DESIGN AND CONSTRUCTION OF A MANIPULATOR TYPE SCARA, IMPLEMENTING A CONTROL SYSTEM

John Faber Archila Diaz, john.faber@ufrj.br, joaofaber@gmail.com
Robotic and Automation Laboratory – COPPE/UFRJ
Federal University of Rio de Janeiro - UFRJ
Industrial University of Santander – UIS Colombia
Postal Box 68.503 – CEP 21.945-970 – Rio de Janeiro, RJ, Brazil.

Max Suell Dutra, max@mecanica.coppe.ufrj.br
Robotic and Automation Laboratory – COPPE/UFRJ
Federal University of Rio de Janeiro - UFRJ
Postal Box 68.503 – CEP 21.945-970 – Rio de Janeiro, RJ, Brazil.

Claudia Johana Diaz, cayita1_diaz@hotmail.com
Industrial University of Santander – UIS Colombia
Postal Box 68.503 – CEP 21.945-970 – Rio de Janeiro, RJ, Brazil

Abstract. *This paper describes the design and construction of a Robot manipulator type SCARA (Selective Compliance Assembly Robot Arm). The robots SCARA are robots of 3 degrees of freedom, uncounted the end off, designed for the assembling of pieces and the selective manipulation its control system, allows the positioning of the end effector in their points of work (control point to point - PTP). For the design of SCARA, was developed the robot's kinematics and dynamic study, developing and applying a Mechatronics methodology using CAD (Computer Aided Design) and CAE (Computer Aided Engineering) tools. In this paper is presented the mechanical and control system, the electric and electronic components for the operation, and the implementation of the control system. This robot uses servo-motors and DC motors to generate the necessary torque to make their tasks. The motors control is developed whit PWM signals and used three microcontrollers for it. The microcontrollers generate a signal PWM beginning from calculus of inverse kinematics developed in the Mechatronics design*

Keywords*: SCARA, robotics, Direct kinematics, forward kinematics, Mechatronics Design Methodology, CAD-CAE*

1. INTRODUCTION

This work takes the idea of robot SCARA and develops a methodology for the design and construction of these types of robots. The design was aided in software of engineering CAD and CAE and considers the differents stages of the process. The control system works whit microcontrolers, and the system of supervision control and data acquisition SCADA was development in matlab, all the robot was development whit technology available in the country.

The SCARA (Selective Compliance Assembly Robot Arm) manipulators are devices whose geometric configuration is angular of cylindrical type, they are the most used in applications that require quick movements and uniforms; a particular characteristic is its selective adaptation that is extremely useful in assembling operations that require the insert of objects in pallets.

Due to their construction the SCARA is extremely rigid in the vertical address; but it can adapt laterally, facilitating the palletization task. Figure 1

Figure 1 commercial robots type SCARA.

2 DESIGN

2.1 MECHATRONICS DESIGN METHODOLOGY

The Design of robot SCARA required knowledge of diverse disciplines of engineering including topics of mechanics, electronic, control, and programming, for the success of the project it was developed the methodology that is presented in the figure 1.

