ROBOTIC HAND CONTROLLED THROUGH VISION AND BIOMECHANICAL SENSORS

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1. INTRODUCTION

Engineering projects try to solve technical problems, optimizing solutions and meeting the requirements and constraints of material, technology, economy, legal and other considerations related to the human environment [1]. According to this definition, the motivation of this project is based on the authors' interest in making the available technology accessible, exploring alternatives and implementing solutions that optimize resources.

Hence the proposal for a bionic hand built from a design Creative Commons InMoove [2] which can be made with a 3D printer. The movements are executed by actuators (servomotors) driven by a board open source Arduino Uno receiving a control command (Leap Motion) vision sensor or a biomechanical sensor for EMG electromyogram (Myo). Biomechanical EMG sensor identifies a series of movements based on the contracted muscles of the forearm.

There are several precedents of bionic arms that use advanced technology and biomedical developments, such as:
Arms controlled by brain implants or nerve activity of the arm base which transmits the movement commands from the brain to the servomotors that drive the fingers and wrist and whose movements are adjusted with pressure sensors, temperature and contact [3 - 6].

This article explores alternatives to build a bionic arm, driven from motion sensors and EGM. The proposed motion sensors are non-invasive, that is to say, they not require surgical implants. The vision sensor Leap Motion is a small desktop device incorporating two cameras. The small change of viewpoint offered by the cameras allows three-dimensional reproduction of the image of the operator's hand and further analysis to actuate a robotic arm.
In the application environments, one of the possible applications is the remote control from the user's arms.
Another application environment would be to assist the disabled by controlling a bionic arm from a skilled arm.

2. MATERIAL AND METHODS

2.1.- OBJECTIVES

The main objective of this project is to build an arm, with 3D printing technology that is able to follow the movements captured from a real hand (Figure 1).

Specific objectives of the project:

- Research about 3D printing technology arms looking for designs that enable major movements, both hand and wrist.
- Develop a skit on the Arduino platform able to control the main movements of one hand.
- Explore the technologies used for mocap (motion sensor) in the market, its operation and features.
- Define a channel of communication between devices, compatible with the software used.

- Develop programming code (in C language) capable of receiving, interpreting, manipulating the data obtained by a motion sensor, and able to communicate with all the devices in the project [7-8].
- Find a practical application of these technologies to assist in the daily lives of disabled people.

Project elements

Hardware:

Robotic arm
I2C board Adafruit
Arduino Arduino UNO and accessories
Bluetooth Arduino HC-06
Adafruit PWM / Servo Shield
Tower pro MG995 Servo
Leap Motion
Myo armband

Software:

Arduino language source code
User program written in C language
Leap Motion and Myo utilities to interpret the movement in the real hand.

2.2.-ROBOTIC HAND

The robotic hand used for this project is the so-called BIONIC, extracted from the InMoove initiative [2] Gael Langevin. It is based on the creation of a full-scale humanoid robot, made from a 3D printer.
BIONIC is open source (Creative Commons) so it can be manufactured by anyone, the aim of this initiative is to provide prostheses to people with limited resources.

We compared different designs of prosthetic hand that can be made with a 3D printer: CYBORGBEAST, robohand, DESTRUS, VOICE2HAND, Exiii-HACKBERRY and BIONIC-inMoove.
CYBORGBEAST and robohand are discarded because they cannot be controlled electronically. While Exiii-HACKBERRY was also discarded because it is a finished product, despite it is a very interesting project it is not flexible enough to suit the objectives.

Finally, BIONIC-InMoov project was chosen, adapting it to the needs of this project: open and close the hand and control the movements electronically. It has better finishes than dextrous and VOICE2HAND. Servomotors are placed inside the forearm and looks more like a real hand. Arm robot is part of InMoov. Its basic features are:

- It lets you control your fingers separately.
- It has wrist movement.
- It can be controlled by Arduino.
- It is built using 3D printing.

PLA (polylactic acid) is chosen as printing material. The PLA with ABS (Acrylonitrile Butadiene Styrene) are the most commonly used 3D printing materials. The PLA is created from natural, renewable resources as corn starch. Its main advantage is that it is a biodegradable compound.

