Handling robotic system composed by robots petit

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Abstract

This paper presents the development of a handling system with 3 fingers anthropomorphic 4 degrees of freedom, controlled through a graphical interface. The study of direct and inverse kinematics, simulation, assembly and command system thereof, have been made; to ensure anthropomorphic finger movements, a design previously made, has been used. The restrictions have human fingers, as the rotation between each phalanx, have been considered, also the natural coupling between the penultimate and final joints. The graphical interface has been implemented in MATLAB®, the design of the components of the prototype has been made in SOLIDWORKS® and ARDUINO® MEGA2560® has been used for serial communication with the servo motors in the system command. This system allows noting the work performed and is a basis for the development of future robots, robotic systems and applications.

Robotic Handling system, modeling, design, interface, simulation

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1. Introduction

An important part in the realization of this project is the study of direct and inverse kinematics that allows to know the paths of the human finger simulating it, the control of a manipulation system, made up of 3 anthropomorphic fingers, which are controlled by means of the GUI designed with MATLAB® software, also emulates the movement of human fingers.

The human hand is very complex since its study involves the behavior of muscles, bones, tendons and ligaments, in order to obtain a functional design. It is noted that the fingers have been the fundamental basis of previous studies. In the proposed design, the three phalanges of the fingers and their joints were considered. In particular, the aspects related to direct and inverse position modeling are discussed.

1.1 Justification

As part of the development of the project "Design and construction of robots, robot telemanipulation devices and robotic systems for manipulation", the work presented in this article is included. In particular, it is emphasized in the design of robotic systems for manipulation.

1.2 Problem

Obtaining a robotic manipulation system composed by three petit robots, with a total of 12 degrees of freedom, commanded through a graphical user interface that incorporates the geometry designed in computer aided design software.

1.3 Hypothesis

A robot manipulation system will be obtained by using robotspetit, direct and inverse kinematic modeling, high-level language and interactive environment for numerical calculation, visualization and programming, MATLAB®, SOLIDWORKS® computer-aided design software and ARDUINO® MEGA2560® board.

1.4 Objectives

1.4.1 General objective

Design a robotic system to manipulate objects using 3 robots petit.

1.4.2 Specific objectives

- Design the robotic manipulation system with 3 robots petit in solidworks.
- Determine the direct and inverse kinematics of the robotic system.
- Develop the graphical user interface to be able to command the 12 servo motors of the handling system manually.
- Perform tests in simulation.
- Perform validation with the robotic system.

2. Background

As a complement to the previous work support at the Technological Institute of Nuevo León, it can be first mentioned that in (Jiménez Villalobos & Ramírez De La Cruz, 2005) the construction of a robotic arm of three gdl (degrees of freedom) type puma (programmable universal manipulator for assembly).

Equations have been developed for both the direct kinematic model and the inverse kinematic model. Using the Lagrange equations, we have obtained the equations of the dynamic model.

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In the architecture of this robot it is observed that there is a pair of articulations with parallel axes. Then in the work developed in (Cimadevilla Lajud & Pérez Herrera, 2006), it is mentioned that it has been tried to reproduce some limbs of the human being for medical purposes or for the industry. Spatially the hand, this being of paramount importance for everyday activities has become a research topic, robots have been built but to this day has not been able to imitate their skills.

To address the problem of inverse kinematics, the authors consider a finger with three degrees of freedom. The finger develops its motion in an x-y plane, which simplifies the solution of the inverse kinematic model, since the analysis focuses on the configuration of the three joint variables that allow the desired point to be reached (P_x, P_y). However the system turns out to be redundant in a degree of freedom, so the problem lies in how to resolve such redundancy.

In (Aguilar Acevedo & Ruiz González, 2011), the direct kinematic model is shown. The direct kinematic problem is reduced to finding the transformation matrix that relates the coordinate system of the link to the coordinate reference system.

Then in (Cuevas Ramírez, Ramírez Vargas, & Cruz Hernández, 2012), a project involving the design, construction, and control of a 4-degree-of-freedom manipulator arm is presented. The project is divided into 3 stages, the first is the design and mechanical construction of the robot manipulator, the second is the instrumentation and implementation of the control system and the third corresponds to the adaptation of the manipulator arm to a mobile robot to have a robot of Exploration and safety.

