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Electronic simulation of the control of a sub-actuated robotic hand

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Abstract: *The present study has as principal objective to simulate the control of sub-actuated robotic hand, using resistive sensors capable of interpreting finger movements and converting them into electrical signals, sending them to a central controller. This research aims to develop a biomechanical prototype capable of efficiently controlling devices and equipment at a distance, applying theoretical concepts of the Mechatronic. This situation is discussed because of the difficulty of accurately replicating the movements with the highest degree of mimicry of the human hand, in order to get as close to reality, generating the need to use a more complex architecture and with a high cost. Initially, only the control of the signals emitted to the microcontroller will be analyzed, in order to classify them in a scale and, later, to execute specific movements of the motors. Several tests were carried out to validate the effectiveness of the application of the mechanism, whose results were satisfactory, allowing, in parallel, the better development and understanding of the interdisciplinary didactic methodology, besides affirming the relevance and scientific value of the project in future applications.*

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I. Introduction

Robotics in today's world is well advanced, but despite this it is far from having an intelligent and versatile robot to replace the human being in his simpler everyday tasks[1,2]. Pitarch et al.[3]afirm that robots, although increasingly anthropomorphic in their external resemblance, are still lacking in comparative motor performance.According to Maciel and Silva[4], the most common commercial teleoperated robots are used in automobile production lines, small housework, medical surgeries, oceanic or space environments, rescue and salvage, or as military support in combat operations. Such devices are controlled remotely and reproduce the commands sent by the operator.Turner et al.[5] increase that these systems are of the master / slave type, in which a remote robot (slave) is operated directly by a human through a manual controller (master).

Sub-actuated hands are increasing targets of studies and researches on the biomedical engineering area, with several types of drives and degrees of freedom. They are classified as sub-actuated because the number of degrees of actuation is less than the number of actuators[6-8].Initially developed for the manipulation of radioactive materials, teleoperation is extremely important in performing tasks in remote areas and in hazardous environments[9-11]. There is a wide area of application of this technology, such as battlefields, underwater and space explorations, remote surveillance, environments where there is exposure to risk, telemedicine and so on[12,13].Subsequently, an increasing number of researches have been carried out due to the magnitude of application and control of biomechanical prototypes.Rezzoug and Gorce[6] proposed a technique based on neural networks to understand the inverse kinematic mapping between the 3D position of the fingertip and the corresponding articular angles. The finger movements were obtained by an instrumented sleeve and mapped to a multi-chain model of the hand. From the desired position of the fingertip, the neural networks made it possible to predict the angles of articulation of the corresponding finger, maintaining specific subject coordination patterns.Touvet et al.[14] prepared a biomimetic sensory-motor control system with the objective of providing an intelligent approach between object-dependent and capturing the capacity of such systems. The proposed model is based on a multi-network architecture that incorporates multiple correspondence units trained by a statistical learning algorithm (LWPR).Zhang et al.[15] developed a new algorithm for obtaining segmental locations of the finger rotation center during flexion-extension from the measured movements of the in vivo surface marker. The algorithm employs an optimization routine minimizing the time variation of the internal bond lengths and incorporates an empirically quantifiable relationship between the local movement of a surface marker around a joint and the extent of flexion of the joint.El-Khoury and Sahbani[16] presented a new strategy to capture unknown 3D objects according to the correspondingly desired task, identifying the objects from the human movement. The authors intended to calculate the closing force in the act of grasping the object, demonstrating the adaptability of the respective strategy to the kinematics of the hand.Saezand Saez[17] developed a functional prototype of a human-like robotic hand considering anthropomorphic characteristics. Image processing analysis was performed from computed tomography, generating a model for the synthesis of a four-bar sub-mechanism to grasp objects with different geometries considering the functionality, appearance and symmetry of the system for the human body.Astaras et al.[18] a robotic arm with six degrees of freedom, operated by an exoskeleton connected to a brain-computer interface (BCI headset). The system has been successfully tested, allowing the user to perform tasks with immersive control, speed and smooth movements.

