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# Trajectory Control of A Manipulator of Five Freedom Degrees Through Facial Expressions

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## BACKGROUND

The encephalography is a method that consist in register the electric activity present in the brain through electrodes located in the scalp. Nowadays, this method has been the focus of studies in the last 10 years reaching apply the encephalography in fields such as medicine, engineering o entertainment.

## OBJECTIVE

Design of a trajectory control of a manipulator with five freedom degrees using encephalographic signals (EEG) associated with the movement of face muscles, registered by the Brain-Computer Interface (BCI) Emotiv®.

## RESULTS

A tool was obtained, which through of a collective operation of the reverse kinematic, EEG signals and C++ programming allows controlling the final position of the manipulator gripper with facial expressions.

## CONCLUSION

The scopes of this project were defined from the tests of the system, where had an average position error of 1, 86 cm with regard to the desired position. This means that the system has a low accuracy that prevents the execution of accuracy works, this is caused by manipulator configuration.

**KEYWORDS:** Encephalographic signal, Emotiv, manipulator, reverse kinematic

## INTRODUCTION

The encephalography is a functional exploration technic of the central nervous system through which is obtained a register of brain activity in real time[1]. This register is known as encephalogram (EEG) which is a representation of spontaneous bioelectrical activity generated by neurons[2]. In general, an encephalogram registers different electric rhythms that vary depending of its location, frequency and functional properties [3].

Due to the EEG's capacity of show the activity and pathology of brain, it has been used as a medicine tool for diagnosing epilepsy, encephalopathy or ischemia [4]. In addition, EEG has applications in engineering, due to evolution of technology have been developed devices known as BCI (Brain Computer Interface), that use the electric impulses of cerebral cortex to communicate with an external machine [5].

There is two ways of brain signals acquisition, the first one is an invasive form which consists in the implementation of sensors or electrodes directly in the brain, through an operation called craniotomy [6]. This

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technic has the best space and temporal resolution but due to that requires a physic implementation, can cause infections or permanent damage in the user [7].

The second one is a non-invasive form which consists in the acquisition of signals from the scalp using technologies such as EEG, FMRI (Functional Magnetic Resonance Imaging), MEG (Magnetic encephalography), etc [8]. this technic has less accuracy than the previous, due to the deviation of bioelectrical signals of neurons caused by the skull curvature, even this technic is the most useful tool for BCI applications [9].

Nowadays, the recent researches in non-invasive techniques to acquisition of bioelectrical signals have been focusing in the efficiency of signal processing of brain signals such as Wavelets, FFT, ERP, etc. Example of this is the study of a non-invasive acquisition device called Emotiv, demonstrating that its sensors with best accuracy are located in the motion cortex of brain [10].

The second approach is the increasing of the application fields of this technology. For example, the applications in robotics use the recognition of facial expressions o specific movements to control the direction of a robot [11], other example is in home automation through the recognition of cognitive signals of people with physical disability to operate basic features of any home automation environment [12].

Another application field is in medicine, where have been developed systems with command recognition based on BCI for people with motor and speech disability [13]. Finally, this technology is applying in video games over the past 5 years, involving feelings on the game and in this way recognize the user mood and focus the storyline of the game based of this mood [14].

According with the previous, this work proposes the application of a non-invasive acquisition device of brain signals (Emotiv), that will provide the necessary data to control the gripper position of a manipulator through the reverse kinematic calculating. Obtaining as a result, an application developed in C# that interprets the user facial expressions to move the XYZ axes of a manipulator with five freedom degrees.

## *Methodology:*

This project began with the kinematic analysis of the manipulator with five freedom degrees, as well with the identification of facial expressions. Finally, through the development of a graphic user interface, the interaction between the facial expressions and the manipulator movement was made. This process is shown in figure 1.