In (Suárez & Grosch, 2003) is presented the description of the mechanical hand called MA-I (Intelligent Artificial Hand) as part of an integrated system for the experimentation and testing of strategies of apprehension and manipulation of objects.

As previous developments in the institute, the design of a robotic finger, with anthropomorphic movements, has been presented in (Hernández Hernández, Garcia Andrade, Fernández Ramírez, & Cuan Duron, 2014) and (Hernández Hernández, Garcia Andrade, & Fernández Ramírez, 2014).

Later in (De Leon Treviño, Garcia Andrade, Fernández Ramírez, Cuan Duron, & Urquizo Barraza, 2015) and (Gomez Perez, Fernández Ramírez, Cuan Durón, Urquizo Barraza, & García Andrade, 2016), a robotic grip system is presented, in that system, two robotic fingers are integrated adaptations are made in hardware, electronics and software.

3. Methodology

In this case, the manipulation system is mathematically modeled. In particular, the equations of direct kinetics and inverse kinetics are obtained.

The D-H parameters are used to obtain the matrices of homogeneous transformation and these to be able to calculate the direct kinetics. In the case of reverse kinetics, the natural coupling that exists in the movement of the middle and distal phalanges, allows us to determine the solution of inverse kinetics as the intersection between two circles. The robot petit is used in software SOLIDWORKS® , to assemble the robotic manipulation system composed of 3 robotspetits. It is worth mentioning that the robot petit, has also been designed in soliworks.

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The interface is designed in Matlab, to be able to command the twelve servomotors of the system. The communication is done using the serial port so that ARDUINO® MEGA2560® transform the configurations of robots petit in movement in each one of the degrees of freedom.

3.1 Forward kinematics

In the kinematic modeling of position of a manipulating robot, the relations between the operational space (in which the location of the terminal organ is defined) and the articular space of the robot (in which the configuration is defined) are established.

The direct model is the relation that allows to determine the vector x of operational coordinates of the robot corresponding to a given configuration q.

$$\mathbf{x} = \mathbf{f}(\mathbf{q}) \quad (1)$$

The direct geometric model of a robot can be obtained from the homogeneous transformation matrix of the robot defining the frame n of the terminal link with respect to the frame 0 of the base of the robot. In the case of simple-structure robots, the transformation matrix is given by:

$$^{0}\mathbf{T}_{n} = {}^{0}\mathbf{T}_{1}\,{}^{1}\mathbf{T}_{2} \ldots {}^{n-1}\mathbf{T}_{n} \quad (2)$$

The transformation matrix ${}^{f}T_{E}$ defines a frame of the tool of the terminal organ E with respect to a fixed base f, this matrix can be calculated by:

$$^{f}\mathbf{T}_{E} = \mathbf{Z}\,{}^{0}\mathbf{T}_{n}\,\mathbf{E} \quad (3)$$

3.1.1 Forward kinematic modeling of robots petit

The D-H parameter tables for robot petit 1, 2, 3, which constitute the manipulation system, are shown next in tables 1, 2 and 3.

Link	α_i	d_i	θ_i	r_i
1	0	0	θ_1	0
2	90º	0	θ_2	0
3	0	4	θ_3	0
4	0	3.9	θ_4	0
5	0	1.5	θ_5	0

Table 1 DH Parameters for robot petit 1

Link	α_i	d_i	θ_i	r_i
1	0	0	θ_1	0
2	90º	0	θ_2	0
3	0	4	θ_3	0
4	0	3.8	θ_4	0
5	0	1.5	θ_5	0

Table 2 DH Parameters for robot petit 2

Link	α_i	d_i	θ_i	r_i
1	0	0	θ_1	0
2	90º	0	θ_2	0
3	0	4	θ_3	0
4	0	3.8	θ_4	0
5	0	1.5	θ_5	0

Table 3 DH Parameters for robot petit 3

These parameters of each link i, with i = 1, 2, 3, are replaced in the following formula:

$$^{i-1}\mathbf{T}_{i} = \mathbf{Rot}\,(\mathbf{x}, \alpha_i)\,\mathbf{Trans}\,(\mathbf{x}, d_i)\,\mathbf{Rot}\,(\mathbf{z}, \theta_i)\,\mathbf{Trans}\,(\mathbf{z}, r_i)$$

$$= \begin{bmatrix} C\theta_i & -S\theta_i & 0 & d_i \\ C\alpha_i S\theta_i & C\alpha_i C\theta_i & -S\alpha_i & -r_i S\alpha_i \\ S\alpha_i S\theta_i & S\alpha_i C\theta_i & C\theta_i & r_i C\alpha_i \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (4)$$

Where S is the sine function and C is the cosine function. Figure 1 shows the distances between the bases of each of the robotic fingers that make up the manipulation system once built.