In this way, the present project introduces the initial study of the control of devices and/or remote equipment. For this purpose, initially only the control of signals emitted to the microcontroller will be studied and tested, in order to classify them in a scale to later execute specific movements of the motors. Realized signal control, will be demonstrated in a practical way the remote control of the sub-actuated robotic hand, where a sensor-glove will be developed using resistive sensors – Flexforce - capable of interpreting the finger movements of the human hand, converting them into electrical signals and sending them to a microcontroller that will simulate the movement of the sub-actuated hand.

II. Materials And Methods

The proposal of the research consists of the construction of a sensorized glove for the control of an underhanded hand. Which is to capture the movements of a human hand, through sensors coupled thereto, and the movements in the sub-actuated hand must be repeated. For to obtain a satisfactory result the speed of processing of the capture of the movements to the repetition of the movements, must be considerably fast. Figure 1 presents the block diagram of the project.

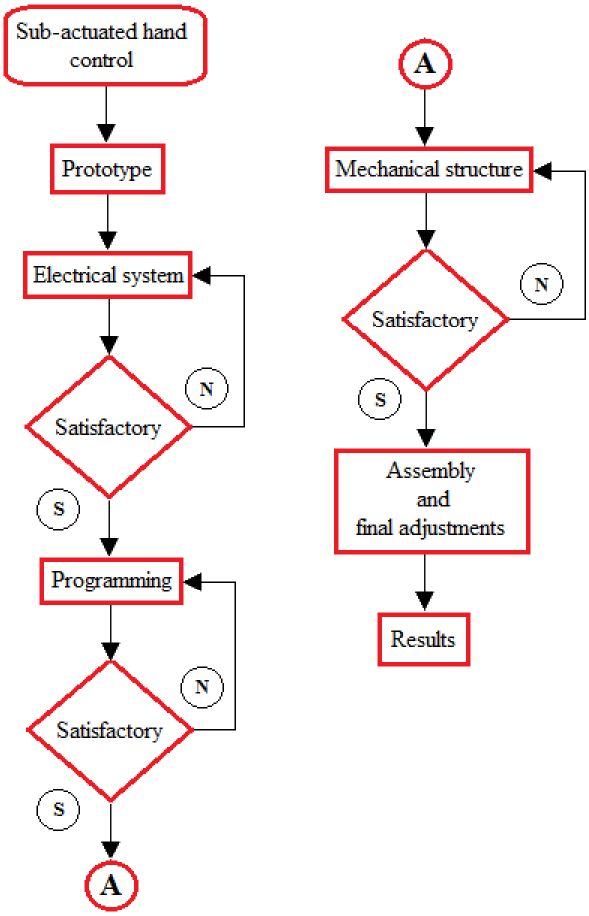

Figure 1: Product Development Flowchart.

Experimental methodology

The mechanical hand used in the project (Figure 2) was provided by Faculdade de TecnologiaTermomecanica (CEFSA-FTT – Brazil), presenting good dexterity and anthropomorphism, making feasible the application of the project in real situations.

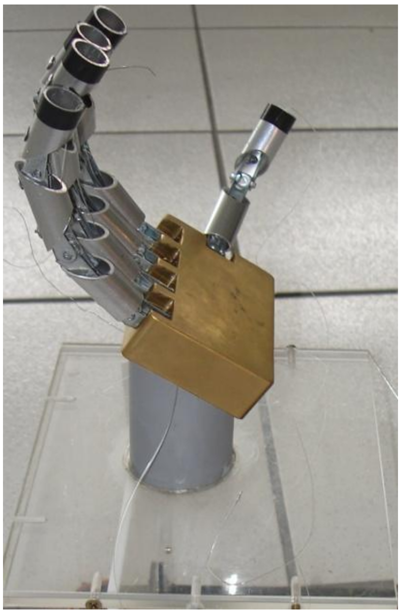

Figure2: Sub-actuated robotic hand.