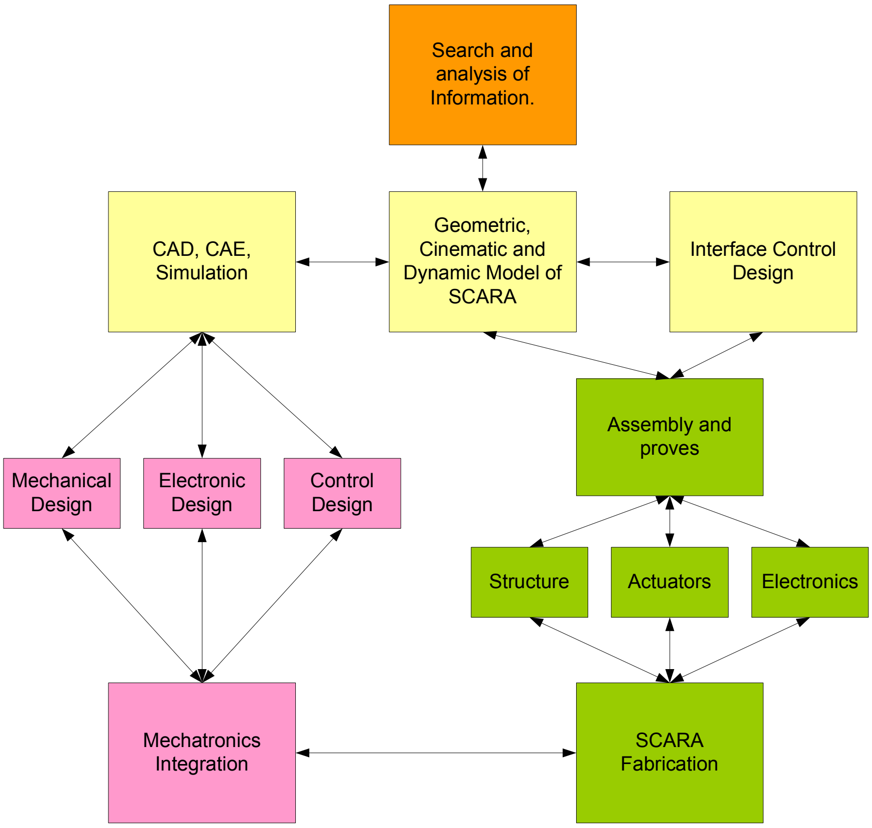

Figure 2 Mechatronics design Methodology

The fist step is the search study and analysis of information in databases, magazines and specialized books in accordance whit the classic methodology of investigation. Whit base in this information one carries out the first geometric model, necessary to make the cinematic and dynamic models of the SCARA.

Whit the mathematical models its possible make the simulations and the first control design, mechanical design, electronics design, and interface control design. all they were developed with the help of specialized software, the mechanical design in solid edge and Ansys Work bench, the design of the control and the control interface in Matlab, the electronic design in circuit maker and mplab.

Once facts the models in each software that was made that denominate mechatronics integration, this integration is the synergy among the mechanical design, electronic design and control design, achieving a virtual model that allows to modify the design variables with easiness, that is to say a model of flexible design was gotten that allowed to make modifications to the robot from the disciplines of the mechatronic, evaluating its influence and acting.

Finished the design stage one carries out the construction of the prototype of the SCARA. in this stage it is closed the knot of the design process making the necessary adjustments characteristic of the construction process and evaluated their influence in the robot's acting.

2.2 MECHATRONICS DESIGN

2.2.1 KINEMATICS

The kinematics model was built whit the algorithm of Denavit Hartenberg; the DH parameters are the relationships among the robot's serial links. The DH parameters was obtained whit the next geometric configuration figure 3.

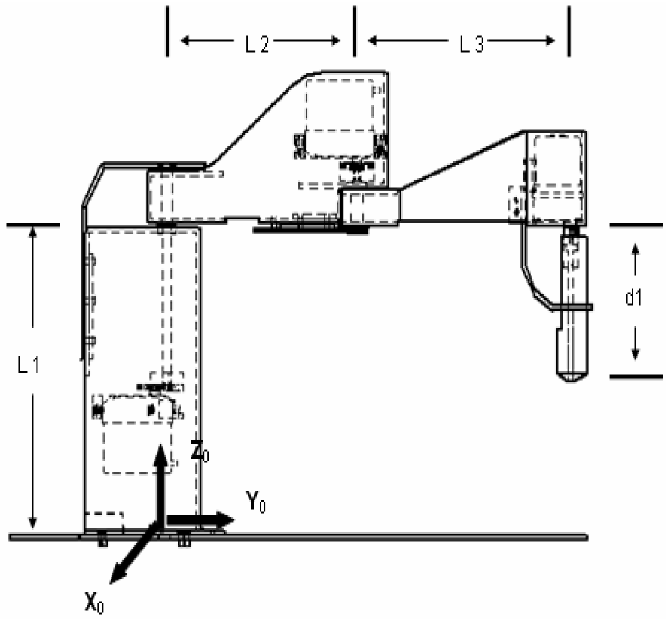

Figure 3 Geometric configuration.

The DH parameters according to the configuration of the SCARA are presented in the table 1

Table 1. DH Parameters.