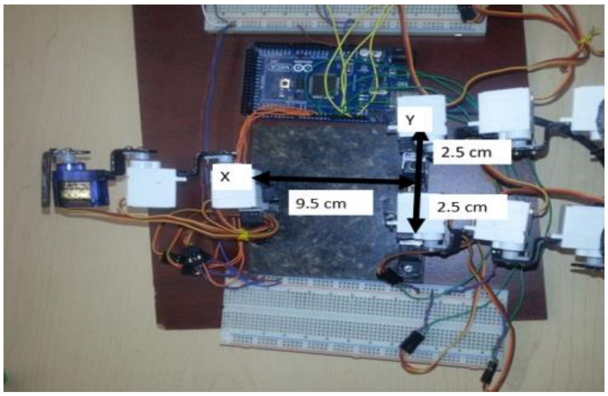

Figure 1 Distances between each finger.

Homogeneous transformation matrix of robot petit 1 with $\theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = 0º$.

$$\mathbf{Z}_1 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 2.5 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \; {}^0\mathbf{T}_1 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$${}^1\mathbf{T}_2 = \begin{pmatrix} 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \; {}^2\mathbf{T}_3 = \begin{pmatrix} 1 & 0 & 0 & 3.6 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$${}^3\mathbf{T}_4 = \begin{pmatrix} 1 & 0 & 0 & 3.5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \; {}^4\mathbf{T}_5 = \begin{pmatrix} 1 & 0 & 0 & 1.5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Homogeneous transformation matrix of robot petit 2 with $\theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = 0º$.

$$\mathbf{Z}_2 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & -2.5 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \; {}^0\mathbf{T}_1 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$${}^1\mathbf{T}_2 = \begin{pmatrix} 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \; {}^2\mathbf{T}_3 = \begin{pmatrix} 1 & 0 & 0 & 3.6 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$${}^3\mathbf{T}_4 = \begin{pmatrix} 1 & 0 & 0 & 3.5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \; {}^4\mathbf{T}_5 = \begin{pmatrix} 1 & 0 & 0 & 1.5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

Homogeneous transformation matrix of robot petit 3 with $\theta_1 = \theta_2 = \theta_3 = \theta_4 = \theta_5 = 0º$.

$$\mathbf{Z}_3 = \begin{pmatrix} 1 & 0 & 0 & 9.5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \; {}^0\mathbf{T}_1 = \begin{pmatrix} 1 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$${}^1\mathbf{T}_2 = \begin{pmatrix} 0 & -1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \; {}^2\mathbf{T}_3 = \begin{pmatrix} 1 & 0 & 0 & 3.8 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$${}^3\mathbf{T}_4 = \begin{pmatrix} 1 & 0 & 0 & 4 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix} \; {}^4\mathbf{T}_5 = \begin{pmatrix} 1 & 0 & 0 & 1.5 \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

In all three cases the matrix **E** is the matrix identity of 4x4.

3.2 Kinematic inverse position model

To obtain the solution of the problem of the inverse position kinematics, in this work, a geometric approach is used. A fixed relationship is used to consider the dependence or coupling of the third and fourth articulations, as mentioned in (Cimadevilla Lajud & Pérez Herrera, 2006), the relationship that was used is the following:

$$\theta_4 = \left(\frac{2}{3}\right)\theta_3 \tag{5}$$

This allowed reducing the problem of inverse kinematics by calculating the intersections between 2 pairs of circles.

In Figure 2, the working space of one of the robot petit of the system is shown. It should be noted here that in order to obtain this working space, the relation expressed in equation 5 is taken into account.