Due to the need to obtain accurate values during the measurements, given the application of the project, it was necessary to use flexible force sensors. Flexiforce, according to Nag and Mukhopadhyay[19], are ultrathin and flexible printed circuit boards that can be easily integrated into power measurement applications. When an external force is applied to the sensitive area, it results in a change in the resistance of the sensor, which is inversely proportional to the force applied thereto[20], in other words, when the sensor is at rest, the sensor curve is characterized by an intrinsic resistance. Already when the sensor is bent, the internal resistive material is drawn and become more distant, less adjacent resistive particles come in contact, thus increasing the resistance. It was used the Flex sensor of the Spectra Symbol (Figure. 3), based on carbon substrate, temperature range of -35ºC to 80^{0} C, operation voltage 0-12 V and resistance in the range of 10 kΩ ~ 30 kΩ.

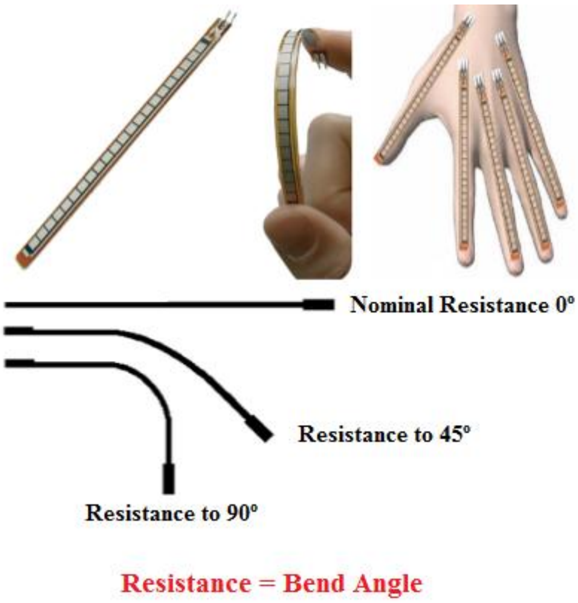

Figure3: Flex sensor bend angle.

When the substrate is folded, the sensor produces a resistance output correlated with the angle of curvature, how much higher the angle, the higher the resistance value.The actuator used in the project is the servo motor HX5010, by virtue of its proper operating speed (0.6 $s.grau^{-1}$), to obtain a torque of 6.5 Kg, by its resolution of approximately 1° and for having adequate dimensions.The servo motor, as stated by Francisco[21], requires a DC supply voltage within the range of 4.8 V to 6 V and a PWM (Pulse Width Modulation) sign indicating to the servo motor the position to be moved. The controller will be responsible for generating this signal, for later correction of the position of the servo motor.To acquire the sensor signal, a setting was used in Wheatstone Bridge, converting the magnitude of the variation of the sensor resistance into an analog signal. After subjecting the sensor to tests, it was found that the voltage signal is very low, its amplitude varying around 10 mV – 600 mV.

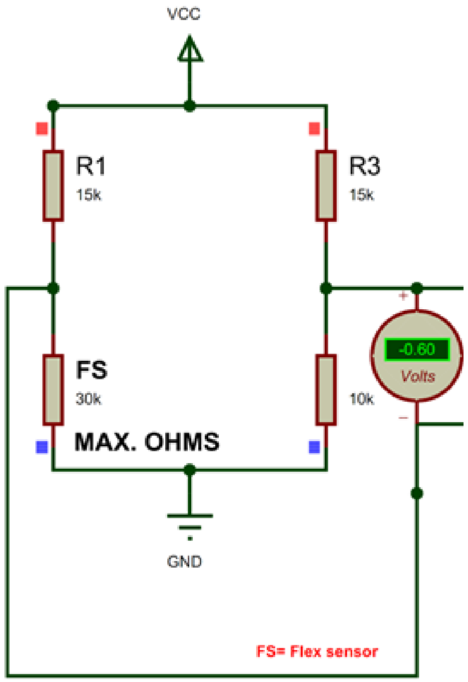

Figure4: Sensor Configuration at Wheatstone Bridge.