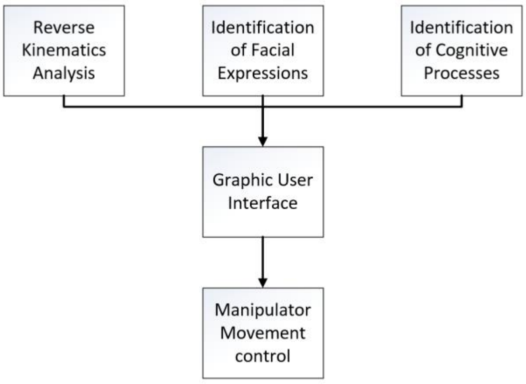


**Fig. 1:** Used methodology.

For making the kinematic analysis, a manipulator with five rotational joints and one gripper was used. According with this, is possible to say that the manipulator has an angular or anthropomorphic configuration, as is shown in figure 2.

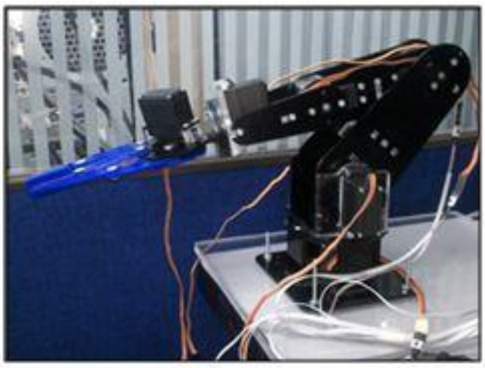


**Fig. 2:** Manipulator with five freedom degrees.

In the kinematic analysis must be specified that each joint has not a spatial movement of 180º, because this movement is limited by the robot structure and the position of each actuator. In table 1 are show the restrictions that have each joint.

**Table 1:** Restrictions of each manipulator joint.

| Joint | Maximum angle | Minimum angle |
|---|---|---|
| 1 | 55º | -55º |
| 2 | 170º | 10º |
| 3 | -10º | -125º |
| 4 | -10º | -125º |
| 5 | 90º | -90º |
| Gripper | 15º | -15º |

In order to control of trajectory, the Denavit-Hartenberg method was used for generating the homogenous matrices of the model and in this way calculate the reverse kinematic. Which from the coordinates given by the user, can be knowing the joint angle and its corresponding trajectory.

According with the steps of Denavit-Hartenberg, the following diagram was obtained that will allow calculating the parameters of each joint, as is shown in figure 3.

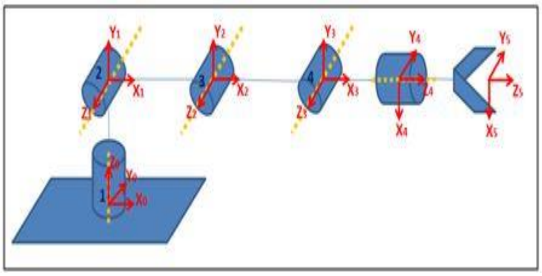


**Fig. 3:** Diagram of Denavit-Hartenberg for the manipulator.

Once identified each homogeneous matrix of the manipulator, the reverse kinematic was calculated through the geometric analysis of the joints angles. In addition, the roll angle was calculated through the iterations taking in to account the restrictions of the manipulator. It is important that the final position of the gripper must be given for making the calculations corresponding, as is shown in figure 4.

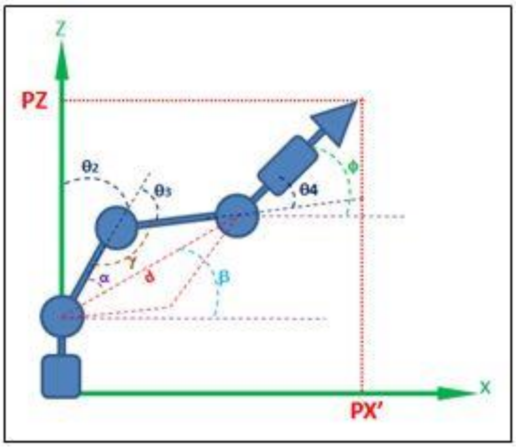


**Fig. 4:** Geometric analysis of the manipulator in the YZ plane.

On the other hand, to data acquisition from the facial expressions of the user was used the Emotiv®, which is an interface for interaction human-computer of high technology and with wireless connection. Emotiv EPOC® uses a set of 14 sensors and 2 references to identify the electric signals produced by the brain and classify the thoughts, feelings and expressions of the user in real time. The sensors distribution of Emotiv® is shown in figure 5.