PLA is very easy to use because it works with lower temperatures than the ABS, between 190ºC and 200ºC. Moreover, the range of colors of the PLA is higher, but it is quite fragile and life expectancy is lower.

3mm diameter PLA strips are used.

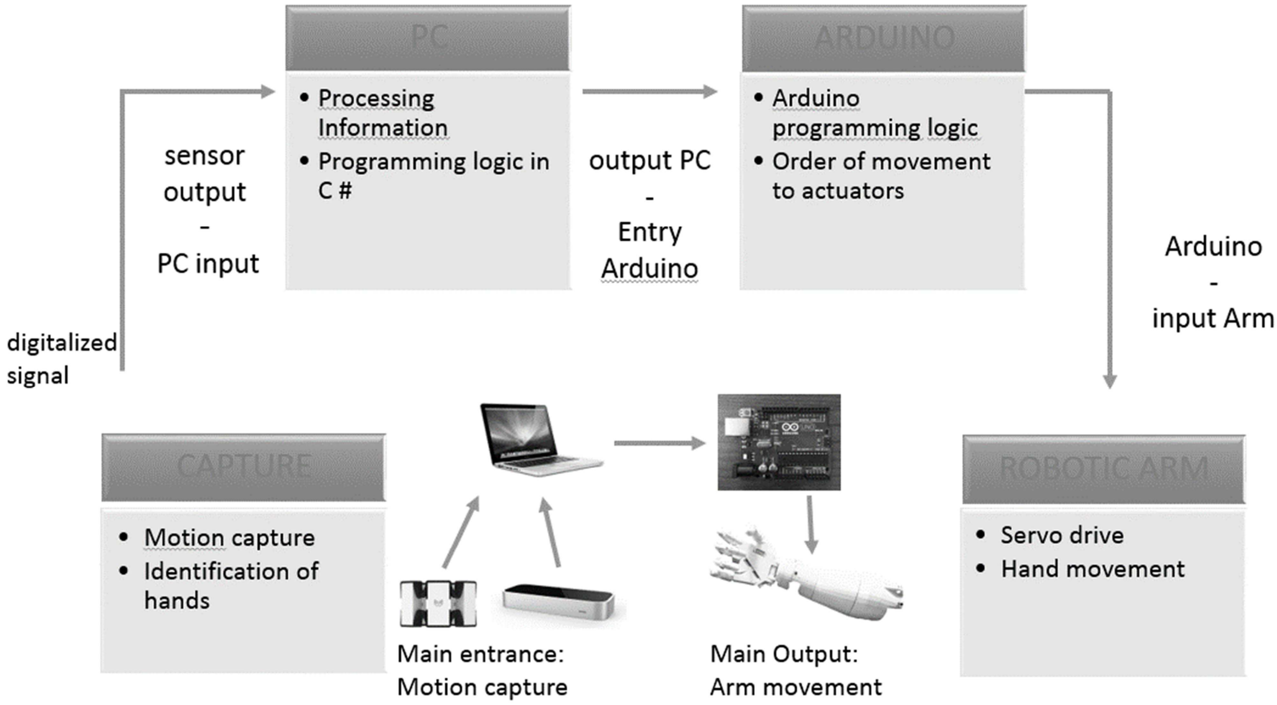

Figure 1. Scheme of the research project

2.3.- HAND MOVEMENTS

Each finger is moved by a servomotor. 5 for fingers and 1 for the wrist.
Servomotors are controlled by the Arduino UNO board.

Servomotors fingers pull wire to cause the movement. Multifilament line diameter of 0.45mm and resistance about 91 Kg (200 lb).

The wrist moves through the action of the servomotor on two gears. As shown in Figure 2, servomotors are placed inside the forearm.

