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LOW-COST DATA GLOVE FOR ROBOTIC HAND-FOREARM TELEOPERATION SYSTEMS APPLICATIONS

Abstract. *Data glove is a device widely used in robotic teleoperation systems and in virtual or augmented reality applications. In these contexts, the correct sensing of movements of the human body is important for the management of activities in a precise and safe way. This project aims to present the development of a prototype of a low-cost and low consumption teleoperation system, capable of making human movements acquisitions from the hand and forearm of a human operator, which can be adapted for different applications. The proposed device consists of three main elements: mechanical structure printed in 3D, sensing system, and teleoperation system. The 3D structure is designed to mold human members (hand and forearm), ensuring mechanical stability and comfort to the user. The sensing of the equipment, which has the function of promoting the acquisition of data on the movement of the hand and forearm, it's composed of an inertial sensor fixed in hand, infrared sensors on flexible structures in the fingers, and a mechanical structure with a resistive sensor that interconnects the joint of the hand with the forearm. Finally, the teleoperation system developed with low consumption hardware, which processes the data from the sensors and transmits them through wireless communication (Radio Frequency).*

Keywords: *Data glove, 3D structure, wireless communication, teleoperation, robotic arm.*

1. INTRODUCTION

The interaction between humans and machines have become even easier with technological growth. An example of this interaction can be observed in the teleoperation of robotic arms by a person, such as in an activity that involves controlling the robotic arm remotely from the movements of the human body. An important aspect of the relationship between humans and machines is that such a relationship can be made both in a real environment, as the teleoperation of an industrial robot, and in a virtual environment, as occurs in training environments of critical activities, as in the medical area.

From these facts, it is observed that the development of systems capable of capturing the movements of the human arm is extremely important for applications of robotic teleoperation and virtual reality. The data glove is a system that was developed to capture the movements of human hands. The data glove can be defined as a glove that is composed of advanced technologies, capable of capturing and identifying the gestures and movements of the human arm, transmitting this data to another device of action in real time. In addition, with the aid of properly applied software, this type of structure can be applied together with Virtual Reality techniques (Zeineddine, 2008).

Briefly, the definition of Virtual Reality is given as an advanced technique of graphical interface. Thus, the user can perform immersion, navigation and/or interaction in a computer-generated three-dimensional synthetic environment, using multisensory channels (Krueger, 1991). The interface with virtual reality encompasses a highly interactive three-dimensional control of computational processes, where the user is compared to a virtual space of applications. The user also can visualize, manipulate and explore the application data in real time, using senses and the three-dimensional natural movements of the physical body (Bishop, 1992).

Teleoperation is defined as a system that has continuous and discrete control, through the teleoperator. The system composed of a teleoperator (Nof, 1999) is described as a composition of a remote unit, being the manipulator, a command unit for input of the operator commands and a communication channel, which is the connection of the command unit with the remote unit.

One of the main intentions and objectives of teleoperation is to promote the ability to control a robot at a distance, through a user, in inconvenient or unsafe situations or environments for human presence (or may affect its physical integrity) and in cases where programming an autonomous robot would be a complex task, with a certain degree of difficulty (Haiying Hu *et al*., 2005) and (van der Smagt *et al*, 2009). Moreover, in applications where robots are controlled by usual input methods, these systems can make the robot control simpler and more convenient for the user (Gadalla, Abdulla, and Seeralan, 2020).

Several schemes of teleoperation controllers are present in numerous society's area, whether in industrial environments or in medicine - also in the academic world. These schemes help humans perform challenging and dangerous tasks in remote environments, for example, in space, submarines, surgical operations, nuclear stations, drones, etc (Hokayem and Spong, 2006).

Also, to complete a teleoperation task, these mechanical contact devices continuously require unnatural movement of the hand and arm, while wearable devices, such as data gloves, can provide the robot with the most human movements. Considering these facts, with the increasing development in data gloves and the technique based on virtual reality (Fang et al., 2015), a more natural and intuitive alternative to control a robot will be developed and proposed in this work.

