with the breadth and depth of events in the digital world, having to deal with the different paradigms breaking down and changing our daily lives, how we do and what we do. The third pillar comes to show the systemic impact that has transformed entire systems between countries and especially within them in the organization of work, in society and thus in the population.

Even living this Fourth Industrial Revolution, there is still no clear vision of where and in which direction society will go, in terms of the social organization that is still on the way. Another path that has been much studied and developed is that of Health as the focus on Biomechanics and Kinesiology.

In the middle of 1607 Borelli, considered the father of Biomechanics, was the first to mathematically study movements and how they are constituted mainly in the act of moving through time and space, generating a trajectory that can be linear, angular and planar. The human being moves through the planar trajectory, which is nothing more than the junction of the linear and the planar, and for the movement to occur there are several aspects such as: strength, vector composition, muscle strength and laws of movement.

The laws of motion proposed by Izaac Newton help to understand more about forces, actions in individual joints, mass and movements and so, in 1967, in his great work Philosophiae Naturalis Principia Mathematica, he bases on the laws and basic principles of mechanics. In his work Newton approaches his known laws, which are the law of inertia, fundamental law of dynamics and law of action and reaction. These three laws together are able to relate the existing forces during a movement and are sufficient to determine any classical system, knowing the forces acting on it, its position and speed of each particle, at instant zero. However, Biomechanics comes to help in human health when performing a movement, helping to minimize and prevent injuries and improve performance in each movement.

The main history of Kinesiology ends up getting mixed up a little with the field of body mechanics, through physical experiments that took place around 400 BC. Thinking about movements and how they occur has always left great scientists such as Newton, Galileo, Torricelli and so many others fascinated to the point of creating and developing connections between rigid body mechanics and body mechanics. Physiologists also make major contributions to advancing the understanding of the functioning of living organisms, generating the relationship between human physiology and the study of mechanics.

This science was developed with the objective of analyzing, from a physical point of view, the various forces that act on the human body so that it can then be manipulated in order to bring benefits during treatment procedures. This study encompasses both the skeletal structure and the muscle structure, showing how the different sizes and shapes of bones and muscles can positively or negatively influence the performance of a movement.

2.2 Considerations for 3D Printing

The study and development of the first rapid prototyping method came in 1980 when the Japanese lawyer Hideo Kodama, from the Industrial Research Institute of Negoya, used his knowledge to create a technique that is still used today. In 3D printing, rapid prototyping makes it possible to create a layered formation for creating objects. Just four years later, 3D printing emerged through the American engineer Charles Hulk, who developed the first 3D printer committed to stereolithography technology. Aiming at the application landscape, in 1986 he patented it, calling his creation the SLA. Soon after, he dedicated time and resources to found his own corporation for the commercialization of his technology, the company 3D Systems.

In this way, 3D printing can be defined as a manufacturing process and one of the main aspects of the Fourth Industrial Revolution, as it has the ability to transform various production processes and even life through the creation of prostheses, medical guides and even food. In orthopedics, this technology has been gaining a great deal of space, as it enables the creation of a 3D structure equal to the one that will be treated. In this way, physicians were able to visualize a better way to perform the operation and even train the action plan, before starting the surgery or treatment on the patient, then knowing the best way to proceed in view of the risk that lies ahead.

This orthopedic technology has been used for some time in the treatment of dogs and cats at the University of Pennsylvania, Ryan Veterinary Hospital, Philadelphia, USA. Through the Smart Neuro 3D printer, they are able to recreate anatomical models through clinical cases in orthopedics and animal neurology, which will aid in the understanding and treatments of spinal factions. Polylactic Acid (PLA) is one of the most used 3D printing materials worldwide. It has many advantageous features, highlighting good charge absorption, in addition to being easily printed. Having a good finish, which adds value by improving the look of the final product. The PLA filament has excellent surface quality (Figure 1).

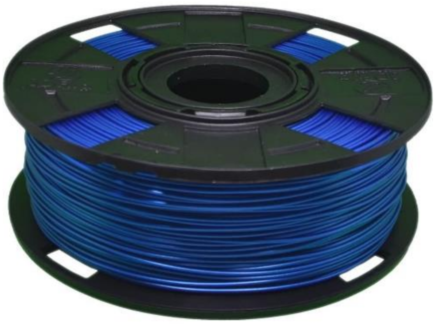

Figure 1: PLA
Source: 3d fila

The PLA filament is still a great material, if environmental characteristics are taken into account, as it comes from corn starch, which is a renewable raw material (Munteanu, Aytac, Pricope, Uyar & Vasile, 2014). As it is a biodegradable element, it has significant environmental advantages. Starch, because of its composition, when transformed into PLA and then printed on a product, has a sweet smell, which is then most often pleasant to the human being's sense of smell.

