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ROBOTIC ORTHOSIS PROJECT TO ASSIST IN PHYSICAL THERAPY TREATMENT FOR PATIENTS WITH FINE MOTOR DIFFICULTIES

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Abstract: The hand of the human being is essential for carrying out several daily tasks. Its movement and precision in movements make it possible to manipulate objects, as well as perform complex functions that require high precision and control, such as in surgeries. Despite the great functionality of the hands, there are some diseases and traumas that cause people to lose part of their functionality, in the sense of reducing their motor skills and/or decreasing the effectiveness of the aforementioned functions. The research project is intended to develop a robotic mechanism of the exoskeleton type, involving a glove that will help people who have diseases that affect the motor actions of the hands in the treatment of diseases or traumas. Through this mechanism, physiotherapists will be able to help patients with these pathologies to carry out physical therapy activities and, consequently, these patients will be able to carry out activities of daily living with less difficulty. For the operation of the robotic mechanism, a robotic orthosis in the shape of a glove will be developed, controlled by the action of an instrumented glove. Up to the present moment of execution of the project, project drawings are being executed through CAD software, the manufacture of the exoskeleton parts of the actuation glove and for a test bench and Arduino programming for receiving signals from the control glove and the transformation of these signals to exoskeleton movement.
Keywords: Rehabilitation of movements, Robotic orthosis, Exoskeleton.

INTRODUCTION

The human hand is essential for carrying out various tasks of daily life. Its movement is precise and enables the manipulation of objects, as well as performing complex functions that require high precision and control, such as surgery. Recently, Chao et al. (1989) demonstrated that the hand is one of the most essential parts of the human body, because through it it is possible to perform a large number of functions, such as: prehension, perception, exploration and manipulation.

Despite the great functionality of the hands, there are some diseases and traumas that cause people to lose part of the functionality of the hands, in the sense of reducing their motor skills or decreasing the effectiveness of the aforementioned functions. Among the diseases that affect the hands more frequently, Rheumatoid Arthritis stands out, a chronic disease in which the immune system gets confused and starts to attack the body itself, mainly the joints, causing swelling, stiffness and pain in the joints, limiting the movements. According to research by Folha de Londrina, this disease affects approximately 1% of the population, that is, 2 million people (Folha de Londrina, 2017).

Other popularly known diseases are Tendinitis, Carpal Tunnel Syndrome and Dupuytren's Contracture disease. Tendinitis is an inflammation of the tendons of the hands, which can cause trigger finger that involuntarily stretches the finger; the main cause is related to repeated movements that can be the cause of tendinitis, developing symptoms such as swelling, tingling, burning and pain in the hands, even with small and light movements (Pinheiro, 2017). Carpal Tunnel Syndrome is an injury involving the nerve that passes through the wrist, causing chronic and painful pain, affecting the motor capacity of the hand and causing weakness in the extremities and severe pain that extends to the arm. Dupuytren 's contracture disease, which happens when there is a contraction in the connective tissue in the palm of the hand; this disease affects the movement of the ring, middle and little fingers, causing loss of mobility in the hand (Cipolli, 2015).

As it was mentioned above there is also the existence of traumas that cause loss of movement in the hand, according to Mattar (2001) traumas in the hands can be divided into incised, cut - blunt, crushing, avulsion and complex injuries. Incised and blunt wounds generally do not cause extensive injury and require minor debridement. Traumas caused by crushing are those that require debridement in the affected area and the removal of all crushed tissue. Avulsion traumas are said to be the most complicated, as it is difficult to define how far the actual extent of tissue impairment goes; in this wound, it is necessary to determine the boundary between normal and pathological tissue. Finally, complex traumas are those that involve injuries to multiple structures and tissues of the hand.

After having said this explanation about diseases and traumas, it is noticeable the great importance of studying and developing new products in the area of robotics, as well as the prototype presented in this document, which are capable of improving the lives of people who suffer from diseases or traumas. in the hands, which hinder their motor actions, consequently affecting their daily tasks.

Thus, the present research project is intended to develop a robotic mechanism of the exoskeleton type, which is an electromechanical device intended to supply or correct the morphological alteration of an organ, a member or a segment of a member or to impairment of a body function. This involves a glove that will help people who have diseases or trauma in their hands. Through this mechanism, physiotherapists will be able to help people with these pathologies to carry out physiotherapeutic treatment activities, consequently, these patients will be able to carry out their day-to-day activities with less difficulty.

In addition to knowledge about trauma and disease, I also need to understand the composition of the hand, its bones and connections.