Therefore, the present work aims to present the elaboration of a data glove with low-cost hardware, for the execution of teleoperation tasks. Thus, each of the data glove constituent parts and all the requirements observed for their elaboration are presented. In addition, in order to evaluate the operation of the proposed device, an instance of the use of the glove for movement control of the mechanical claw is presented.

This paper is divided into four sections. The first section, in this case, gives a brief introduction (1 - Introduction). The second section, 2 – Development, is subdivided into five topics, where they represent descriptions of the development of the prototype. Finally, the section 3 - Results and 4 - Conclusions, demonstrate the results obtained and the final considerations/conclusions, respectively.

2. DEVELOPMENT

The data glove is composed of three interconnected blocks that complement each other: 3D mechanical structure, teleoperation system and sensing system, as shown in Figure 1. The mechanical structure has the function of joining all parts of the project safely and comfortably to the user. The teleoperation system is responsible for sending the glove data to external actuators, acting as a bridge for external applications. Finally, the sensing system is responsible for obtaining data on the operation of the glove. All these systems will be detailed below.

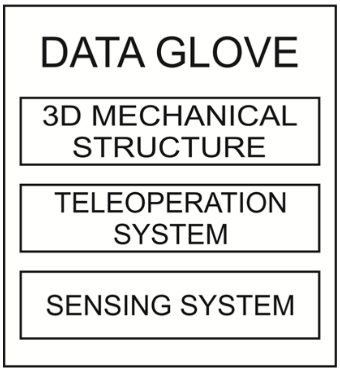

Figure 1. Schematic blocks of the parts of the data glove.

2.1 3D mechanical structure

A 3D structure has been developed capable of connecting sensing and teleoperation systems in the same structural system, allowing it to adapt comfortably and ergonomically to the limbs of the human hand and forearm. This design contains two supports to connect sensors that detect finger movement, a central base for fixing the hardware of the teleoperation system and a joint to interconnect the resistive sensor (potentiometer) between the hand and forearm to detect the flexion and extension movements between these two parts.

In the 3D modeling project of this mechanical structure, the 3D Builder software was used. The modeling was made with reference to the size of the members of the hand and forearm of one of the team members, but it is easy to modify to adapt to anyone else who has different dimensions, to ensure ergonomics in use. To better illustrate this structure, Figure 2 and Figure 3 contain 3D modeling of all the parts that make up this structure and interconnect all systems.

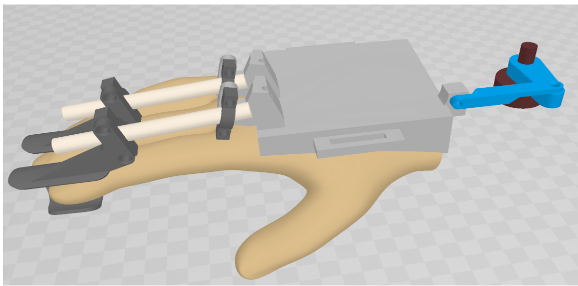

Figure 2. Data glove - 3D mechanical structure.

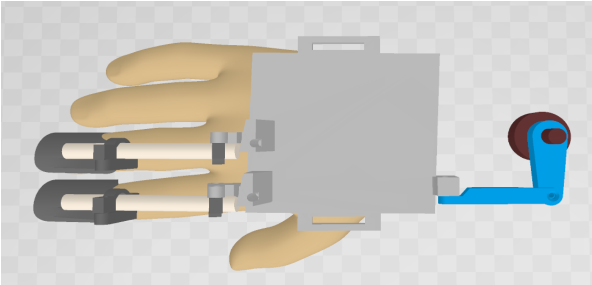

Figure 3. Data glove - 3D mechanical structure (top view).