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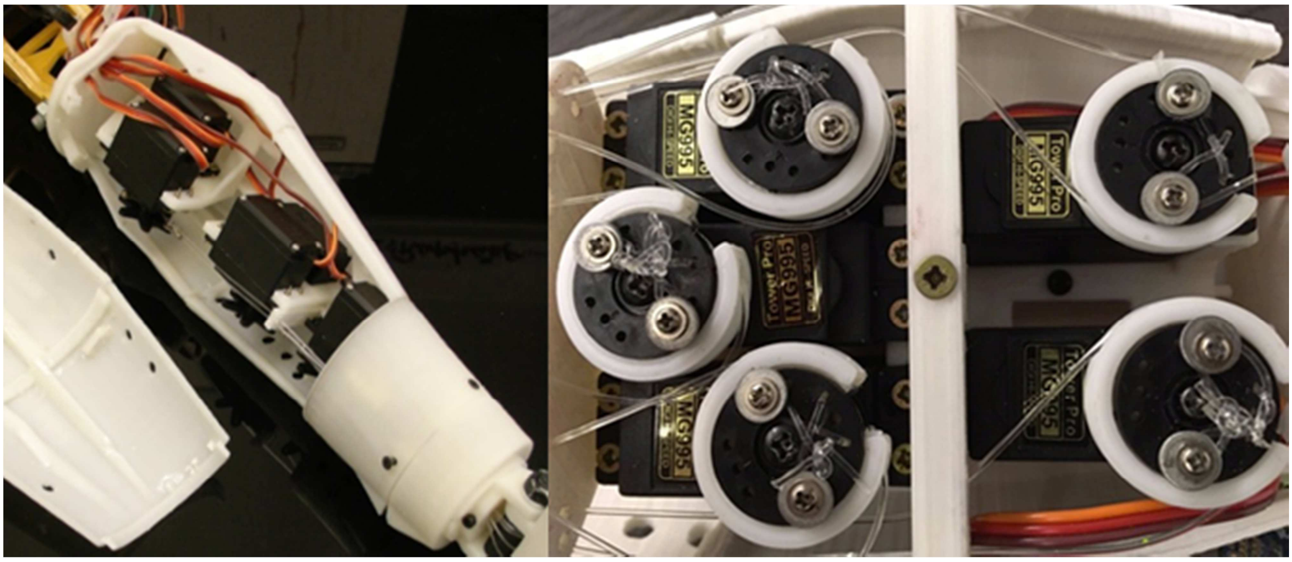

Figure 2. Operation detail of the robot arm

Basic characteristics of servomotors:

Model: MG995 TowerPro
Operating Voltage: 4.8 V to 6 V
High speed
Operating speed: 0.2 s/60º (4.8 V), 0.16 s/60 (6 V)
Arrested Torque: 13kg/cm. (4.8 V), 15kg/cm (6 V)
Double bearing
Rotation angle: 180 approx.
Dead band: 5 μs
Weight: 55 g
Dimensions: Length 40.7 mm, 19.7 mm wide, 42.9 mm height approx.

2.4.-MOTION CONTROL SYSTEM

Arduino is a board with digital and analog inputs and outputs, which can be programmed for a multitude of functions. the ArduinoUNO board was selected because its characteristics are suited to the project.
The choice of microcontroller is based on the large amount of hardware extensions (Shields) available as well as programming facilities. Other models like Teensy 2.0, Picaxe 08M2 or Raspberry Pi could also be used, but minor programming capabilities and oversizing issues drive us to choose Arduino.

ArduinoUNO has a ATmega 328 processor that allows you to load programs directly from the USB port.
Own programming environment and compiler is written in Java and based on Processing. The language is very similar to C ++ language, but with some modifications, since Arduino has its own libraries to interact better with the hardware.

ArduinoUNO features:

Name:	Arduino UNO
Processor:	ATmega 328P
Input Voltage:	5 V / 7-12 V
CPU speed:	16 MHz
Analog In / Out:	6/0
Digital IO / PWM:	14/6
EPROM [kB]:	1
SRAM [kB]:	2
Flash [kB]	32
USB	
UART:	1

Adafruit board I2C PWM / Servo Shield
"Adafruit 16-Channel Servo Driver with Arduino"
To control 16 servo motors with only 2 pins from Arduino.

Bluetooth HC-06
Communication between PC and Arduino is done via Bluetooth.
The main additional boards or shields to control Arduino Bluetooth are Bluetooth HC-05 and HC-06 module "wireless transceiver module Arduino wireless". The most noticeable difference is that the HC-06 has four connecting pins and HC-05 six. In addition, the HC-06 can only be a slave Bluetooth device while the HC-05 can act as master and slave.