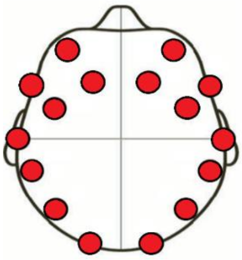


**Fig. 5:** Sensor distribution of Emotiv EPOC®.

In order to interpret the data sent by the Emotiv® SDK in positions to the manipulator, a graphical user interface in C# was developed. The GUI relates the device response from a facial expression of the user with a movement in the XYZ axes of the manipulator. All the expressions used are described in table 2.

**Table 2:** Relation of facial expressions with the manipulator movement.

| Emotiv Response | Position | Description |
|---|---|---|
| Raise brow | X+ | Positive increase in the value of axis X |
| Furrow brow | X- | Negative increase in the value of axis X |
| Smirk right | Y+ | Positive increase in the value of axis Y |
| Smirk left | Y- | Negative increase in the value of axis Y |
| Right eye wink | Z+ | Positive increase in the value of axis Z |
| Left eye wink | Z- | Negative increase in the value of axis Z |
| Smile | GG+ | Positive turn of the gripper. |
| clench | GG- | Negative turn of the gripper. |
| Blink | POn | Close Gripper |

The GUI has as objective simulate the desired position of the manipulator, this simulation was made in Solidworks® through the importation of the 3D model of the manipulator, as is shown in figure 6.

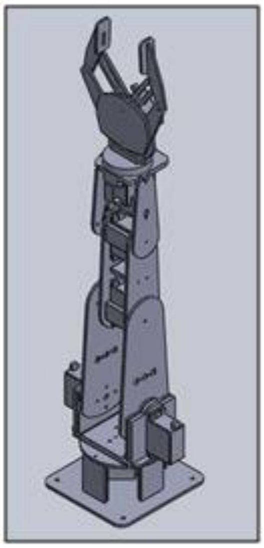


**Fig. 6:** 3D model of the manipulator made in Solidworks®.

The purpose of made this simulation is to avoid the collision and position errors, that can affect the physical integrity of the actuator and the manipulator structure.

Once confirmed the desired position of the manipulator, the communication with itself through the STM32F4DISCOVERY board is made. This board has the minimum requirements to operate this project, which are: 7 PWM channels and TX/RX serial transmission. In this way send the PWM information, through RS232 to the 6 actuators located in the center of each joint, these actuators are metallic servo motors with 10Kg of strength and 0,10 sec/60ž of velocity.

*Results:*

In this case of the manipulator with five freedom degrees, the reverse kinematic was made in two parts. The first one was a geometric analysis followed by an iterative analysis for determining the roll angle appropriate for the given coordinates.

Another limitation in the result of the reverse kinematic is that the servomotors have an average move of 125°, reason why a big quantity of configurations and space work is lost.

According with the previous information, the constants of the reverse kinematic were found, which they were defined as: $d_1$= 91mm, $a_2$= 119.5mm, $a_3$= 97.4mm, $a_4$= 128.95mm, $a_5$= 113.23mm and $d_5$= 242.18mm. With these values, the homogeneous matrices were calculated, represented each by the equations 1, 2, 3, 4 and 5.