From the human body, the human hands stand out as a mechanism divided between Carpus (wrist), Metacarpus (back and palm) and phalanges (fingers). Hands have the following characteristics (according to (Sanchez, 2008)):

- Prone supination: rotational movements of the forearm around a longitudinal centerline and flexion or extension movements of the elbow or wrist. This movement allows the hand to adapt to different circumstances.
- Flexion and closure of the fingers: this is a very important function of the hand, made possible by the superimposition of the three joints of each finger and the existence of extrinsic polyarticular muscles.
- Thumb Opposition: Situated in front of the palm and other fingers, the thumb can be used in conjunction with the other fingers as a claw to manipulate objects, particularly this is a natural effect between the thumb and index fingers.

This part of the human body has 27 bones and many connections, which allow the occurrence of different types of movements. The main joints are the wrist joint, which uses the carpal bones, connecting the hand itself with the forearm; metacarpophalangeal joint that is of the synovial type, which are those in which the bone surface is covered by an articular cartilage and which are joined by ligaments and covered by a membrane called the synovial membrane, according to (Mota, 2020), this joint connects between the metacarpal bones and phalanges; and the interphalangeal joint, which is also of the synovial type, connecting the phalanges.

A very important criterion for hand movement is the degree of freedom, which is the minimum number of independent coordinates to describe the position of a system. The human hand has four degrees of freedom for each finger, with the exception of the thumb, which has five, three for flexion and extension and one for adduction and abduction, and two degrees of freedom for the wrist, as described in (Nargem, 2007). To calculate the degree of freedom of each finger of the hand, kinematics was used, an area of physics that studies the movements of bodies, without addressing the cause, relating position, velocity and acceleration, more specifically we used kinematic equations, for the project's exoskeleton, which were developed using the Python programming language and are presented in the topic Results and discussions.

MATERIALS AND METHODS

DEVELOPMENT OF THE ROBOTIC MECHANISM

Dealing with the robotic mechanism, its structure is composed of two gloves, where one acts as a sensorial means (left hand) and the other as a means of action (left hand), being the same initially constituted of plastic material, which is normally used as a PPE, requiring further detailed research to find out what type of material the glove must have, so that it can support the exoskeleton attachment that will be mounted on it, and at the same time offer comfort to those who use it. The dimensions for the constituent parts of the exoskeleton will be defined from the studies according to (Paschoarelli et all, 2010) and from the measurement of the dimensions of the hand by the professor coordinating the research.

PROTOTYPE DESIGN DEVELOPMENT

To carry out the manufacture of the prototype, sketches were first made, which were reflections of discussions among the participants on the best way to develop the process of executing this stage. Subsequently, detailed drawings of the entire structure were made, and this execution was divided into two stages: CAD drawings of the structure: where the drawings of orthographic views of the structure were made, using the AutoCAD software; and 3D drawings of the prototype: stage in which the three-dimensional drawings of the entire prototype were developed using the Solid Edge® ST6 and SolidEdge 2020 software. in the choice of dimensions of the glove and its constituent parts. The 3D drawings developed in the prototype design development stage are aimed at manufacturing the exoskeleton parts of the drive sleeve and manufacturing the test hand parts for the movements of the mechanism to be developed. In Fig. 1 it is possible to visualize, respectively from top to bottom, the three-dimensional drawings of the exoskeleton of the phalanges for the index finger, the exoskeleton of the phalanges for the middle finger and the exoskeleton of the phalanges for the little finger.

In Fig. 2 below, an assembly drawing of the exoskeleton of the phalanges for the ring finger is shown as an example. The proximal interphalangeal and distal interphalangeal joints will be represented on the exoskeleton by the articulation pins.

DEVELOPMENT OF TEST BENCH DESIGN DRAWINGS

In addition to the exoskeletons of the phalanges, the prototype structure test bench was designed, where the base of the exoskeleton traction cables was developed, which can be seen in Fig 3. In general