For controlling the actuators through a controller, it has become necessary to apply an operational amplifier to expand such generated voltage signal. In this way, it was used the operational amplifier LM324, using two stages of amplification in order to reach a variation of approximately 36 mV to 4.8 V. Therefore, when the sensor is fully flexed the final output voltage will be close to 4.8 V, as shown in Figure 5.

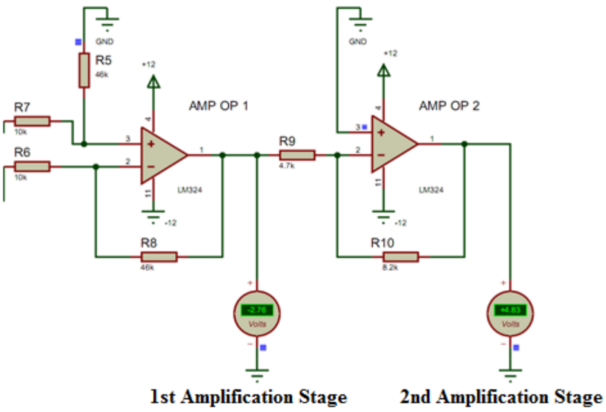

Figure5: Amplification of the signal.

For the control of the actuators, the microcontroller PIC 18F452 was chosen, manufactured by Microchip, by having A/D channel applying a supply voltage of 5 V and a crystal oscillator of 20 mHz to the clock. After amplification, the signal arrives at the analog channel of the microcontroller which, through programming, generates the actions for the servo motors to make the correct position corrections.