Power supply
Power 6 servomotors, 6V and 7A.
The power supply is directly connected to the I2C Adafruit board, to power the six servomotors.

Once the hand is built and its movements are controlled, we implement the I2C board Adafruit, the HC-06 Bluetooth module and the power supply. The connection boards and the Arduino can be seen in Figure 3.

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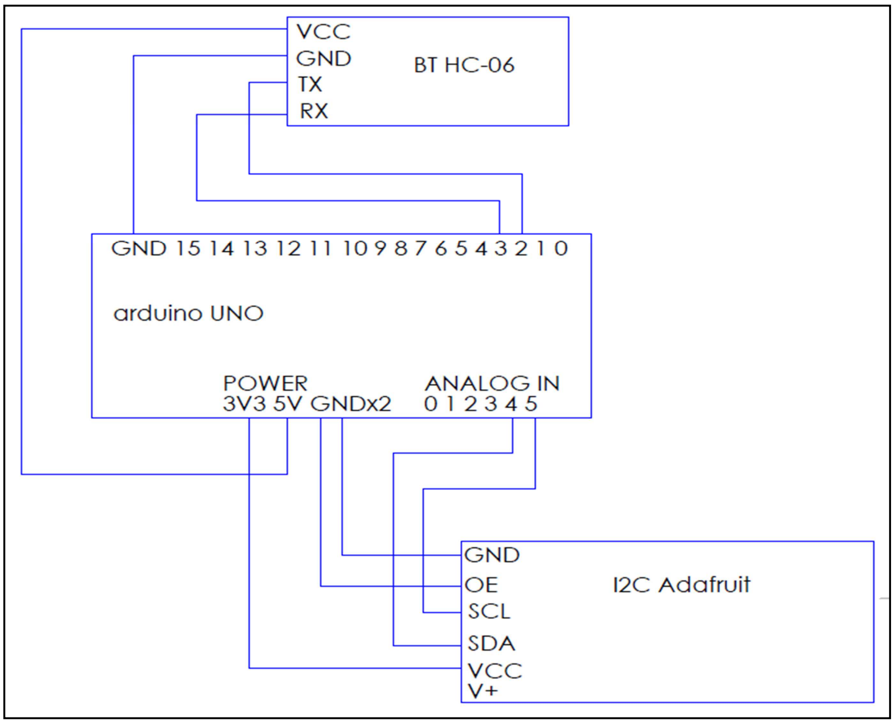

Fig. 3: Final scheme configuration

Communication between the board I2C Arduino occurs connecting the following pins:

- VCC -> + 5V
- SDA -> ANALOG IN 4
- SCL -> ANALOG IN 5
- OE-> GND
- OE-> GND

The connection of the servomotors with the board is done by the servo's three-pin female to pins installed on the board. The connection sequence is the same for the servomotor and the board being in order PWM, V + and GND. Respectively correspond to yellow brown, red and brown cables of servomotor.

Example of a servomotor control function in arduino:

```
void setup () {servos.begin ();

servos.setPWMFreq (60); // PWM frequency 60Hz or T = 16,66ms

Serial.begin (9600);
}
```

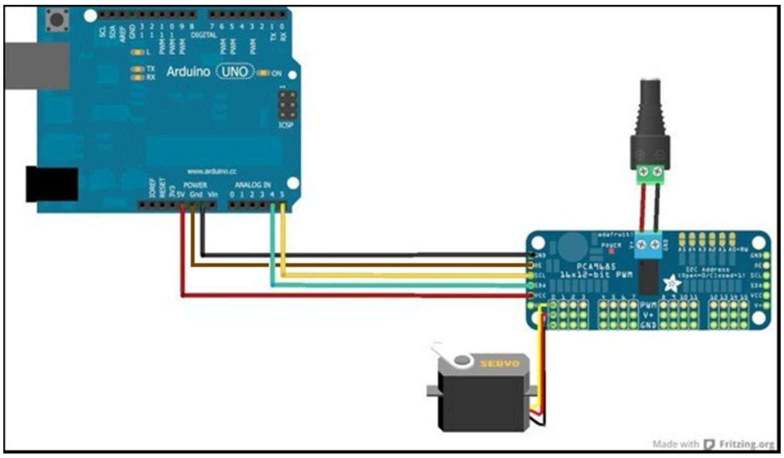

Fig. 4: connection between Arduino, Adafruit board and the servomotor

You can add a total of 16 servos to Adafruit board. If more servos are needed, the Adafruit boards can be connected to one another thanks to the pins present on the side of the board (figure 4).