2.2 Sensing system

The sensing system consists of three main types of sensors, each responsible for capturing the movements of each human hand and forearm member. A flexible mechanism to detect the opening and closing of the fingers of the hand was developed, and allows monitoring the displacement of the finger joints.

This mechanism consists of an opaque and flexible plastic tube with a light emitter in one of the holes of the tube and in the other hole a phototransistor to capture the incidence of light from the infrared LED. This sensor is fixed from 3D-made supports at the fingertips to the top end of the finger, so as the closing and opening movement of the finger is made, the center of the tube will bend, making the more the finger closes, there is less light passing from the light emitter to the phototransistor. The operating principle of this sensor is illustrated in Figure 4, showing the behavior of the light incidence from the emitter (LED) to the receiver (Phototransistor), when the finger is extended and flexed.

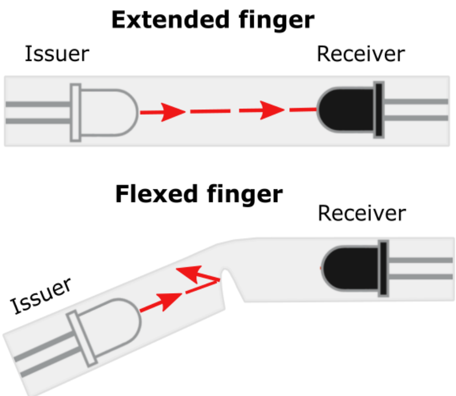

Figure 4. Illustration of the operation of the finger motion sensing sensor.

In the orientation of the movement of the human hand, an inertial sensor MPU-6050 of 6-axis of low consumption and small size was used. This sensor is positioned on the teleoperation hardware, located at the top center of the hand. The inertial sensor can detect the angular velocity around a reference axis (gyroscope) and measure linear acceleration in the direction of a reference axis (accelerometer). With this, for example, it is possible to obtain the movements of the human hand and relate them to the robotic manipulator control.

Another sensor, known as a potentiometer, is used to detect flexion and extension movements between the limbs of the hand and forearm. This sensor is fixed on the forearm and in the 3D structure, in the hand has a joint that connects this sensor in the forearm with the hand, so as these flexion and extension movements occur this joint rotates the axis of the potentiometer, modifying its resistance and varying the sensor output signal, making it possible to identify this human movement.

2.3 Teleoperation system

The teleoperation system of hardware is responsible for making the acquisition and processing of the reading data of the sensors and thus perform the transmission of this data by communication via Radio to the reception and actuation system, such as a robotic arm. The teleoperation circuit system consists of several subcircuits with different functions. In Figure 5, represent an electrical diagram of this hardware.