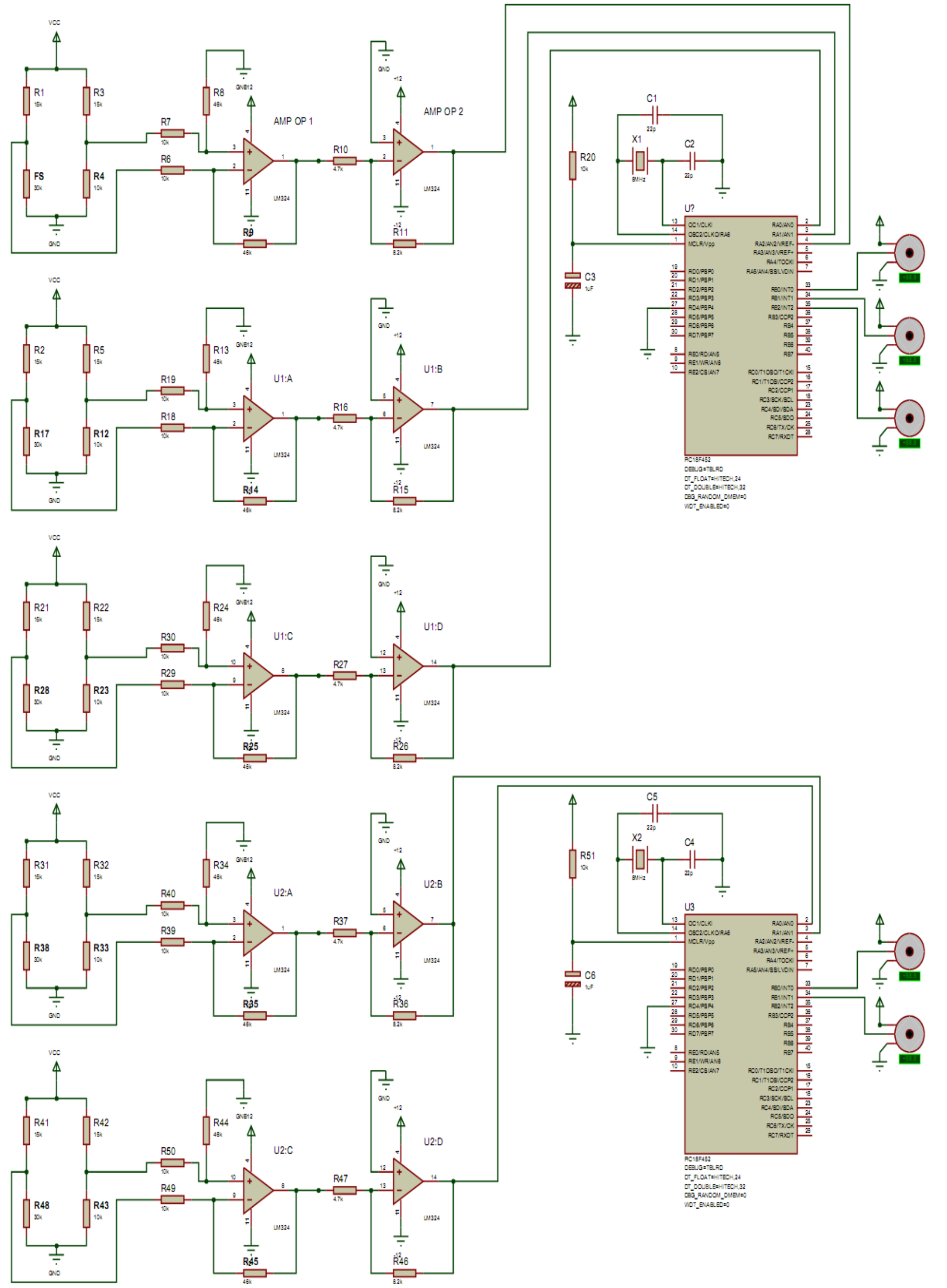

Figure6: Complete circuit, simulated in Proteus program.

III. Results And Discussion

The objective of the initial experiments was to have control over the operation of the A/D channel of the microcontroller. Eight Leds were connected to the PortB and a potentiometer in the peripheral AN0. The function of the circuit was to turn on the LEDs according to the variation of the voltage that the potentiometer caused in the peripheral AN0.The first experiment did not obtain the expected result, since the LEDs did not respond proportionally to the movement of the potentiometer. After much investigation, it was verified that the error was in the GND of the circuit, in which two different GND were used causing the system malfunction.Right after the correction, using only one GND common to all, operation flowed correctly.This development made it possible to acquire the necessary skills regarding the use of the A/D channel of the microcontroller (PIC 18F452) bearing in mind its fundamental importance in the future construction of a prototype. It is through this peripheral that makes possible the communication between the sensor that will be employed in the prototype and the microcontrollers.

Subsequently, a programming was developed to simulate the PWM through the delay function of the microcontroller, since the PWM function of the microcontroller could not control the servo motor due to the non-compatibility of the pulse period generated by the PWM peripheral of the microcontroller and the period required for servo motor control.However, the expected result was not obtained, because the servo motor did not respond proportionally to the variation of the A/D channel, undergoing great oscillations in its movement.Other possibilities were analyzed to control the servo motor. It was decided to test a program that generated the PWM through the TIMER functions, existing in the microcontroller. For this experiment a programming with 9 positions was generated using the TIMER 0 for the active cycle and the TIMER 1 for the inactive cycle of the PWM. TIMERS calculations were performed using the program Timer Calculator 0.9.6 developed by Ronald Nisblé, according to Figure 7.