2.5. - MOTION CAPTURE

Motion capture is a technique of movement recording initially created for military and medical purposes. However, at present, its usefulness has changed and is mainly used in the world of video games or cinema, to replicate real movements on the digital world. Gesture recognition is based on two types of devices. In our study we will use one of each:

- Vision-based devices: using one or more cameras (Leap Motion)
- Other recognition devices: special gloves, armbands, and other tracking devices (Myo).

2.5.1 Vision-based devices

These devices typically include one or more cameras and generate data to be processed from the captured images. Each frame is filtered, analyzed and interpreted. Some of the vision devices are:

- Video cameras: There are recognition techniques based on data generated by a common camera. Detection methods used are usually color or shape.
- Stereoscopic cameras: This technique is based on capturing images from two cameras that can generate a 3D model from the recorded data.
- Active Techniques: These cameras need some kind of structured light projection; such as Kinect or Leap Motion.
- Marking techniques: This system requires body markers, like a color glove or, as in the case of PlayStation Move Controller, LED lights.

Stereoscopic and common cameras are discarded. These technologies are oriented to cinema so they have no useful application in our work.

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In the case of Playstation Move Controller, the device itself needs the hand to hold it so it is impossible to perform actions with our hand.

Finally, we highlight three techniques: Kinect, Leap Motion and Digits (under development by Microsoft).
Kinect is possibly the best known gestural interface. It is developed by Microsoft and including an infrared camera and a depth sensor it measures the relief of the object. It is not adapted to our project because of its excessive size 249 x 66 x 67 (mm). It is ready to detect the human body and should be adapted to capture the movement of the fingers.
Leap Motion is a gestural interface completely dedicated to the movements of the hand. This device has gained real importance with the arrival of virtual reality (VR). Its size is reduced 75x25x11 (mm) and maintains a device that can be placed on the worktable.

Leap Motion was developed by David Holz and marketed for the first time in July 2016, it is a small USB peripheral device that is designed to be placed on a physical desktop or in a virtual reality helmet. Two monochromatic infrared cameras and three infrared LEDs, the device observes a hemispherical area, at a distance of about 1 meter. LEDs generate light and infrared cameras generate nearly 200 frames per second. 3D position data are compared with the 2D frames generated by the two chambers.

Several studies [12,13] showed that the overall accuracy of the controller is around 0.7 mm, being the resolution greater than Kinect device. The controller can perform tasks like browsing a web site using gestures and high-precision 3D scenes manipulation.
Some experiences can be found combining Leap Motion and Microsoft Kinect device [14].

Leap Motion has three main parts: cameras, LEDs and micro controller. The two cameras are a key since they are responsible for capturing images. These have a monochrome sensor sensitive to infrared light with 850 nm wavelength. This sensor reaches a working speed of 100 fps. The cameras have a CMOS sensor that is comprised of cells. This allows in addition to a higher processing speed and lower cost, reduce the device size significantly compared with CCD sensors. These sensors also allow removing Blooming phenomenon, that occurs when a saturated pixel light saturates those around them.

LEDs illuminate the area covered with the infrared light with the same wavelength than the camera sensor: 850 nm.

Finally, the microcontroller is responsible for regulating the illumination and collecting information from the sensors to be focused to the controller installed in the computer.

The interaction zone, called "Interaction Box" by the API has a volume of 110.55 mm x 110.55 mm x 69.43 mm. In this area is the origin of Leap Motion coordinates. There is a possibility to set the center of the interaction zone from the device driver and its height can be modified from 7 to 25 cm.

The microcontroller makes appropriate resolution adjustments and sends them to the driver on the computer.