Just like every product that is characterized as the basis for the development of another product, PLA filament has been tested and approved for use in several brands of 3D printer around the world. As the tables that present characteristics and comparison numbers of the 3 main materials used in 3D printers follow, it is highlighted that for the creation of the tables, the materials compared were PETG (Polyethylene Glycol), ABS (Acrylonitrile Butadiene Styrene) and PLA (Polylactic Acid). Thus, the filament is preferred in the national and international market, as it presents superior values in all the aspects presented above. Thus, it is of great advantage and safety over other raw materials, in which the PLA filament is marketed by NatureWorks, an American company that holds the title of being the largest producer of PLA in the world. The PLA (Polylactic Acid) filament during printing and even for storage, has parameters to be followed, that is, during printing it must be at a temperature of 200°C to 220°C. The temperature of the table where the printing of a given project is carried out must be at 60°C. As the element is produced on top of a base (table), it is recommended that the material be fixed on the table, in order to avoid movements that displace the product and thus damage the printing and consequently the final product (Rocha, 2020), (Figure 2).

Propriedades Materia Prima 3D LAB - Grãos			
Propriedades	PLA	ABS Premium	PETG
Densidade	1,24 [g/cm3]	1,04 [g/cm3]	1,27 [g/cm3]
Temp. Fusão	185 [°C]	220 [°C]	240 [°C]
Tg	60 [°C]	100 [°C]	85 [°C]
Tensão de Escoamento	66 [Mpa]	38 [Mpa]	51 [Mpa]
Resistencia a Flexão	130 [Mpa]	66 [Mpa]	72 [Mpa]
Modulo de Elasticidade	4350 [Mpa]	2200 [Mpa]	2120[Mpa]
Resultado ensaio de Tração segundo a Norma ASTM D 638 - Corpo de provas Impresso			
Propriedades	PLA	ABS Premium	PETG
Tensão de Escoamento	24,8 [Mpa]	14,7[Mpa]	18,6 [Mpa]
Modulo de Elasticidade	1896,0 [Mpa]	1335,9 [Mpa]	1067,9 [Mpa]
Tensão de Ruptura	46 [Mpa]	29 [Mpa]	32,6 [Mpa]
Alongamento	3,69 [%]	7,08 [%]	7,74 [%]
Resultado ensaio de Dureza segundo a Norma ASTM D 2240 - Corpo de provas Impresso			
Dureza Shore D	85 [Shore D]	74 [Shore D]	75 [Shore D]
Resultado ensaio HTD segundo a Norma ISO 75 - Corpo de provas Impresso			
Temperatura HDT	55,11°C	86,13°C	67,3 °C

Figure 2: Material Properties Table for 3D Printer.
Source: 3dlab

2.3 About Servo Motors

The servo motor was developed for applications in electronic components and robotic projects, being also used in model aircraft for prototyping platforms, featuring the ARM, PIC, AVR and Arduino. The differential of this component is its ability to perform 180° rotations, with a maximum torque resistance being 4.2 kg/cm at 6V. With this, it generates greater convenience and several possibilities for adaptation to the most diverse projects in which the use of the servo motor is intended. The component can be easily installed as it has perforated tabs and has a wire of approximately 280mm, having a connector that brings advantages during its installation and use. It comes with a kit containing accessories. The operating speed can be 60/0.23 degrees/second with 4.8V and 60/0.19 degrees/second with 6.0V, so its torque is 3.2k-cm and 4.2kg-cm, respectively. Its movement is characterized in such a way as to perform a 180° turn, adapting it to back and forth movements, this movement occurs through bushing-type bearings, its purchase specification is presented by the Futuba S3003 nomenclature (Ribeiro, 2020) (Figure 3).

Figure 3: Servo motor
Source: Deltakit

2.4 Arduino Board

The Arduino R3 is a differential in the board market, as it does not have an FTDI chip that performs the serial signal conversion. Instead, the ATmega8U2 is used, which is programmed to convert the serial signal to the USB platform, or the other way around. The Arduino Uno board used is the R3 which is a microcontroller made from the ATmega328, which has 14 digital input and output pins, of which six can be used as PWA (Progressive Web App) outputs, and six as analog inputs. It also has a 16MHz oscillated crystal with a USB input, in addition to this input it has a power input with an ICSP-type connection and a reset button. All components described are capable of supporting the microcontroller and connecting to a computer behind the USB port or being powered by an external power source such as a battery. Its physical characteristics are 68.58 mm wide and 53.34 mm long, with the USB and power connectors extending beyond these dimensions (Sono, 2020). (Figure 4).