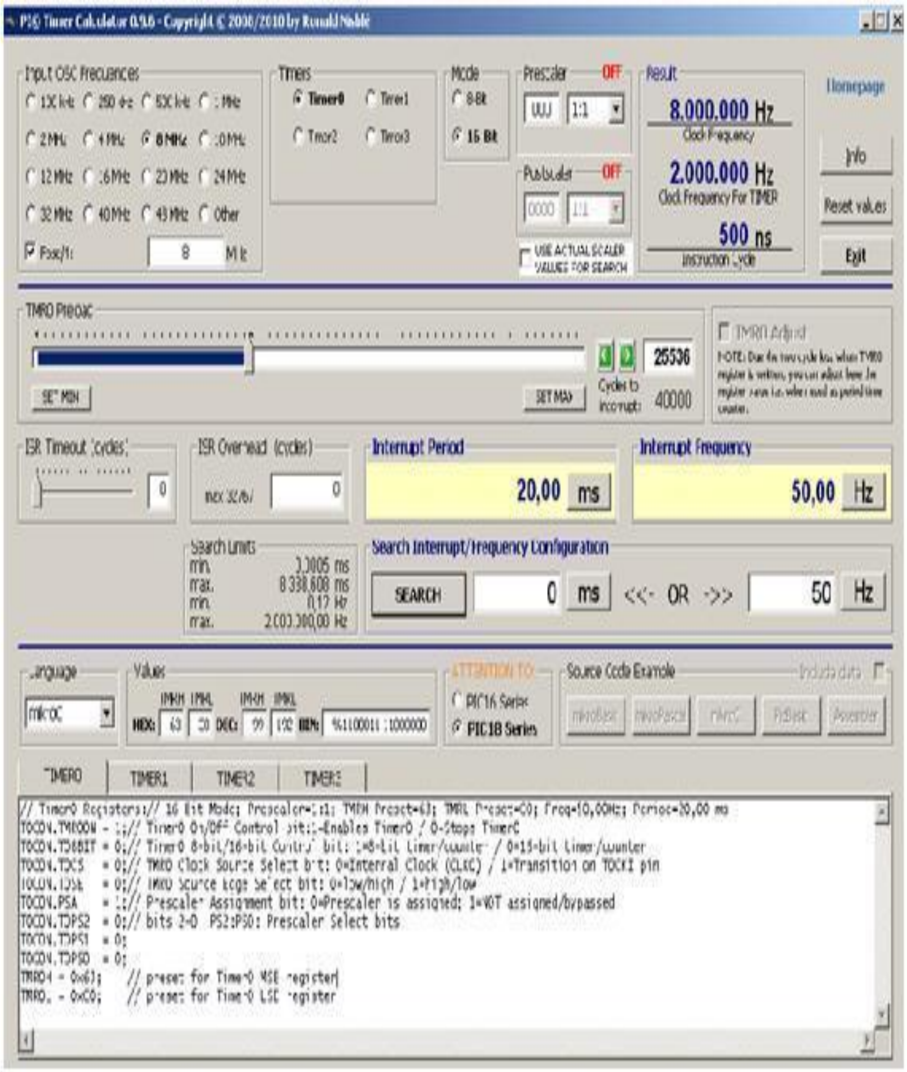

Figure7: Timer Calculator 0.9.6 program.

The respective experimental stage fulfilled with its objective positively, enabling accurate knowledge of each position of the servo motor and its respective pulse width.Regarding the next phase of the study, joined him the developed concepts about the operation of the A/D channel of the microcontroller, with the concepts acquired during programming. The purpose was to use the A/D channel, already with Flex sensor, or voltage variation and use the PWM function to control a servo motor. The developed circuit had the function of controlling the servo motor according to the voltage variation caused by the sensor.

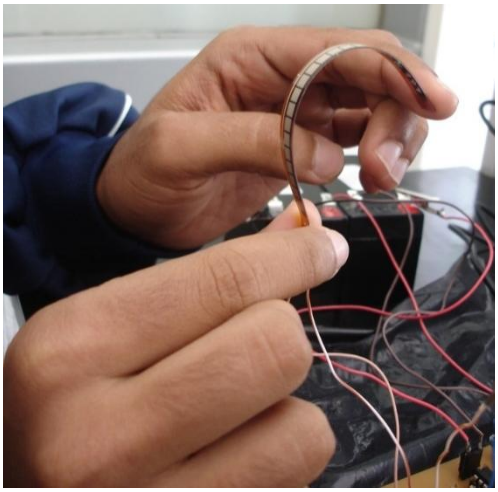

Figure8: Tests performed with the Flex sensor.