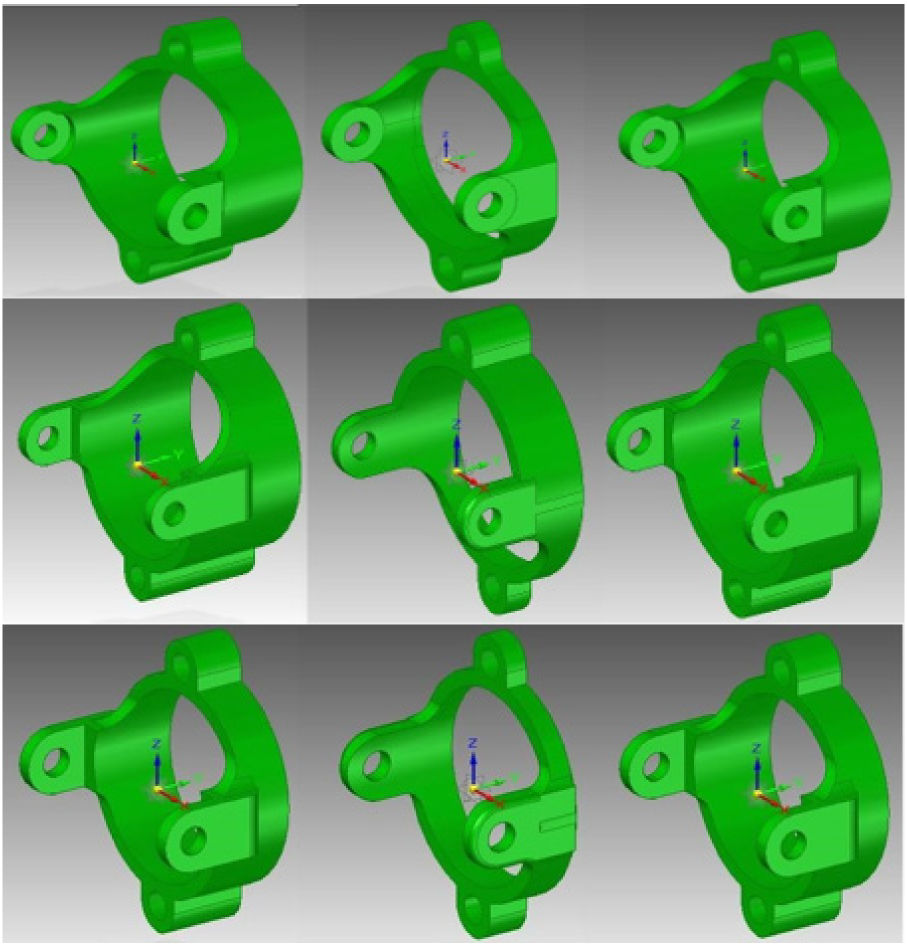

Figure 1. Three-dimensional drawings of the exoskeleton of the phalanges of the index, middle and little fingers, from top to bottom, respectively.

Source: Authors.

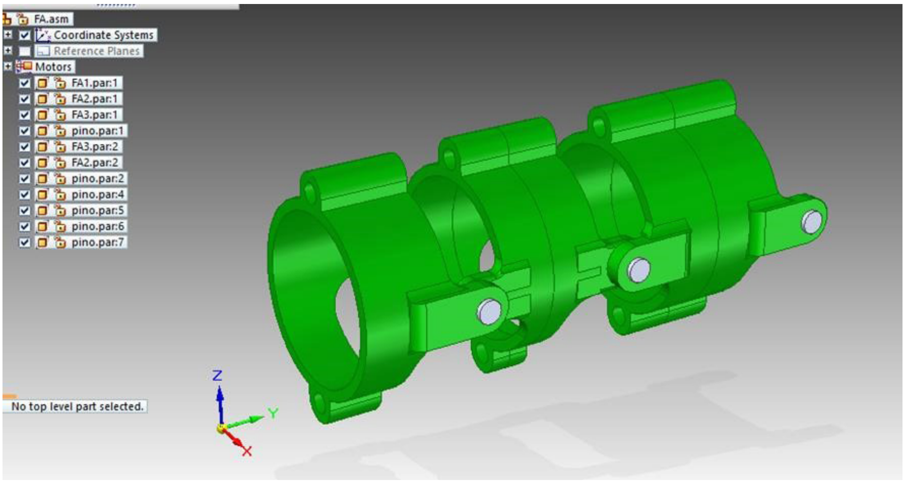

Figure 2. Three-dimensional assembly drawings of the exoskeleton for the ring finger.

Source: Authors.

terms, the exoskeleton drive mechanism is composed of a motor base, a set of bevel gears and a traction drum, which are duly illustrated in Figs. 3, 4 and 5 below. After the development of the design drawings, all the developed files were converted, which were changed from design drawings to 3D printer printing files, a step which is usually known as slicing.

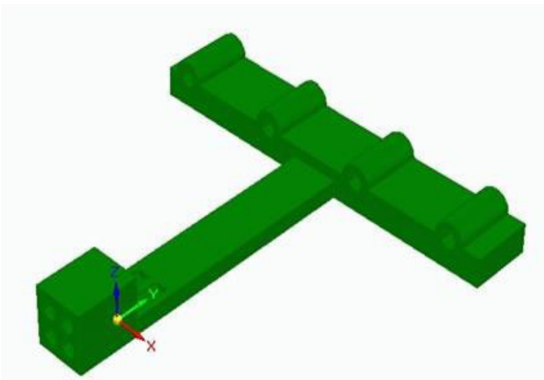

Figure 3. Three-dimensional drawing of the base of the cables. Source: Authors.