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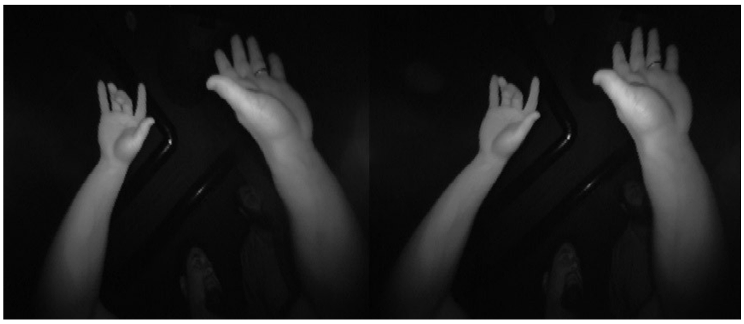

Figure 3. Leap motion uncovered, showing the LEDs. The two images received by the driver of Leap Motion.

The digitized image is represented by a brightness value, measured in bytes per pixel captured and stored in a buffer. This byte is used to produce a RAW image gray scale; a total of 256 possibilities of different luminosities for each pixel. A total of 640 x 120 = 76,800 pixels per image.

When the image reaches the driver, a mathematical model of anatomical characterization identifies the fingers and hands. The driver also uses another algorithm for depth.

2.5.2 Based devices other recognition

Devices not based on vision sensors use various types of motion detection technologies. Here are some of them:

- Inertial sensors that measure the earth's magnetic field variation using accelerometers and gyroscopes to detect motion (e.g. Wiimote)
- Haptic touch devices (e.g. Apple Trackpad)
- Electromagnetic devices measuring the variation of an electromagnetic field generated artificially by wireless networks (e.g. WiSee)
- Fiber optic gloves (e.g. Dataglove)
- Biomechanical. Devices using electromyography to record the parameters of a gesture (e.g. Myo armband).

It was decided to analyze biomechanical devices since the inertial sensors detect wrist movements not fingers. Haptic detects movements on a screen. Electromagnetic devices detect hand movements, but they not have enough precision to detect fingers.

Dataglove optical fiber could be used for the purposes of this paper, but we decided to test the Myo armband, much more affordable economically. Myo recognizes predetermined movements, limiting the number of moves that can be detected. Furthermore, the Dataglove is able to detect any fingers bending.

2.5.3 Biomechanical devices

Some devices rely on electromyography to record the parameters of a gesture. Myo armband is able to identify movements such as closing the fist or stretch fingers. 8 EMG sensors are used which graphically record the electrical activity produced by our muscles.

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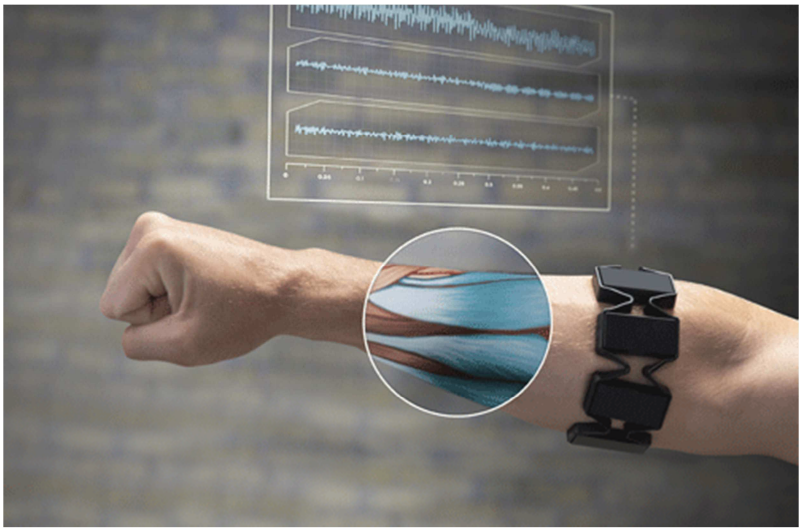

Figure 4. Myo armband control activity forearm. Movements captured by Myo

The controller also has IMU (Inertial Measurement Unit) made with nine highly sensitive axes with a gyroscope, an accelerometer and a guiding (Euler angles) of three axes each. The application can collect data generated by the IMU and identify the movements made by the arm, linear, rotary and positioned in space.