Through the oscilloscope measurement it was possible to visualize the correct functioning of the PWM control with the variation of the sensor.With the correct operation of the system and knowing the need of the control using the minimum of possible microcontrollers, another sensor has been inserted for another PWM output, now two outputs with two distinct input signals would be controlled using the two remaining TIMERS.However, this experiment did not work as expected, causing a split in the frequency of the second PWM.Because of the reasons that caused the failure in the previous experiment and because of the short time available, new alternatives were sought. It was decided to use a program with the functions TIMERS and INTERRUPTION.

The experiment presented excellent results, once PWM control was successfully achieved (Figure 9). Nevertheless, when inserting more than three channels of control of the servo motor, it was observed considerable tremors in the operation of the motors. Since the focus of the project is on the accuracy of the system, it was decided to use two microcontrollers to control the five servo motors, where one microcontroller controls three servo motors and another microcontroller controls the two remaining servo motors.

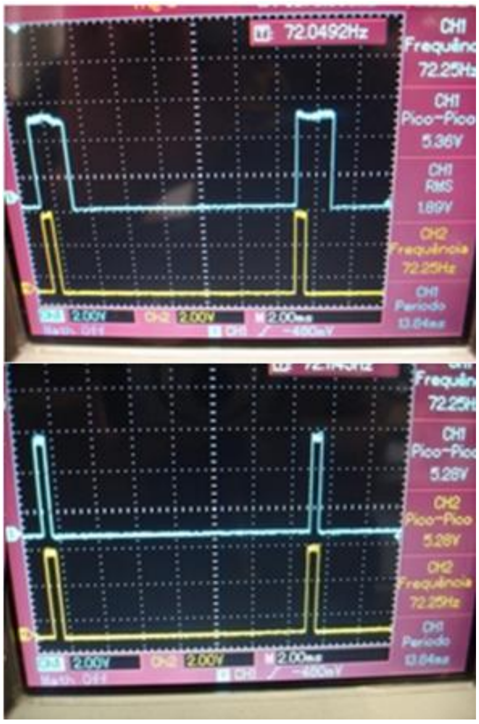

Figure9: Measurement of two generated PWMs.

Comparing the results of the Flex sensors with the human hand, the following conclusions were obtained:

Figure10: Comparison of tension in relation to human hand movement.

With the control defined, the prototype of the sensorized glove was developed, as verified in Figure 11, by sealing channels on the fingers of the sleeve so that the Flex sensors. The transmission of the data captured by the movement of the robotic hand was performed through the control via serial cable.

Figure11: Prototype of the sensorized glove.

For better accuracy, two ways of collecting the variation of the sensor were realized. The first measurement (Figure 12) was based on the relation to the degree of curvature of the sensor, where it was possible to observe that its variation is concentrated in an average point.

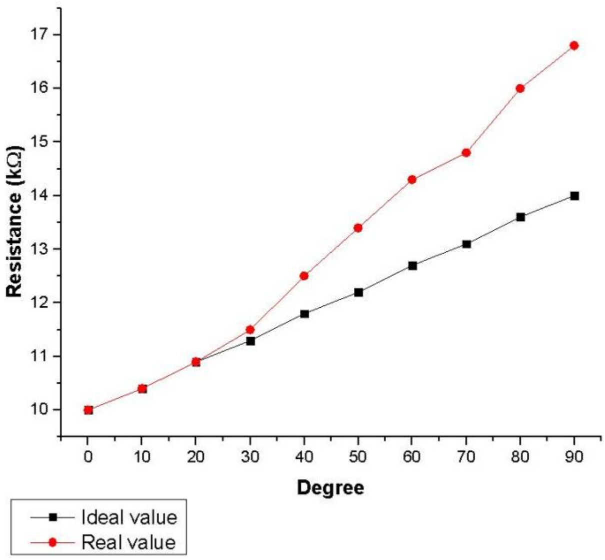

Figure12: Graph of relation Ideal x Real.

In the second measurement, the data were collected through the relation of Resistance x Radius (Figure 13). The second measurement showed greater regularity, since now the whole area of the sensor is flexed, that is, this measurement is of greater reliability.