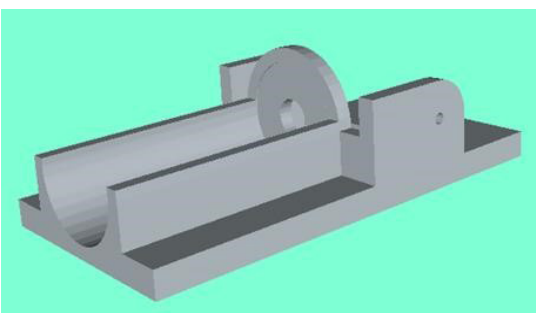

Figure 4. Three-dimensional drawing of the engine base. Source: Authors.

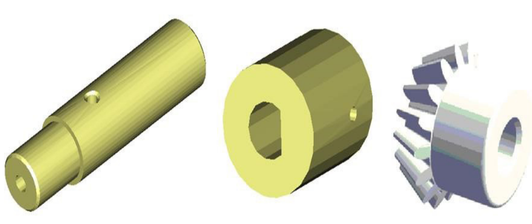

Figure 5. Three-dimensional drawings of the bevel gears and drum of the drive mechanism. Source: Authors.

DEVELOPMENT OF ELECTRONIC SCHEMATICS AND PROGRAMMING

Another stage of the practical development of the developed project was the making of the electronic scheme and programming, where for the development of the electronic drive and control system the following hardware components were necessary: Arduino Mega 2560 microcontroller, Flex sensors, load sensors, Bridge H L298N, male-female and male-male jumpers, 6v DC motor with Encoder and 1:34 reduction, resistors and 10K logarithmic potentiometer.

For the development of the hardware of the prototype, the electronic schematic of the same was first developed by the members of the group, a step in which the open-source software Fritzing was used, this schematic being used as a resource in order to simulate how the components would be arranged electronics. In Fig. 6 below shows the electro-electronic scheme developed and designed for the prototype.

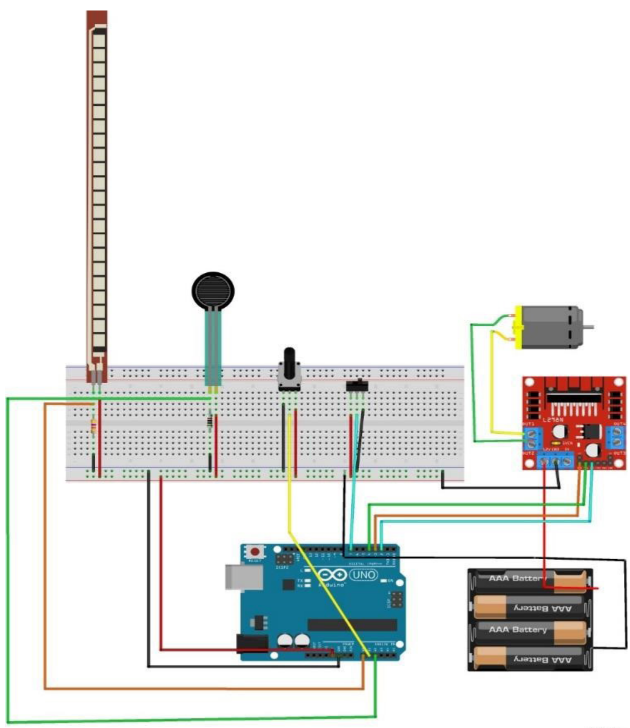

Figure 6. Electroelectronic schematic for the prototype. Source: Authors.

RESULTS

KINEMATIC ANALYSIS

The kinematic analysis was obtained through a programming code, made in the Python 3 language, using the Python symbolic library, called Sympy. Due to the use of symbolic computation, it became necessary to assign symbolic values to the lengths of the phalanges. The assigned symbolic dimensions can be seen in Fig.7. Note that in this figure only the dimensions related to the index finger are represented, for the other fingers just change the letter "i" in the names of the lengths by "M", "a" and "m" for the middle, ring and finger fingers. minimum, respectively.

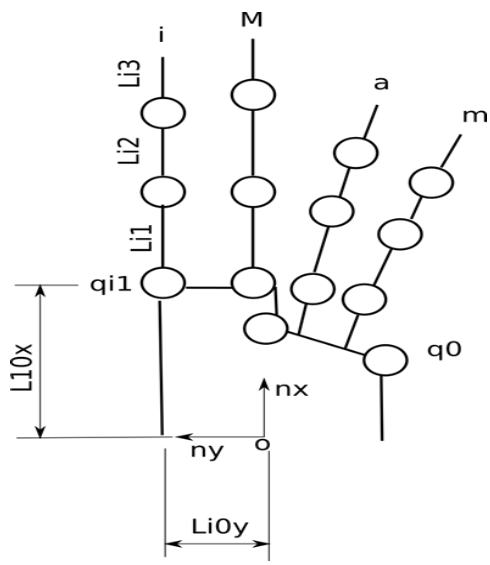

Figure 7. Symbolic parameters.