$$A_{01} = \begin{bmatrix} \cos(\theta_1) & 0 & \sin(\theta_1) & 0 \\ \sin(\theta_1) & 0 & -\cos(\theta_1) & 0 \\ 0 & 1 & 0 & 91 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{1}$$

$$A_{12} = \begin{bmatrix} \cos(\theta_2) & -\sin(\theta_2) & 0 & 119.35\cos(\theta_2) \\ \sin(\theta_2) & \cos(\theta_2) & 0 & 119.35\sin(\theta_2) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{2}$$

$$A_{23} = \begin{bmatrix} \cos(\theta_3 - 1.57) & -\sin(\theta_3 - 1.57) & 0 & 97.4\cos(\theta_3 - 1.57) \\ \sin(\theta_3 - 1.57) & \cos(\theta_3 - 1.57) & 0 & 97.4\sin(\theta_3 - 1.57) \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{3}$$

$$A_{34} = \begin{bmatrix} \cos(\theta_4) & 0 & -\sin(\theta_4) & 0 \\ \sin(\theta_4) & 0 & \cos(\theta_4) & 0 \\ 0 & 1 & 0 & 242.18 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{4}$$

$$A_{45} = \begin{bmatrix} \cos(\theta_5) & -\sin(\theta_5) & 0 & 0 \\ \sin(\theta_5) & \cos(\theta_5) & 0 & 0 \\ 0 & 0 & 1 & 242.18 \\ 0 & 0 & 0 & 1 \end{bmatrix} \tag{5}$$

For verification the result of the reverse kinematic, tests of position error were made, in which were took 10 random positions to evaluate its kinematic and determine the difference between the result and the initial value. These results are shown in table 3.

**Table 3:** Test of position error of the reserve kinematic.

| Px | Py | Pz | Error |
|---|---|---|---|
| 166 | 96 | 380 | 2.3552 cm |
| 2 | -2 | 447 | 1.2336 cm |
| -93 | -199 | 355 | 0.7342 cm |
| 249 | 100 | 286 | 0.0002 cm |
| -57 | 0 | 356 | 1.8353 cm |
| 50 | 50 | 428 | 3.2353 cm |
| -12 | -9 | 451 | 3.5254 cm |
| 138 | 138 | 354 | 2.1255 cm |
| -86 | 106 | 285 | 0.5676 cm |
| -149 | 89 | 266 | 2,9578 cm |
| Average | | | 1,8570 cm |

Once identified the reverse kinematic of the manipulator, the data acquired to control itself was analyzed. This process was made in the graphic user interface which use the expressive and cognitive modules of the Emotiv® for manipulating the system.

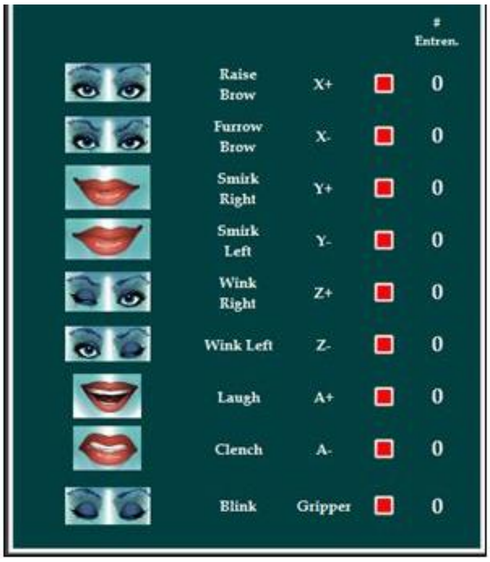
For detection of brain signals, these are measured in intensities between 0 and 1. Through different tests in signals acquisition, the minimum level of intensity was defined, which is 0,2 in order to identify correctly the user decision.

The states used in each Emotiv® module were the easiest expressions acquire by the system. In the cognitive module were assigned actions as a reflection of movement in the Cartesian axis. This allow that the user with less effort, imagines the manipulator movements can do. The imagined movements are shown in figure 7.

| | | | | # Entren. |
|---|---|---|---|---|
| | Pull | X+ | 🟥 | 0 |
| | Push | X- | 🟥 | 0 |
| | Right | Y+ | 🟥 | 0 |
| | Left | Y- | 🟥 | 0 |
| | Lift | Z+ | 🟥 | 0 |
| | Drop | Z- | 🟥 | 0 |
| | Clockwise | A+ | 🟥 | 0 |
| | Unclockwise | A- | 🟥 | 0 |
| | Disappear | Gripper | 🟥 | 0 |