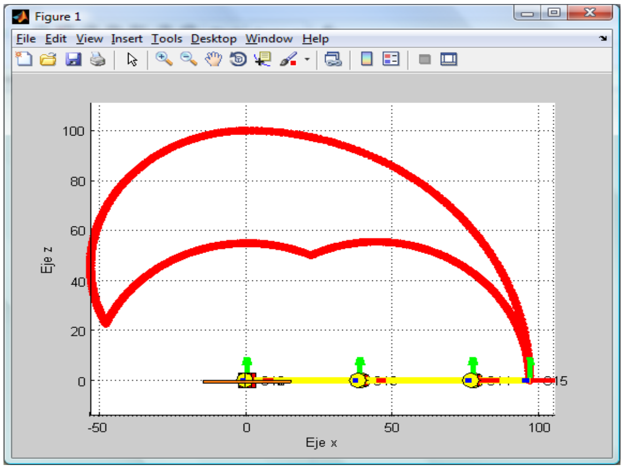

Figure 2 Workspace for each robot petit.

3.3 Manipulation System Modeling.

Petit-robot modeling was done using 3D CAD design software SOLIDWORKS® . Figure 3 shows the different elements or components that were used to assemble the handling system in the SOLIDWORKS® environment.

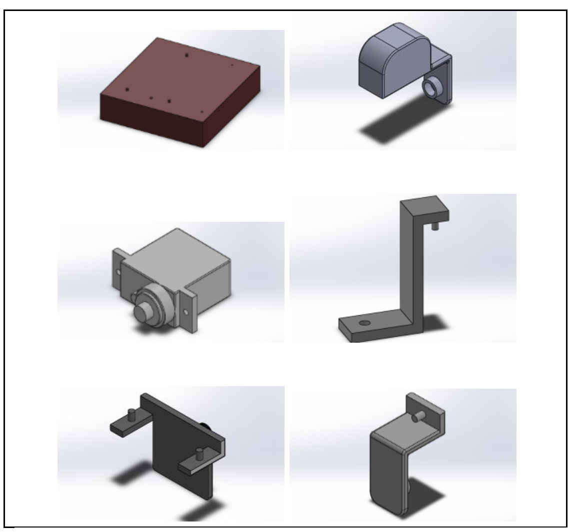

Figure 3 Components for assembly of the manipulation system.

Once each of the robots petit was constructed, the manipulation system was assembled, then in Figures 4-6, the system is shown in some configurations.

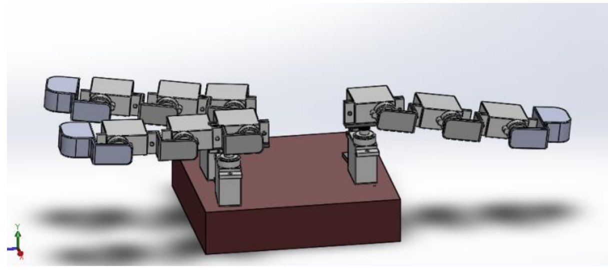

Figure 4 Initial configuration **q** = [0º, 0º, 0º, 0º] for each of the 3 robots.

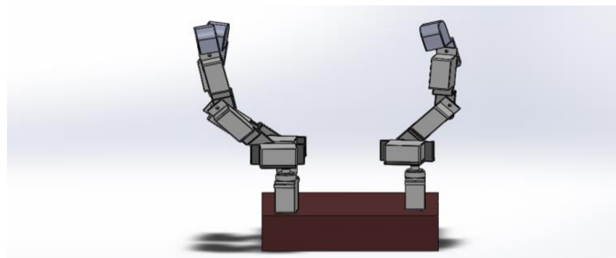

Figure 5 Configuration **q** = [0º, 30º, 50º, 33.33º] for each of the 3 robot petit.

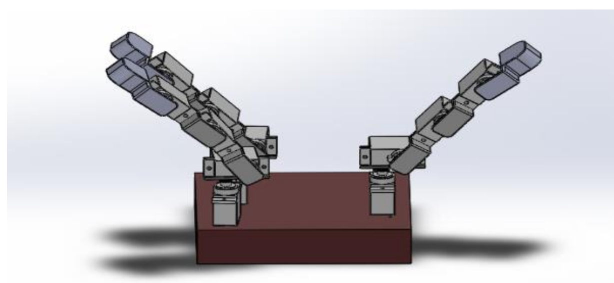

Figure 6 Configuration **q** = [0º, 45º, 0º, 0º] for each of the 3 robot petit.