Source: Authors.

Below are the kinematic equations for the position, velocity, and acceleration of the index, middle, and little fingertip. These equations were obtained as one of the outputs of the code.

$$L_{i0x}\hat{n}_x + L_{i0y}\hat{n}_y + L_{i1}\hat{a}_{i_x} + L_{i2}\hat{b}_{i_x} + L_{i3}\hat{c}_{i_x} \quad (1)$$

$$-L_{i1}\dot{q}_{i1}\hat{a}_{i_z} - L_{i2}(\dot{q}_{i1} + \dot{q}_{i2})\hat{b}_{i_z} - L_{i3}(\dot{q}_{i1} + \dot{q}_{i2} + \dot{q}_{i3})\hat{c}_{i_z} \quad (2)$$

$$-L_{i1}\dot{q}_{i1}\hat{a}_{i_x} - L_{i1}\ddot{q}_{i1}\hat{a}_{i_z} - L_{i2}(\dot{q}_{i1} + \dot{q}_{i2})^2\hat{b}_{i_x} - L_{i2}(\ddot{q}_{i1} + \ddot{q}_{i2})\hat{b}_{i_z} - L_{i3}(\dot{q}_{i1} + \dot{q}_{i2} + \dot{q}_{i3})^2\hat{c}_{i_x} - L_{i3}(\ddot{q}_{i1} + \ddot{q}_{i2} + \ddot{q}_{i3})\hat{c}_{i_z} \quad (3)$$

Where: L_{i0x}, L_{i0y}, L_{i1}, L_{i2}, L_{i03} are the length of the index finger; q_{i1}, q_{i2} and q_{i3} refer to the index finger angles; $\hat{n}_x$, $\hat{n}_y$ are the unit vectors of the inertial frame; and $\hat{a}_{i_x}, \hat{a}_{i_z}, \hat{b}_{i_x}, \hat{b}_{i_z}, \hat{c}_{i_x}$ and $\hat{c}_{i_z}$ are the unit vectors of the movable references fixed in each phalanx of the index finger.

Eq. (1), Eq. (2) and Eq. (3) refer to the index finger, being: Eq. (1) the calculation of the position of the tip of the index finger relative to a point in the middle of the hand, Eq. (2) the calculation of the velocity of the tip of the index finger and Eq. (3) the calculation of the acceleration of the tip of the index finger.

$$L_{M0x}\hat{n}_x + L_{M0y}\hat{n}_y + L_{M1}\hat{a}_{M\,x} + L_{M2}\hat{b}_{M_x} + L_{M3}\hat{c}_{M_x} \quad (4)$$

$$-L_{M1}\dot{q}_{M1}\hat{a}_{M_z} - L_{M2}(\dot{q}_{M1} + \dot{q}_{M2})\hat{b}_{M_z} - L_{M3}(\dot{q}_{M1} + \dot{q}_{M2} + \dot{q}_{M3})\hat{c}_{M_z} \quad (5)$$

$$-L_{M1}\dot{q}_{M1}\hat{a}_{M_x} - L_{M1}\ddot{q}_{M1}\hat{a}_{M_z} - L_{M2}(\dot{q}_{M1} + \dot{q}_{M2})^2\hat{b}_{M_x} - L_{M2}(\ddot{q}_{M1} + \ddot{q}_{M2})\hat{b}_{M_z} - L_{M3}(\dot{q}_{M1} + \dot{q}_{M2} + \dot{q}_{M3})^2\hat{c}_{M_x} - L_{M3}(\ddot{q}_{M1} + \ddot{q}_{M2} + \ddot{q}_{M3})\hat{c}_{M_z} \quad (6)$$

Where: L_{M0x}, L_{M1x}, L_{M2x} and L_{M3x} are the lengths of the middle finger; q_{M1}, q_{M2}, q_{M3} give the angles of the middle finger; and $\hat{a}_{M_x}$, $\hat{a}_{M_z}$,, $\hat{b}_{M_x}$, $\hat{b}_{M_z}$, $\hat{c}_{M_x}$ and $\hat{c}_{M_z}$ are the unit vectors of the mobile references fixed in each phalanx of the middle finger.