Link	θ_i	d_i	a_i	α_i
1	q_1	l_1	l_2	0
2	q_2	0	l_3	0
3	0	$-d_1$	0	0

Once found the parameters of each link, you begins to calculate the matrix A for each link, for obtain the matrix of transformation equation 1 and 2

Carrying out the product among matrix, the matrix of transformation T is obtained and indicates the localization of the final system with regard to the system of reference of the robot's base.

$$T = [A_1^0 \times A_2^1 \times A_3^2\ ] \tag{1}$$

$$T = \begin{vmatrix} c\theta_1 \times c\theta_2 - s\theta_1 \times s\theta_2 & -c\theta_1 \times s\theta_2 - s\theta_2 \times c\theta_2 & 0 & l_3 \times (c\theta_1 \times c\theta_2 - s\theta_1 \times s\theta_2) + c\theta_1 \times l_2 \\ s\theta_1 \times c\theta_2 + c\theta_1 \times s\theta_2 & -s\theta_2 \times s\theta_2 + c\theta_2 c\theta_2 & 0 & l_3 \times (s\theta_1 \times c\theta_2 + c\theta_1 \times s\theta_2) + s\theta_1 \times l_2 \\ 0 & 0 & 1 & -d_1 + l_1 \\ 0 & 0 & 0 & 1 \end{vmatrix} \tag{2}$$

With the matrix T it is possible to calculate the values of (P_x, P_y, P_z) whit respect to coordinate system fixed.

Then the (P_x, P_y, P_z) obtained whit direct kinematics are equations (3), (4) y (5)

$$P_x = l_2 Cos\theta_1 + l_3 Cos\theta_{1-2} \tag{3}$$

$$P_Y = l_2 Sin\theta_1 + l_3 Sin\theta_{1-2} \tag{4}$$

$$P_Z = l_1 - d_1 \tag{5}$$

To find the values that adopt the coordinated of the robot's articulations $q = [q_1, q_2, d_1]$ that allow to position and to guide their end articulation according to a certain space localization, were used geometric methods according whit the figure 4, the equations (6), (7) and (8) show the mathematical model for the inverse kinematic.

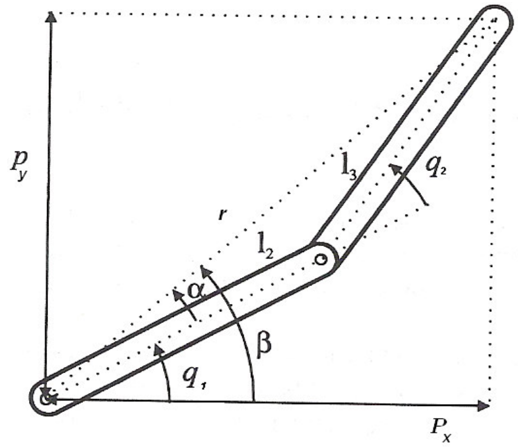

figure 4 Coordinated of the robot articulations.

Inverse kinematics:

$$q_1 = tan^{-1}\left(\frac{P_y}{P_x}\right) - cos^{-1}\left(\frac{l_2^2 + P_x^2 + P_y^2 - l_3^2}{2 \times l_2 \times \left(P_x + P_y\right)^{1/2}}\right) \quad (6)$$

$$\theta_2 = q_2 = cos^{-1}\left[\frac{P_x^2 + P_y^2 - l_2^2 - l_3^2}{2 \times l_2 \times l_3}\right] \quad (7)$$

$$d_1 = l_1 - P_z \quad (8)$$

Direct Jacobian matrix:

The manipulator's speeds are calculated by means of the Jacobian matrix, where knowing the speeds of the articulations we obtain the speed with which the SCARA describes a trajectory. With the equations of the cinematic models the following matríx is obtained equations (9).

$$\begin{bmatrix} \dot{x} \\ \dot{y} \\ \dot{z} \end{bmatrix} = \begin{bmatrix} -(l_2S\theta_1 + l_3S\theta_{1-2}) & -(l_3S\theta_{1-2}) & 0 \\ (l_2C\theta_1 + l_3C\theta_{1-2}) & -(l_3C\theta_{1-2}) & 0 \\ 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} \dot{q}_1 \\ \dot{q}_2 \\ \dot{q}_3 \end{bmatrix} \quad (9)$$

The matrix jacobian inverse is showing in the follow equation (10), this matrix allow to find the speed of joints or articulations for speeds of the end off.