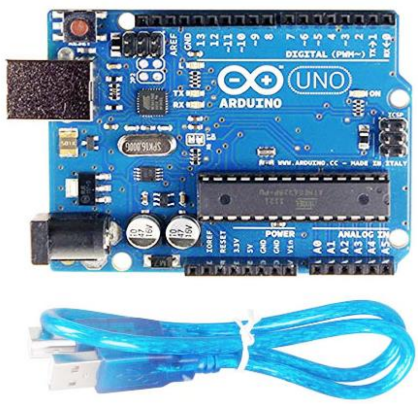

Figure 4: Arduino Board
Source: Enhanced Radid Devices

3. PROJECT METHODOLOGY AND RESULTS

This work is characterized as a technical report, with an action-research procedure. From bibliographical research, the necessary theoretical basis for the development of an operational prosthesis of good quality and durability was obtained.

The multidisciplinary electronics laboratory was used during all the creation and development processes of the project, as it provided all the necessary structure, from benches to adequate equipment for the configuration of the electronic components contained in the prosthesis, computers with access to the necessary Software for the printing and configuration data for the 3D printer.

The researchers who worked on this report for several months in the school environment were: Lucas Daniel researching and assembling the structure of electronic circuits contained in the work, studying which would be the best component to exercise hand movements, Camila Maiara looking for sources of references for the writing of the project body, noting the processes and goals achieved throughout the process. Together they sought a deeper understanding of 3D printing and codes that were later used.

Under the guidance and attention of Professor Felipe Luz and from several calculations of strength, resistance and compatibility with the FATEC 3D printer, it was possible to choose the appropriate material for our prosthesis. Professor Victor Tedeschi provided guidance on the prototype printing process, preparation of codes for printing and data transformation into the language used by the printer.

Two computers were used, the main one being the Dell Inspiron 3583 notebook, with a CORE i5-8265U processor, 8.00 GB of installed RAM and a 64-bit Windows 10 operating system. The secondary is a Sansung X30 notebook with a CORE i5-10210U processor, 8.00 GB of installed RAM and a 64-bit Windows 10 operating system where the entire theoretical and printing project was developed.

To perform the printing of this first prototype, the Stella 2 printer, from the company Boa Printing 3D, was used, as in addition to being a national company, it has high quality during printing and a low final cost, which makes the finished product even more viable. Stella 2 performs 3D printing through 3 step motors that move in three dimensions, its programming is done through a Software that transforms and encodes our language to the C++ language that the printer understands. The prints are molded on the glass surface of the printer, but before starting the printing process it is necessary to apply a thin layer of stick glue on the glass so that during the process the part does not move.

The literary contents used throughout the process come from books, articles and reports for research and theoretical foundations. The materials used were the PLA Filament, the 3d printer and the glue stick, to produce the prototype of the hand prosthesis. In addition to these, Servo motors, an Arduino board and a computer were used to create the basic codes for the operation of hand movements, keys, wires, a protoboard board, power supply and voltage controller, to test the operation of the previously programmed movements.

The procedures developed in the preparation of the prosthesis complied with the protocol presented below.

The choice of the manufacturing process through 3D printing was made in order to make the cost feasible and make the product accessible and more resistant, bringing comfort and quality in the use of the prosthesis. Thus, the materials described below are suitable for the purpose of the project, allowing the finished and ready-to-market product to be resistant to the most diverse situations to which it is exposed (Figure 5).

Figure 5: Intended prosthesis

The prosthesis was printed on a 3D printer with PLA filament, showing good resistance, enabling great durability of the material, not needing to be changed periodically. The 3D project was developed in parts and printed individually. The pieces ending with number 1 make up the Medial Phalanxes, the pieces ending with number 2 make up the Distal phalanges and those ending with number 3 make up the distal phalanges, the number 6 refers to the carpus and metacarpus, the number 7 and 8 refer to the joints. All programming of the movements and voice command was developed on Arduino Uno® platform and servo motors.

It was later transferred to Arduino Nano®, reducing the size of components and electronic circuits located in the forearm (Figure 6).