Eq. (4), Eq. (5) and Eq. (6) refer to the middle finger, being: Eq. (4) the calculation of the position of the tip of the middle finger relative to a point in the middle of the hand, Eq. (5) the calculation of the velocity of the tip of the middle finger and Eq. (6) the calculation of the acceleration of the middle fingertip.

$$L_{a0x}\hat{n}_x + L_{a0y}\hat{n}_y + L_{a0}\hat{n}_{2\,x} + L_{a1}\hat{a}_{a_x} + L_{a2}\hat{b}_{a_x} + L_{a3}\hat{c}_{a_x} \tag{7}$$

$$-L_{a0}\dot{q}_{a1}\hat{n}_{2_z} - L_{a1}(\dot{q_0} + \dot{q_{a1}})\hat{a}_{a_z} - L_{a2}(\dot{q_0} + \dot{q_{a1}} + \dot{q_{a2}})\hat{b}_{a_z} - L_{a3}(\dot{q_0} + \dot{q_{a1}} + \dot{q_{a2}} + \dot{q_{a3}})\hat{c}_{a_z} \tag{8}$$

$$-L_{a0}\dot{q}_0\hat{n}_{2_z} - L_{a0}\ddot{q}_0\hat{n}_{2_z} - L_{a1}(\dot{q_0} + \dot{q_{a1}})^2\hat{a}_{a_x} - L_{a1}(\ddot{q_0} + \ddot{q_{a1}})\hat{a}_{a_z} - L_{a2}(\dot{q_0} + \dot{q}_{a1} + \dot{q}_{a2})^2\hat{b}_{a_x} - L_{a2}(\ddot{q_0} + \ddot{q}_{a1} + \ddot{q}_{a2})\hat{b}_{a_z} - L_{a3}(\dot{q}_o + \dot{q}_{a1} + \dot{q}_{a2} + \dot{q}_{a3})^2\hat{c}_{a_x} - L_{a3}(\ddot{q}_0 + \ddot{q}_{a1} + \ddot{q}_{a2} + \ddot{q}_{a3})\hat{c}_{a_z} \tag{9}$$

Where: L_{a0x}, L_{a0y}, L_{a0}, L_{a1}, L_{a2} and L_{a3} are the lengths of the ring finger; $\dot{q}_0$, $\dot{q_{a1}}$, $\dot{q}_{a2}$ and $\dot{q}_{a3}$ are the angles of the ring finger; $\hat{n}_{2\,x}$ and $\hat{n}_{2_z}$ are unit vectors of the auxiliary mobile reference frame for the ring and little fingers; and $\hat{a}_{a_x}$, $\hat{a}_{a_z}$, $\hat{b}_{a_x}$, $\hat{b}_{a_z}$, $\hat{c}_{a_x}$ and $\hat{c}_{a_z}$ are the unit vectors of the movable references fixed in each phalanx of the ring finger.

Eq. (7), Eq. (8) and Eq. (9) refer to the ring finger, being: Eq. (7) the calculation of the position of the tip of the ring finger in relation to a point in the middle of the hand, Eq. (8) the calculation of the velocity of the tip of the ring finger and Eq. (9) the calculation of the acceleration of the tip of the ring finger.

$$L_{m0x}\hat{n}_x + L_{m0y}\hat{n}_y + L_{m0}\hat{n}_{2\,x} + L_{m1}\hat{a}_{m_x} + L_{m2}\hat{b}_{m_x} + L_{m3}\hat{c}_{m_x} \tag{10}$$

$$-L_{m0}\dot{q}_{a1}\hat{n}_{2_z} - L_{m1}(\dot{q_0} + \dot{q_{m1}})\hat{a}_{m_z} - L_{m2}(\dot{q_0} + \dot{q_{m1}} + \dot{q_{m2}})\hat{b}_{m_z} - L_{m3}(\dot{q_0} + \dot{q_{m1}} + \dot{q_{m2}} + \dot{q_{m3}})\hat{c}_{m_z} \tag{11}$$

$$-L_{m0}\dot{q}_0\hat{n}_{2_z} - L_{m0}\ddot{q}_0\hat{n}_{2_z} - L_{m1}(\dot{q_0} + \dot{q_{m1}})^2\hat{a}_{m_x} - L_{m1}(\ddot{q_0} + \ddot{q_{m1}})\hat{a}_{m_z} - L_{m2}(\dot{q_0} + \dot{q}_{m1} + \dot{q}_{m2})^2\hat{b}_{m_x} - L_{m2}(\ddot{q_0} + \ddot{q}_{m1} + \ddot{q}_{m2})\hat{b}_{m_z} - L_{m3}(\dot{q}_o + \dot{q}_{m1} + \dot{q}_{m2} + \dot{q}_{m3})^2\hat{c}_{m_x} - L_{m3}(\ddot{q}_0 + \ddot{q}_{m1} + \ddot{q}_{m2} + \ddot{q}_{m3})\hat{c}_{m_z} \tag{12}$$

Where: L_{m0x}, L_{m0y}, L_{m0}, L_{m1}, L_{m2} and L_{m3} are the lengths of the little finger q_o, q_{m1}, q_{m2} and q_{m3} are the angles of the little finger; and $\hat{a}_{m_x}$, $\hat{a}_{m_z}$, $\hat{b}_{m_x}$, $\hat{b}_{m_z}$, $\hat{c}_{m_x}$ and $\hat{c}_{m_z}$ are the unit vectors of the movable references fixed in each phalanx of the little finger.