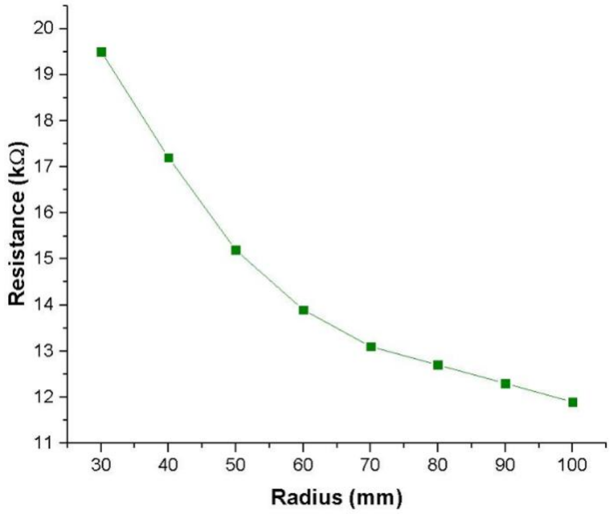

Figure13: Graph of relation Resistance x Radius.

Once the best type of measurement is defined, a ratio can be established between the radius of curvature of the sensor and the angle of variation of the servo motor, comparing the radius of curvature of the sensor and its equivalent resistance, relative to the proportional angle of the servo motor (Figure 14).

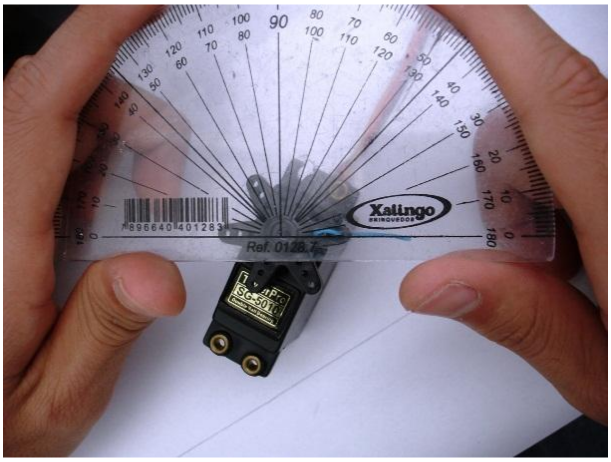

Figure14: Relation Radius x Servo motor.

Table no 1: Analogy to movement.

Radius(mm)	Resistance(kΩ)	Degree(Servo motor)
100	11.9	30
90	12.3	40
80	12.7	45
70	13.1	58
60	13.9	70
50	15.2	75
40	17.2	90
30	19.5	110

Through this test, it was possible to determine the variation of the sensor with respect to the position of the fingers of the human hand, since this mode of measurement is the closest to the kinetics of the hand, in order to, therefore, to move more precisely the fingers of the sub-actuated hand in relation to movements performed with sensorised glove. Fig. 15 and Fig. 16 illustrate the performance of the system in various stimuli, demonstrating the functionality and efficiency of the proposed system.

Figure15: Prototype closed hand.

Figure16: Repetition of hand movement.

IV. Conclusion

The development of a robotic system that is capable of replicating human hand movements involves an interdisciplinarity between the areas of mechanics, biomechanics, electronics and control, being of extreme importance the didactic planning for the greater effectiveness of its development.The use of the Flex sensor working in conjunction with the microcontroller presented excellent results of compatibility, operation and variation control, whose laboratory experiments validated the programming used when demonstrating its efficiency in the command of the PWM with a high degree of precision.The developed system can be safely used for the development and implementation of a biomechanical prototype for the control of remote robotic assemblies. The construction and implementation of the sensorized glove was able to control the movements of the sub-actuated hand in an accurate and efficient way, with fast response time and excellent movement reproduction, allowing its application in the aid to patients in physiotherapeutic treatment or being able to be employed in the industry, where the operator can operate the equipment from a safe place and with extreme rigor, which we leave as proposal for future studies.It can be affirmed that the results achieved exceeded those initially desired, evidencing the relevance and scientific value of the present research.

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