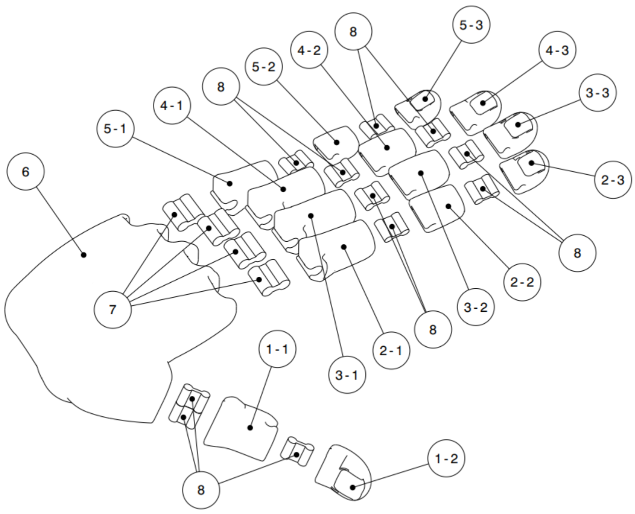

Figure 6: Movement tests

Initial tests of movements such as open, close, one, two, three, four previously programmed showed results that can be considered very good. In the first test of the second phase, a disposable cup was used to regulate the force that the prosthesis uses to exert the closing command and from this test it was possible to regulate the force exerted by the motor servos so that there is no deformation of the object. In the next test, the prosthesis was placed to hold a pen so that it does not slip from the hand and suffer deformation. During the third test, several papers were used and it was possible to program so that you can hold a single sheet of sulfite without it crumpling, as well as holding a pack of 100 and 500 sheets, without it falling. The prosthesis performed the basic movements with quality, approaching natural movements.

At this moment, this research team is working on a voice recognition system, so that it receives basic commands and can perform actions such as opening, closing and greeting, among others. All functions are being performed on a test platform, which will later be attached to an adjustable mobile forearm to be tested on an amputee.

4) CONCLUSIONS AND RECOMMENDATIONS

As the general objective established for this work, it was to produce and offer a product from the compaction of all components, such as Protobord Board, Arduino Board, servo motors and microcontrollers, used for the operation of the upper limb prosthesis, in essence, it can himself assert that he was hit consistently. The project conception, planning, execution and monitoring were coherent and consistent from the initial idea and all purposes and processes were developed in time, scope, space and cost, in accordance with the rituals of dense technological research .

In essence, the prosthesis can be recommended and implanted in the context of orthopedics, being highly usable and consequently adding a lot of value and qualities in the rehabilitation processes of amputees workers, as well as their reinsertion in the functions they performed prior to the accident that caused the amputation or removal of the limb due to medical procedures.

Throughout the entire production, the objectives of each stage that were intended to be achieved were achieved, in a sequential process, thus allowing the conclusion that the project is highly viable. Furthermore, it is characterized as an advantage for it to be implemented and has the main idea of being disseminated, thus causing greater recognition to be evidenced of the work and improvement that it is intended to generate in society and industry.

It was observed in the literature and in the information obtained from professionals, that many individuals who have suffered from amputations are unable to pay up to R$100,000 and enjoy prostheses with high mechanical technology. This project contributes to society, considering the significant cost reduction of other types of prostheses, ensuring material strength and easy maintenance. Furthermore, it does not harm the product or cause major changes in its price. In these cases, the purpose is to ensure that the amputee worker can return to his/her job with an investment of only R$2,000.00, generating the same productivity as a worker who has not suffered from the hindrance of an amputation. Thus, it adds great economic as well as social advantage to people and organizations. Added to these contributions are the potential improvement of the psychological conditions of the bearer of the product that was developed.

Thus, the developed prosthesis shows its potential, with significant contributions to quality of life and commercial viability, with receptiveness by companies and especially by those who will use the product.

This project will contribute to the advancement of biomechanics in the study of arm, forearm and hand movements, being more specific in the movements performed by the hand and how to synthesize them to recreate them artificially through servo motors, actuators, etc. With this scientific report, it will be possible to identify the ability to recreate simple and everyday movements such as holding cups, papers and even pens. Through it, it will also be possible to monitor the results of the first tests carried out with a movement of opening and closing the hand, so that in the near future it can be used as a starting point for the beginning of more specific technologies for this function.

The report also presents a significant contribution to Kinesiology, because through the movements synthesized and recreated in laboratories, it will be possible to generate and create a structure similar to the bone structure. Thus, it will be possible to contribute to the evolution of these devices, hitting the right points for each movement performed by the prosthesis. This achievement will add to the structure that we already have, with the one that will be developed in the future, bringing more and more the prosthesis to the human anatomy, both visually and physically.

The recommendation for future studies is to recreate in the laboratory a structure similar to bone and muscle, in a sustainable way and that does not harm the environment, so that all the points of movement of a hand can be adjusted. Thus, it will be possible to produce a prosthesis as faithful as possible for the amputated limb. For the development of technology in this area, there is still a lot to discover and understand about each movement that can be exercised. For each muscle that contracts and relaxes during the execution of a movement, a technology can be developed that will really meet the needs of a human being, so that it becomes accessible to the large population.

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