Eq. (10), Eq. (11) and Eq. (12) refer to the little finger, being: Eq. (10) the calculation of the position of the tip of the little finger in relation to a point in the middle of the hand, Eq. (8) the calculation of the velocity of the tip of the little finger and Eq. (9) the calculation of the acceleration of the tip of the little finger.

PROTOTYPE MANUFACTURING AND TEST BENCH

After the project drawings were made, the manufacturing phase of the parts and the prototype began. First, the parts for the mechanism to be developed and other parts of the prototype to be used on the test bench were manufactured in the 3D printer. In Figs. 8, 9 and 10 show pictures of the parts for assembling the test bench:

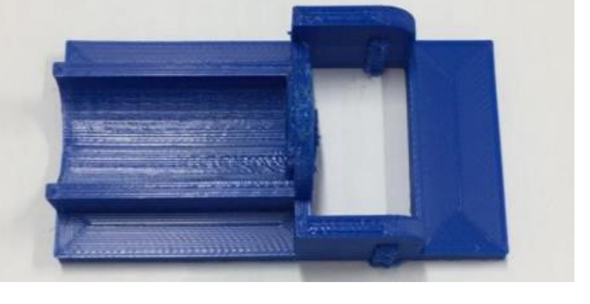

Figure 8. Photo of the motor base and mechanism manufactured in the 3D printer.

Source: Authors.

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Figure 9. Photo of the bevel gears (above) and traction drum (below) manufactured in the 3D printer.

Source: Authors.

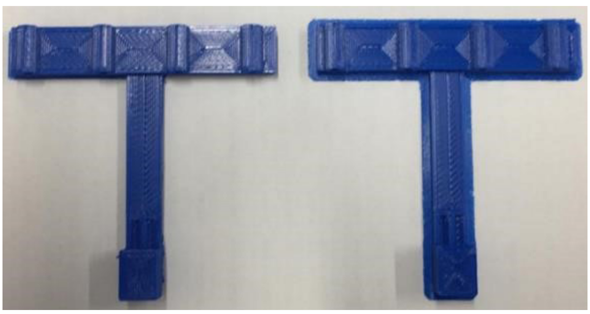

Figure 10. Photo of the bases of the traction cables manufactured in the 3D printer.

Source: Authors.

HARDWARE DEVELOPMENT

The prototype circuits were assembled, according to the electronic scheme shown in Fig. 6, in order to test in practice, the functioning of the electronic components according to the developed programming. Fig. 11 shows how the electronic circuit for the control hand and drive motor is developed.

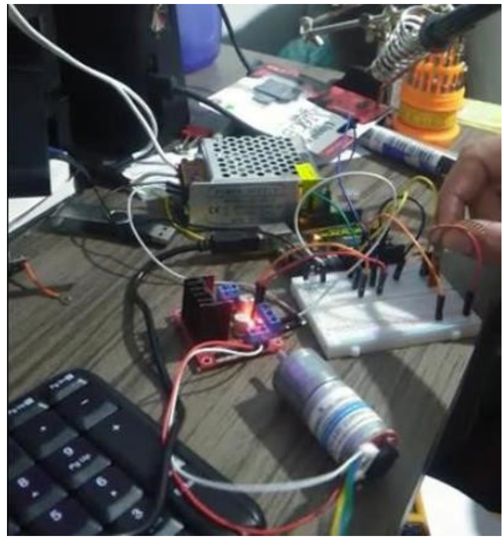

Figure 11. Electronic devices on a *breadboard* connected to an Arduino board to control the hood prototype. Source: Authors.