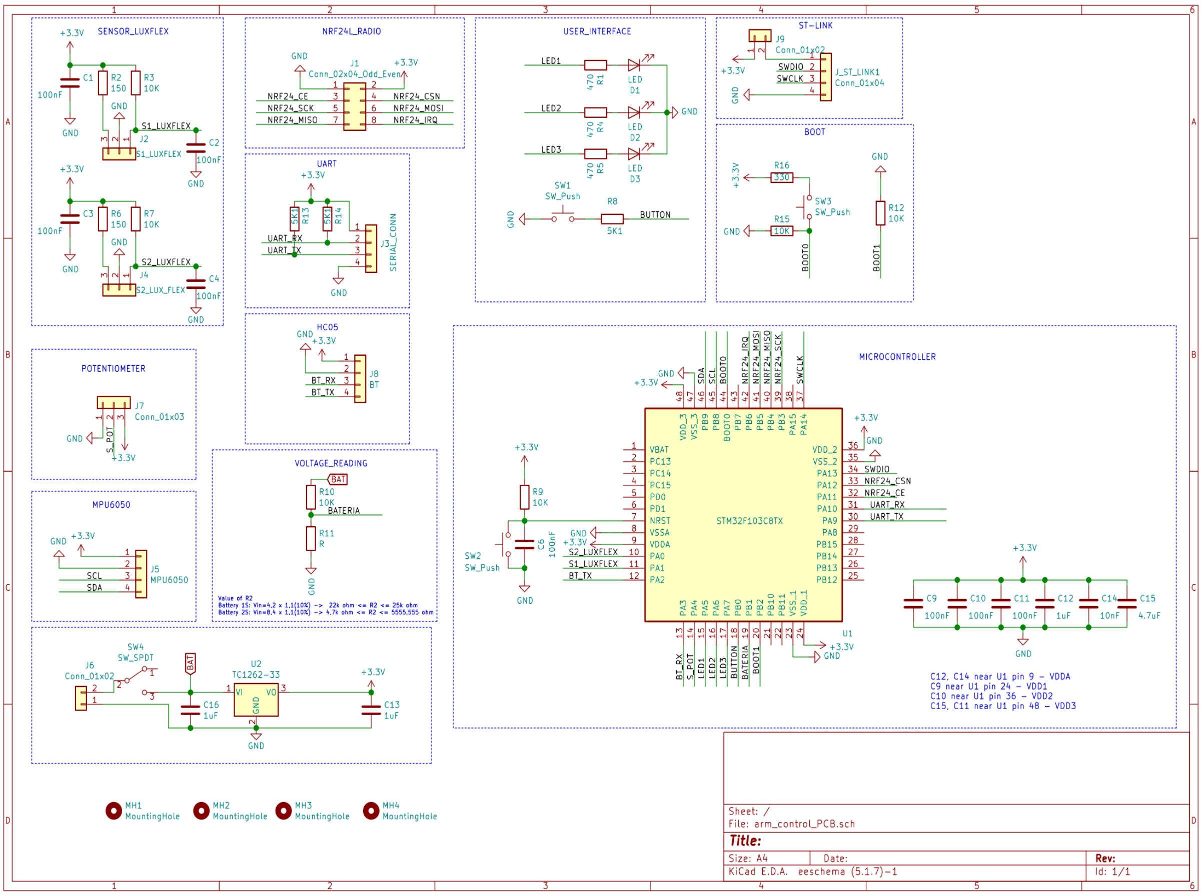

Figure 5. Electrical scheme.

This hardware has several subcircuits, each with its own functionality. In order to power, there is a voltage regulation circuit, to lower the input voltage from 3.6V to 6V to a value of 3.3V that is safe for the proper functioning of the microcontroller and sensors. The STM32F103C8T6 was used as a microcontroller, which has all the necessary resources to read the sensors, such as I2C (Inter-Integrated Circuit) interfaces for reading on the MPU-6050 inertial sensor and reading analog signals such as ADC (Analog-to-digital converter).

Also, this hardware contains communication buss such as SPI (Serial Peripheral Interface) for communication with the NRF24L01 radio and UART (Universal Asynchronous Receiver/Transmitter) to be able to use Bluetooth or Wi-Fi modules for data transmission. It also has peripherals for the human-machine interface such as LEDs and buttons to signal for example if the reading of the sensors is occurring correctly and the transmission of this data. For firmware debugging has available peripherals such as serial and Serial Wire Debug (SWD).

2.4 Firmware operation

The firmware developed for the operation of the data glove aims to get the data from all sensors, treat them and send them via radio to some external device.

The first step is to read all the sensors present on the board (accelerometer, gyroscope, potentiometer, and infrared sensor). Secondly, this data is organized and stored in a buffer. Then, the buffer containing the sensor data is sent via radio and is checked if the operation was successful. If there is an error in the shipment, the package is relayed. Finally, after sending, the sensor read cycle restarts.