3.4 Graphic User Interface, GUI

The graphical user interface was programmed using MATLAB® software. Lines for each of the robotic fingers were used to represent each of the phalanges and cylinders for each of the joints. In order to be able to interact with the interface, sliding bars were used, which can be made to vary each of the joint variables of each of the fingers.

The interface has "+" and "-" buttons, which allow us to solve the problem of inverse kinematics. In Figure 7, the graphical interface is shown for the initial configuration **q** = [0º, 0º, 0º, 0º] of each robot; Figure 8 shows the manipulation system in said configuration.

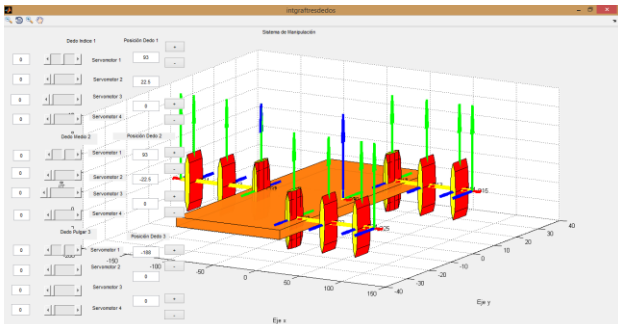

Figure 7 GUI with **q** = [0º, 0º, 0º, 0º] configuration for each robot petit.

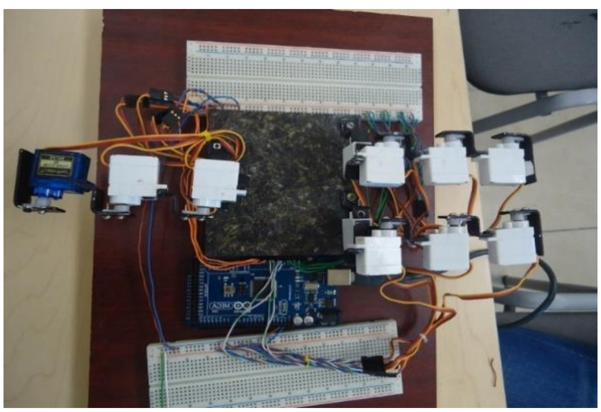

Figure 8 Manipulation system with **q** = [0º, 0º, 0º, 0º] configuration for each robot petit.

3.5 Code

ARDUINO® code used for the operation of the Robotic Handling System.

```
#include <Servo.h>
Servo servo[12];
int pin[12]={
  6,7,8,9,
 10,11,12,13,
 2,3,4,5};
void setup(){
  //servo[0].attach(3);
  for (int i=0;i<12;i++){
    servo[i].attach(pin[i]);
  }
  Serial.begin(9600);
}
int grados;
void loop(){
 if (Serial.available()){
   for (int i=0;i<12;i++){
     grados = Serial.parseInt();
     if(grados>0 && grados < 180){
       servo[i].write(grados);
       delay(50);
     }
   }
 }
}
```

4. Results

With the robotic manipulation system that has been presented, the desired objectives have been achieved; some improvements have been monitored throughout the development of this system.

This robotic system was conceived with the idea of following up on a project of design of construction of mini-robots, previously realized. It has been considered to improve both the design and how to control it through programming. The objective of being able to integrate a more complex robotic system, from the mini-robots previously designed, has been fulfilled.

The number of manipulable degrees of freedom has been multiplied by three, the graphical user interface has been modified for this purpose. The robots petit of the manipulation system move anthropomorphically.

In order to support the results of the developed system, in the graphical user interface as well as in the real robot petit, in figure 9, a second configuration **q** = [0º, 45º, 45º, 45º] is shown; Figure 10 shows the manipulation system in this configuration.

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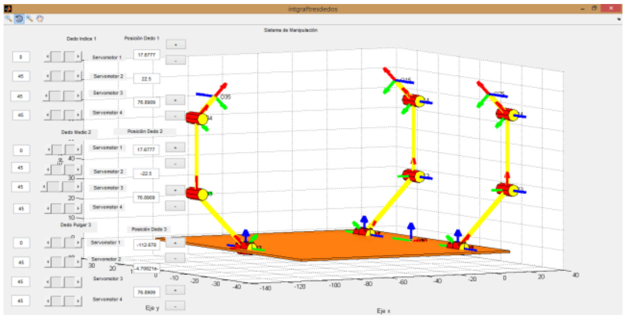

Figure 9 GUI with **q** = [0º, 45º, 45º, 45º] configuration for each robot petit.