$$J^{-1} = \begin{vmatrix} -C\theta_{1-2}/l_2/\left(C\theta_{1-2}S\theta_1 - S\theta_{1-2}C\theta_1\right) & -S\theta_{1-2}/l_2/\left(C\theta_{1-2}S\theta_1 - S\theta_{1-2}S\theta_1\right) & 0 \\ \left(l_2C\theta_1 + l_3C\theta_{1-2}\right)/l_3/l_2/\left(C\theta_{1-2}S\theta_1 - S\theta_{1-2}C\theta_1\right) & \left(l_2S\theta_1 + l_3S\theta_{1-2}\right)/l_3/l_2/\left(C\theta_{1-2}S\theta_1 - S\theta_{1-2}C\theta_1\right) & 0 \\ 0 & 0 & -1 \end{vmatrix} \quad (10)$$

2.2.2 DYNAMICS

The dynamic model was obtained by means of the Formulation of Lagrange-Euler. The Formulation of Lagrange allows to describe the dynamics of the Scara starting from an energy balance. From this point of view the robot is considered like a black box. The equations only keep in mind the stored energy that is expressed in kinetic energy terms and potential. The Langrangiano is a scalar function that is defined as the difference between the kinetic energy and potential of a mechanical system, in function of the widespread coordinated. As equations (11), (12), (13) are the results of lagrange model, all they were made with reference to figure 5

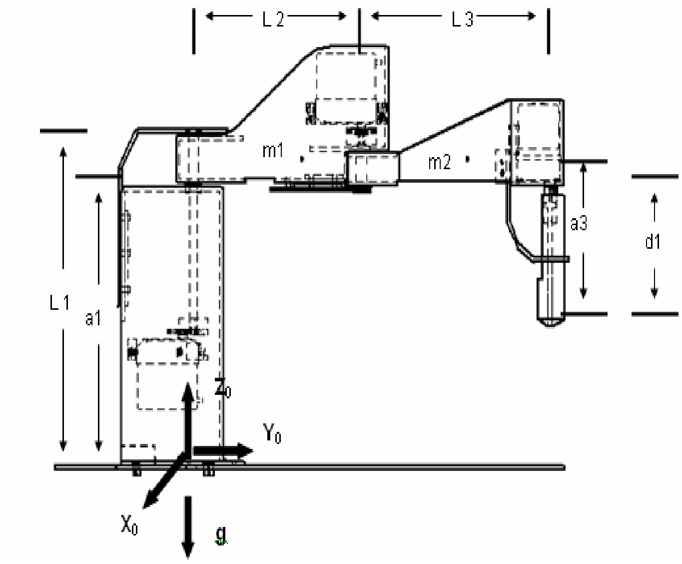

figure 5. Geometric model for dynamics model

$$\begin{aligned} T_1 = &\left[\left(\frac{1}{3}\times m_1 + m_2 + m_3\right)\times l_1^2 + \left(m_2 + 2\times m_3\right)\times l_1 \times l_2 \times cos\theta_2 + \left(\frac{1}{3}\times m_2 + m_3\right)\times l_2^2\right]\times \ddot{\theta}_1 \\ &+\left[\left(\frac{1}{2}\times m_2 + m_3\right)\times l_1 \times l_2 \times cos\theta_2 + \left(\frac{1}{3}\times m_2 + m_3\right)\times l_2^2\right]\times \ddot{\theta}_2 \\ &-\left(m_2 + 2\times m_3\right)\times l_1 \times l_2 \times sen\theta_2\left(\dot{\theta}_1 \times \dot{\theta}_2 + \frac{1}{2}\times \dot{\theta}_2^2\right) \end{aligned} \quad (11)$$

$$\begin{aligned} T_2 = &\left[\left(\frac{1}{2}\times m_2 + m_3\right)\times l_1 \times l_2 \times cos\theta_2 + \left(\frac{1}{3}\times m_2 + m_3\right)\times l_2^2\right]\ddot{\theta}_1 \\ &+\left(\frac{1}{3}\times m_2 + m_3\right)\times l_2^2 \times \ddot{\theta}_2 + \left(\frac{1}{2}\times m_2 + m_3\right)\times l_1 \times l_2 \times sen\theta_2 \times \dot{\theta}_1^2 \end{aligned} \quad (12)$$

$$F_3 = m_3 \times \ddot{d}_1 - m_3 g \quad (13)$$

2.2.3 CAD MODELS

With the cinematic and dynamic models, they were built the model cad that evolved with the load requirements simulations in ANSYS and restrictions in the manipulator's actuators figure 6