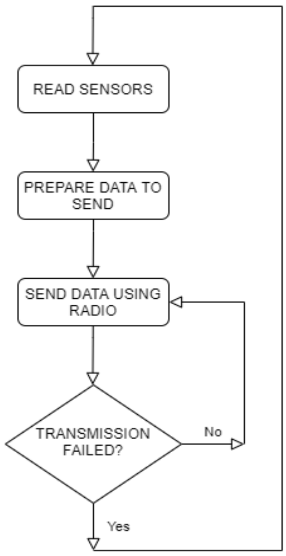

Figure 6. Firmware operation diagram.

2.5 Data gloves price comparison

A survey was made in relation to the costs of market data gloves compared to the prototype developed. The prototype has a very low cost compared to those sold in the market, by the company 5DTs. Table 1 contains a comparison of the costs of the data gloves available on the market versus the prototype (proposed in this paper).

In addition, in the final price analysis, expenses with electronic components, PCB (Printed Circuit Board), 3D printing, sensors, in addition to taxes, freight and labor and possible profit if the product was considered as commercial. These variables were considered, in order to be a comparison as faithful as possible with the data glove models that are sold in the market.

Table 1. Price of data gloves sold on the market and the proposed prototype.

Model type	Item	Description	Price
Model sold on the market	DG05UR	5DT Data Glove 5 Ultra (Right)	$995
Model sold on the market	DG05UL	5DT Data Glove 5 Ultra (Left)	$995
Model sold on the market	DG14UR	5DT Data Glove 14 Ultra (Right)	$5,495
Model sold on the market	DG14UL	5DT Data Glove 14 Ultra (Left)	$5,495
Model sold on the market	DGUWK	5DT Data Glove Wireless Kit (for 2 gloves)	$1,495
Model sold on the market	DGUDMOB	MotionBuilder Driver for 5DT Data Gloves	$495
Proposed prototype	DATA GLOVE	Data Glove (Prototype)	$110

3. RESULTS

Considering that the three parts (3D mechanical structure, sensing system and teleoperation system) had already been built, it was possible to completely unite these parts and form the teleoperation glove, in order to perform functional tests for the system validation. Figure 7 shows the result of the complete assembly of the data glove on a human arm.

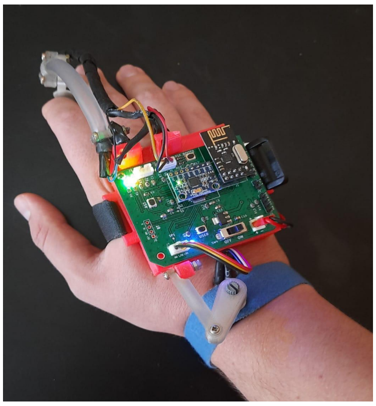

Figure 7. Data gloves - final and real prototype.

For the purpose of validating the data glove, a control application of a robotic manipulator of three freedom degrees was performed and represented in Figure 8. In the tests, the read sensors by wireless radio communication were transmitted to a second device, responsible for the reception of data and interpretation of this information to perform movements of the robotic arm by actuators as servo mechanism interconnected in the robot joints. This experimental diagram has the data glove and a robot station control, also known as a robotic arm, as shown in Figure 9.

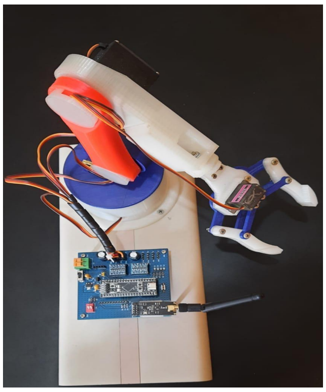

Figure 8. Robotic arm.

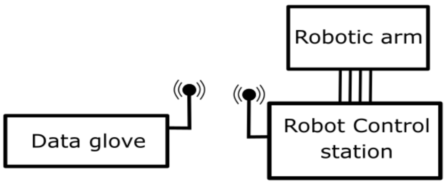

Figure 9. Experimental diagram.