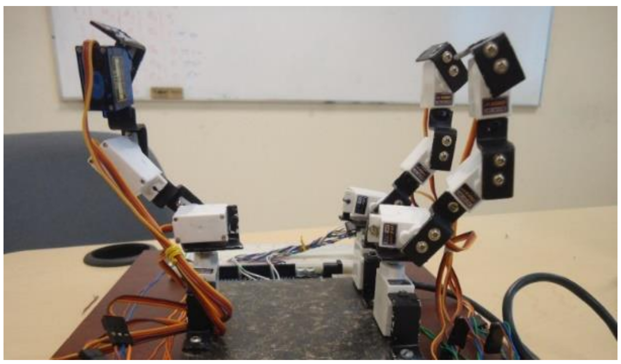

Figure 10 Manipulation system with **q** = [0º, 45º, 45º, 45º] configuration for each robot petit.

In figure 11, a third configuration **q** = [0º, 45º, 45º, 45º] is shown and the manipulation system is illustrated in figure 12.

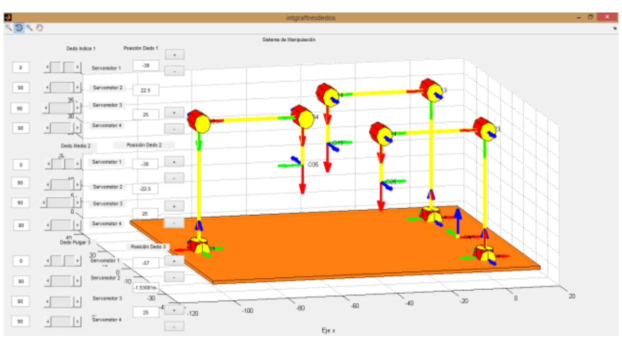

Figure 11 GUI with **q** = [0º, 90º, 90º, 90º] configuration for each robot petit.

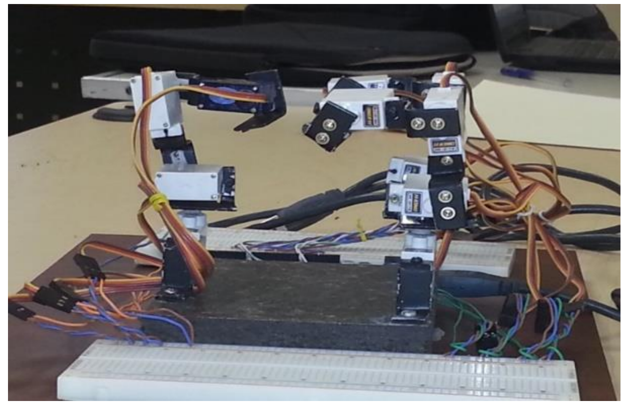

Figure 12 Manipulation system with **q** = [0º, 90º, 90º, 90º] configuration for each robot petit.

5. Conclusions

The dimensions of the links were taken into account and the different models were determined to solve the inverse kinematics and direct kinematics, that is, the calculation of the position considering the joint variables that produce it.

The modeling of the links was done using CAD software SOLIDWORKS® where the design of the system was formed. One aspect that was not taken into consideration when making cuts and folds was the loss of a few millimeters, causing not all links to have the same dimensions, and this in turn, making the assembly specifically for each robot.

Intercommunication via the serial port was also carried out, communicating via MATLAB® and the ARDUINO® MEGA2560® board, controlling it through the Graphical Interface. This allows the comparison of the physical model and the graphical model, since at the moment of giving an instruction so that the manipulation system has a movement. In this comparison, the joint boundaries for each robotic finger were taken into account, as are the angles in which a finger can be moved initially to the end point or limit at which its movement arrives.

Areas of opportunity have been identified, on the one hand improvements in the modeling and design of links, on the other hand can use other type of actuators.

Different ways of telemanipulating the system are also explored.

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