Tests are also being carried out for the sensors, as can be seen in Fig. 12:

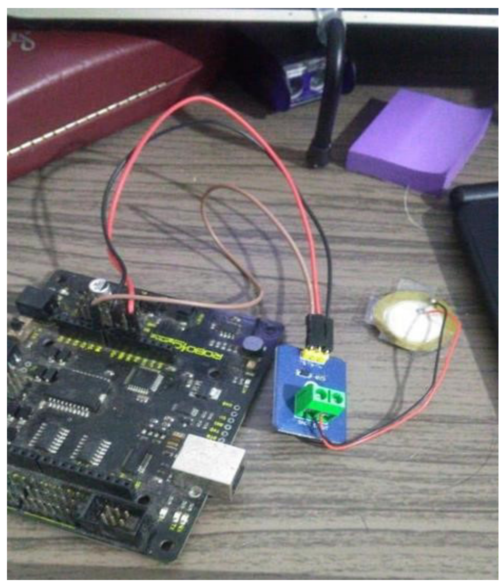

Figure 12. Hardware developed for the control hand (piezoelectric sensors).

Source: Authors.

ASSEMBLY AND TESTING ON THE BENCH

The electric motor was assembled and the gears and drum were assembled at the base of the mechanism, followed by a test run on the gears and drum. After this test, the constituent parts of the bench were assembled on its base, composed of a piece made of wood to support and fix them, which can be seen in Fig. 13:

The test bench occupied the function of the human arm, so that it was possible to carry out the functioning tests. With it, it was possible to test the functioning of the programming, highlighting the achievements and needs that need to be worked on. In Fig. 14 shows the video of the 1st test being performed on the test bench. The mechanism was commanded through the control glove to close the exoskeleton fingers in order to move a bottle of water containing 200 ml.

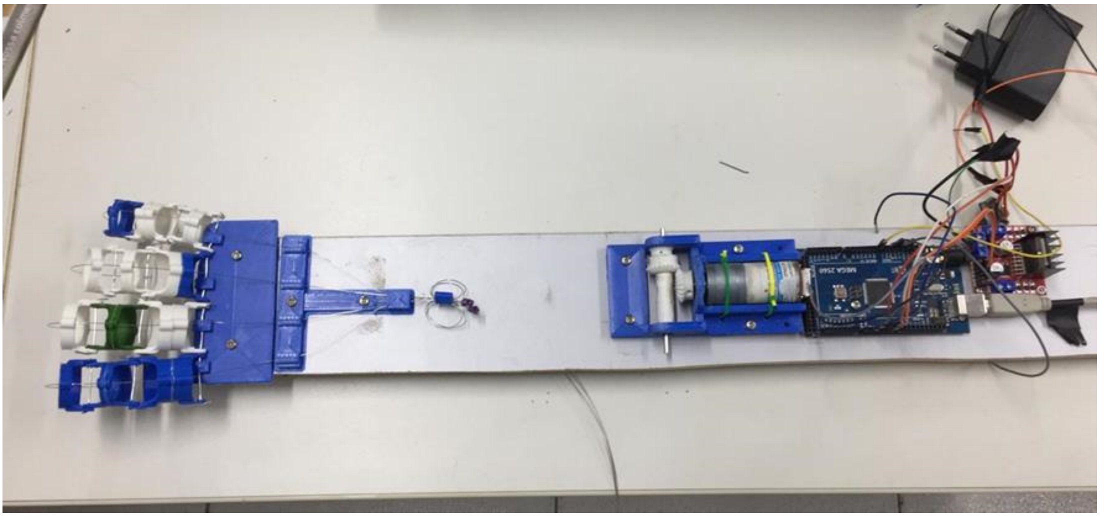

Figure 13. Assembled test bench. Source: Authors.

Figure 14. Function test of the test bench mechanism. Source: Authors.

CONCLUSIONS

Through the CAD drawings carried out, it was possible to obtain all the necessary components for the composition of the equipment, highlighting initial reflections on the best way to prepare such components. It must be noted that the designs throughout the construction underwent several modifications to meet the initial expectations. In the end, the drawings enabled the effective and accurate printing of the components. Through Python programming, it was possible to carry out a kinematic study of the exoskeleton's phalanges.

The main programming was developed to convert the analog signals coming from the flex sensor and, through the programming loaded in the Arduino, transform these values into the flexion angle of the fingers of the control hand. For this purpose, the programming was developed and adjusted in such a way that it could be verified that the resulting signals correctly read the angles described by the flex sensor. Thus, the sensor reading was converted into an angle value and the behavior of the sensor and reading was verified in terms of variation, amplitude, oscillations and response time.

Effective communication between the instrumented glove and the exoskeleton was achieved (partially). With the movement of the glove, the information captured by the Arduino made it possible to move the exoskeleton on the test bench. However, the composition of the programming is still in progress, in order to achieve the objective of developing a robotic glove drive control that allows the gripping and flexion action with greater intensity of strength to the glove user. Through programming it was possible to develop a programming in Arduino to receive signals from the piezoelectric sensor to be placed in the control glove for sensing the load in the hand.

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