The first experimental test was to verify whether the movements of the robotic arm corresponded to the movements of the human arm obtained by the data glove. Each sensor was individually tested. The movement of closing and opening the robotic claw was successful and corresponds to the expectations. And as it opened and closed the hand it was possible to obtain the following analog values (12 bits) from Figure 10. The flexion and extension movement between the hand and forearm was obtained from the analog reading (12 bits), shown in Figure 11, for each configuration of the position between the hand and forearm and from the execution of these movements. The inertial sensor was tested according to the settings of the manual positions on the axes in the XYZ spatial orientation, and for each position the accelerometer reading values were presented in Figure 12. The data were obtained for each of the XYZ configurations in the spatial orientation of the hand.

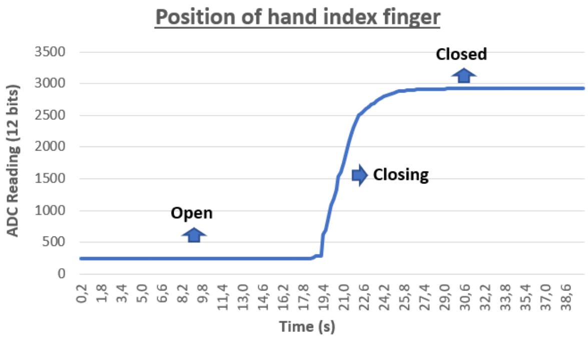

Figure 10. The finger opening and closing - analog output.

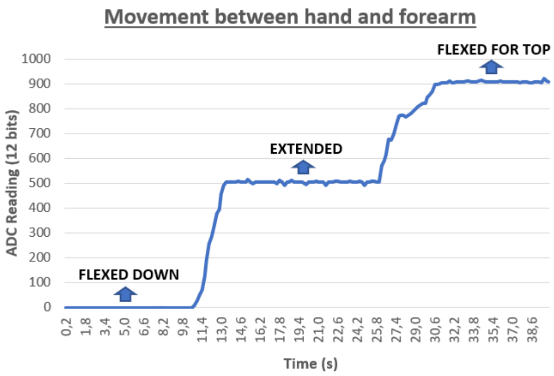

Figure 11. Movements between the hand and forearm - analog output.