**Fig. 7:** Manipulator control with the cognitive module of the Emotiv®.

On the other hand, the expressive module links the activities with major frequency with movements in the XYZ axes. These movements were controlled by eyebrows, mouth and eyes with purpose of allowing the user see the objective, while making the movement of the manipulator. The expressions used are shown in figure 8.



| | | | | # Entren. |
|---|---|---|---|---|
| | Raise Brow | X+ | 🟥 | 0 |
| | Furrow Brow | X- | 🟥 | 0 |
| | Smirk Right | Y+ | 🟥 | 0 |
| | Smirk Left | Y- | 🟥 | 0 |
| | Wink Right | Z+ | 🟥 | 0 |
| | Wink Left | Z- | 🟥 | 0 |
| | Laugh | A+ | 🟥 | 0 |
| | Clench | A- | 🟥 | 0 |
| | Blink | Gripper | 🟥 | 0 |

**Fig. 8:** Manipulator control with the expressive module of the Emotiv®.

Finally, the movement simulation of the manipulator in the GUI had a response almost in real time, showing with more fluency the motion control through facial expressions. However, the movement control directly on the manipulator had a delay, due to the execution of reverse kinematic and the send of data using the STM32F4DISCOVERY board and the RS232 communication.

the figure 9 shows the differences between the simulation and the real movement of the manipulator, taking a vertical position of the robot is possible observe that the real movement has a position error that was analyzed previously.

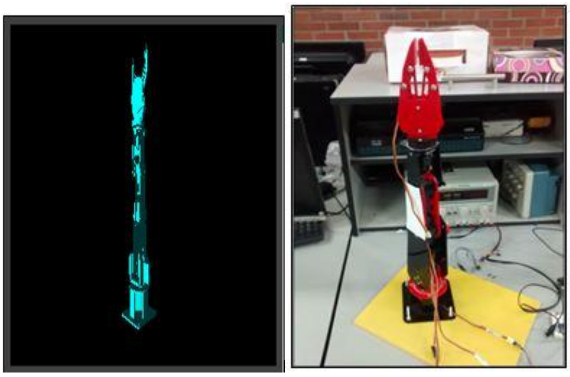


**Fig. 9:** Comparison between the simulation and the real movement.

In this case the position error of the manipulator was analyzed in each joint for the test number seven, which had had an error of 3,5 cm in the final position. This same test has had an average error of 3,8º in the joints position, as is shown in figure 10.

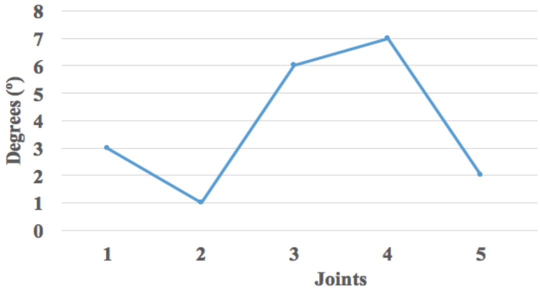


**Fig. 10:** Position error of each joint in the test number seven of the manipulator.

*Conclusion:*

The STM board that was used this project had the capacities necessaries for processing and managing PWM signals to connect the manipulator. However, the velocity and reception of data was low, which affected the execution in real time and caused a delay around 4,65 seconds.

The development of this project was restricted by the servomotors operation, that do not allow appreciating the free interaction of both systems. This is the main reason why was developed a simulation module in the GUI, for giving the option of a control without restrictions. Feature that can be used by designer to analyze and make test of any functionality of the manipulator.

The Emotiv® sensor is a useful device for the brain signals acquisition, but a good performance depends of the abilities and capacities of the user to concentrate and stabilize her expressions and thoughts. In addition, the training of each user parameters allows a better identification of the user signals.

In addition, the scopes of this project were defined from the tests of the system, where had an average position error of 1,86 cm with regard to the desired position. This means that the system has a low accuracy that prevents the execution of accuracy works, this is caused by manipulator configuration. Due to the iterative method which represents big imprecisions with regard to geometric methods that have a better accuracy when are used to calculate the reverse kinematic.

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