On the other hand, thanks to EMG sensor it can be identified a series of movements based on the contracted muscles of your forearm. In this project are focused: the open hand movements, clenched fist and double tap of finger and thumb. Using the API other hand movements such as turning left or right can also be found.
To process information received from the sensors, the device has an ARM Cortex M4 processor that receives the information obtained by the sensors.

This information is transmitted to the computer using Bluetooth ® technology. This allows a constant flow of wireless information. Thus, freedom of movement is achieved. The Bluetooth connection is obtained via a Bluetooth adapter that plugs into the USB port on the computer.

Moreover, the Myo controller contains a vibrator which returns a feedback to the user. Thanks to it, a vibration was added in the code every time the controller identifies that one of the programmed movements has been made.

4. RESULTS

The hand response operated by Myo and Leap Motion was analyzed and compared.
The procedure was to apply a predetermined angle to each finger and check the system response.

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Positions were calibrated performing directly on the fingers with the control program. Different angles of rotation from the extended finger position were triggered. These actions allowed us to check how the fingers reproduce the commands entered by the motion recognition device used. Similar angles were applied with the two systems (Leap Motion and Myo) of motion capture.

Heart, Leap Motion	
Angle inserted	% from deviation
0	0
15	1
30	2
45	1
60	13
75	8
90	14

Heart, Myo	
Angle inserted	% from deviation
0	0
15	7
30	13
45	19
60	12
75	17
90	13

Table 1. Deviation (%) from the finger to Leap Motion and Myo.

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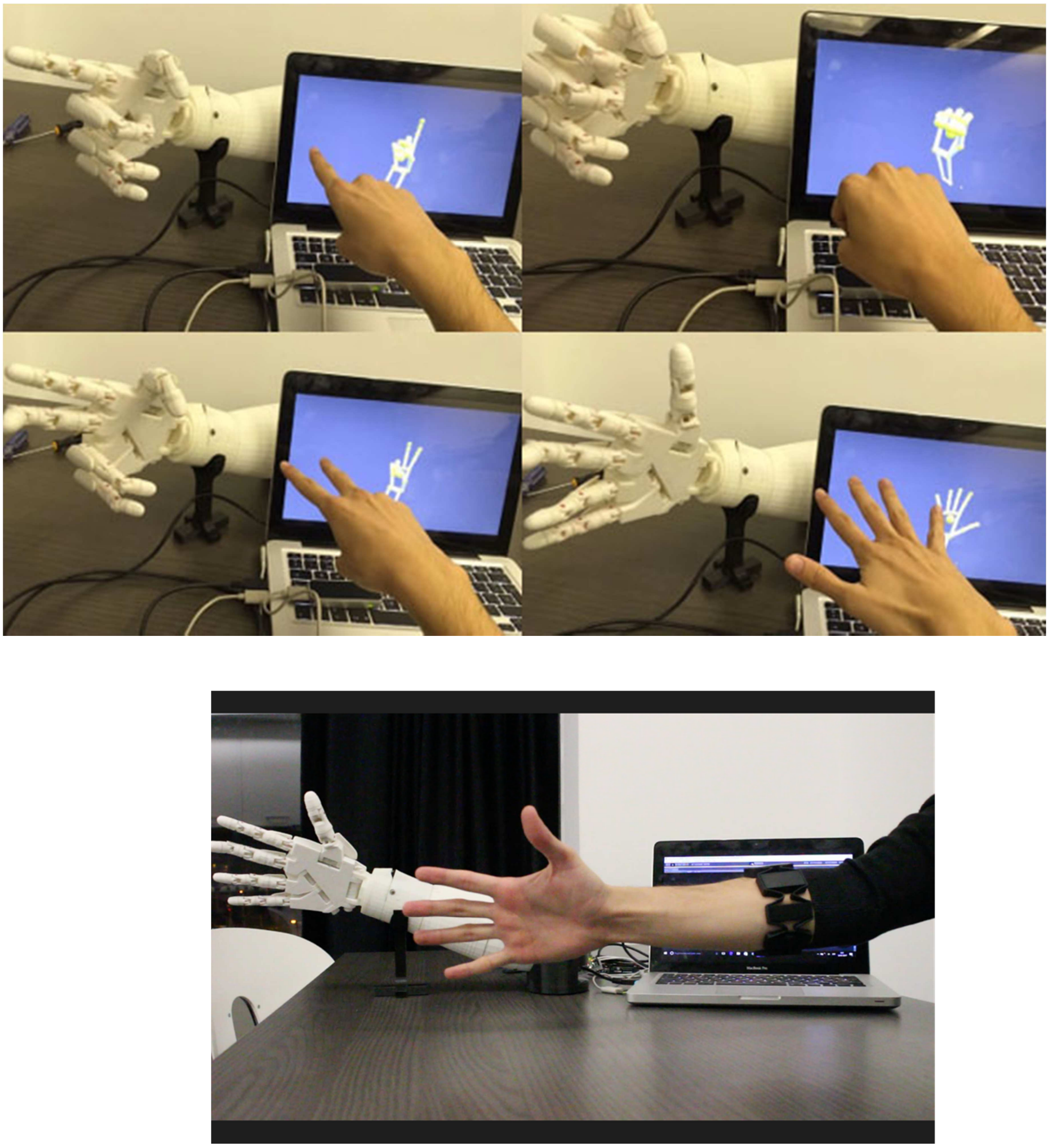