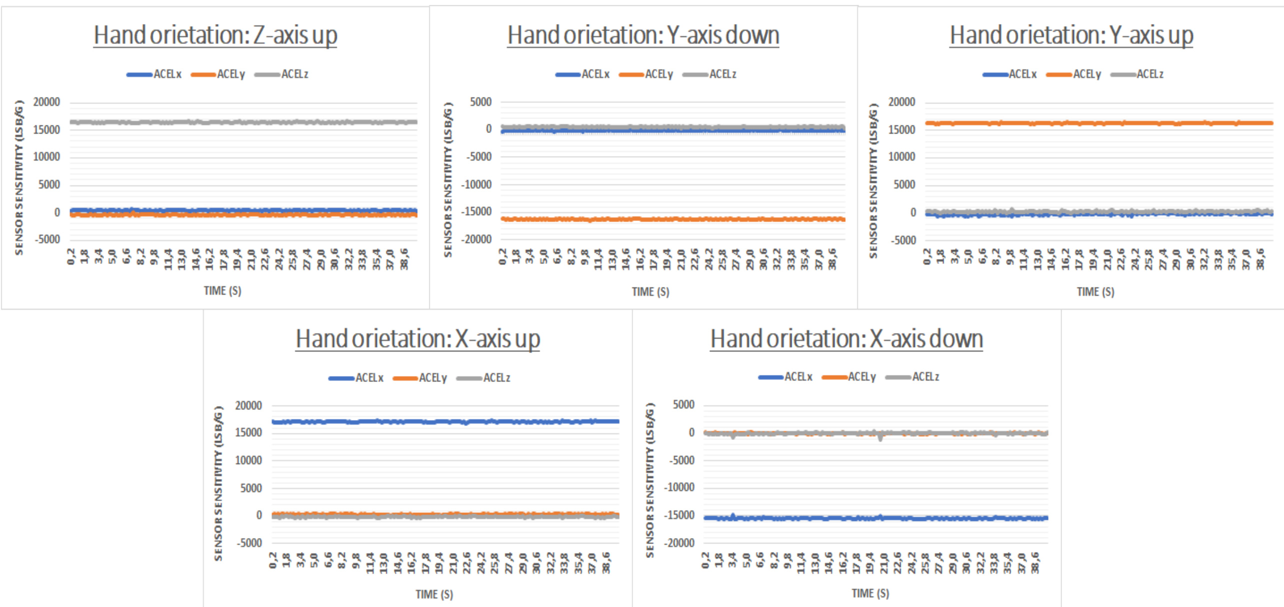

Figure 12. Accelerometer sensitivity readings according to hand positioning.

In view of this, the tests mentioned can affirm that the sensing system accurately responded to the reading of the human arm and forearm movements. Then, data were associated with the readings of the sensors acquired and described in Figures 10, 11 and 12, in relation to the movements of the human hand and forearm and applied to a robotic arm. For the representation of this test, the control of opening and closing of the robotic claw was made. In Figure 13, shows the moment when the opening of the claw was made and Figure 14 shows when the claw was closed.

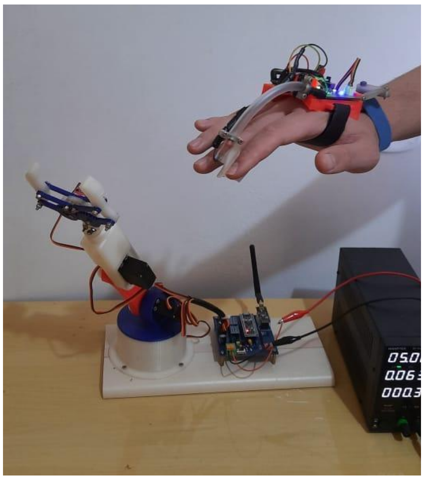

Figure 13. Open robotic claw.

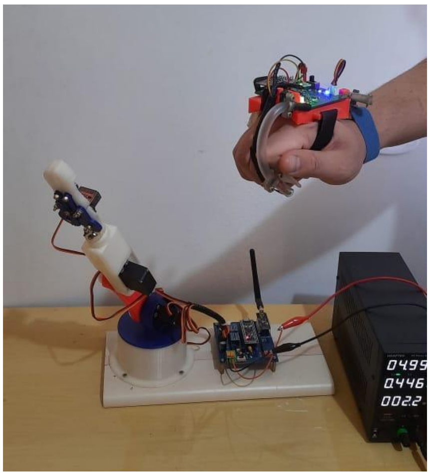

Figure 14. Close robotic claw.

4. CONCLUSION

The developed teleoperation system was able to detect the movements of the human hand and forearm from the data glove, as a result of the robotic arm control. For the system validation, several experiments of functionality of this teleoperation system were carried out in the control of a robotic manipulator. It was analyzed that was efficiently attended to interpreting the movements of the human hand and forearm in this manipulator control.

Furthermore, the structural characteristic has been shown with a good ergonomics and good stability in the human arm, ensuring optimal handling of the user without presenting any difficulty in performing a movement. In addition to the functional requirements, the data glove presented a low cost for its development, costing on average 110 dollars, an affordable price for people who wish to start using this technology in a robotic arm control application, virtual and augmented reality, among other applications that can be associated with human arm movement.

Future work will improve and explore the structure and sensing part of the teleoperation system, so that it can be possible to detect all movements of the human arm, including the shoulder parts and biceps. As a final point, with these structural and sensory implementations for the detection of the entire arm, it will allow it to be possible to control robotic arms with more freedom degrees and other technologies, such as virtual and augmented reality, in a way that contemplates all existing movements of the human arm.

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