Figure 5. Movements captured by Leap Motion and Myo

The monitoring process, which appears on the screen, using "Leap Motion" gives a sense of continuity because instantly imitates the movements of the real hand (Figure 5).

The precision and flexibility of "Leap Motion" makes it more suitable than "Myo", because it allows greater freedom in the individual control of the fingers and introduces fewer errors in the movement (Table 1).

5. DISCUSSION

Although this is a very new technology, first experiences are appearing evaluating their possibilities [15,16,17]. In this work we have developed two motion capture applications to drive a robotic arm. "Leap Motion" uses a small desktop device that captures the image using two cameras, and allows actuating from distance so that the operator can be isolated from potentially dangerous environments where it is necessary to manipulate objects. In the second configuration "Myo" bracelet sensors can identify a set of arm and hand movements previously defined.
The results obtained ensure greater precision and variety of movements with "Leap Motion" compared to "Myo". In the first case all the fingers and the wrist are operated independently, and in the second case a certain number of positions of both are detected.

Nevertheless, the prototype must evolve until the hand action allows more accurate and appropriate movements.

Similar initiatives can be found in applications that help people with disabilities [15]. In this case, the control of a bionic arm is limited to the reproduction of symmetrical movements. However, after a training period, it is foreseeable that the implanted member should be helpful in everyday life. Future work should serve to determine the usefulness of these prostheses.

When we focus on low cost projects and high performance, we find many implementation possibilities covering manufacture and control. The project described in this article enables to build a bionic arm, move your fingers and wrist and activate it by sensors. Obviously, the proposal described is not the only possible and other designs are possible giving priority to other specifications and requirements. It is not the purpose of this works to describe all of them. A proposal is described trying to provide a useful perspective to the solution of a problem.

6. CONCLUSIONS

The development of a 3D printed robotic arm capable of reproducing the movements of a real hand using different motion capture systems has been successful. In compliance with the specific objectives, a research was conducted with different "mocap" devices and choosing those that best suited the project. It was able to reproduce the movements of a real hand in the robotic arm.
The arm was presented in Oslo Innovation Week and The 22nd MMVR (Medicine Meets Virtual Reality) Los Angeles 2016. In these events the interest of the prototype and its potential as a functional and inexpensive solution was recognized.

Future work could have an impact on various aspects:

Referring to the robotic arm motor function and non-invasive drives based on the detection of movement of muscles, nerves or movements of the other hand, you can work on some options, such as:

- Different types of servomotors. You can get the hand movements developed with more or less power.
- Sensors of presence, pressure and temperature. To adjust the applied force and increase the effectiveness and safety of the process.
- Fiber optic instrumented glove (e.g. Dataglove)
- *Freehand 3D Computer Interaction Without Glove* [9]**,** It emits a laser that, when reflected in the fingers, is received by a camera which reads these reflections and is able to determine the gestures.
- Syntouch technology [10] which allows textures identification of materials.
- Microsoft glasses "HoloLens" [11] They allow us to have a vision with depth and positioning. Very interesting feature as it would interact with virtual objects without requiring any other type of sensor.

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