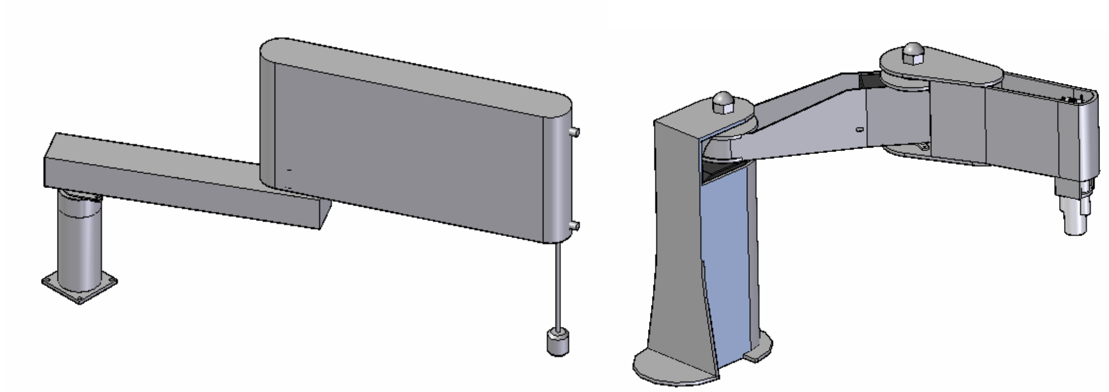

Figure 6 CAD Models , Development in solid Edge V 12

2.2.4 CAE MODELS

The CAE models were evaluated in the software of finite elements Ansys Work Bench 8.1 the loads was determinate whit dynamical model, making the evaluation of their structural behavior. Some simulations are presented in the figure 7, figure 8 y figure 9

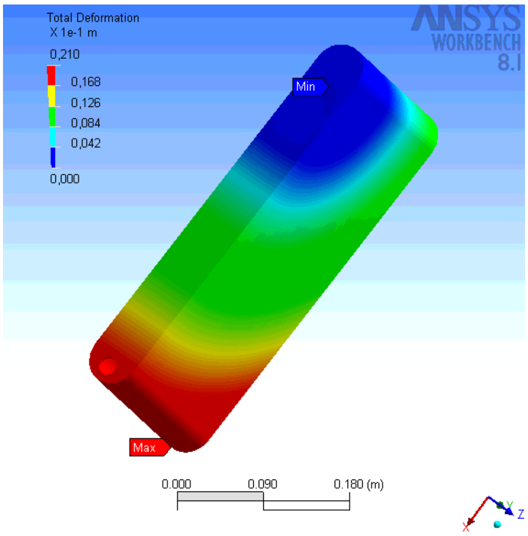

Figure 7 first CAE model

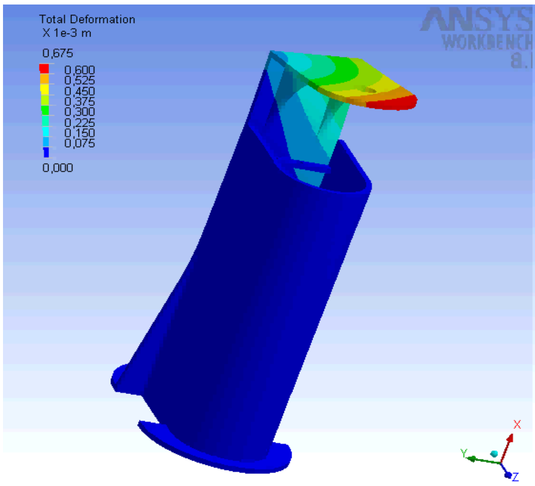

Figure 8 second model (Base)

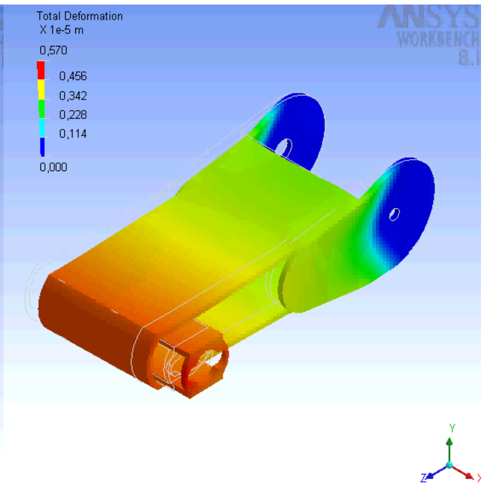

Figure 9 Second Model (Arm)

The simulations CAE allowed to make the evaluations of the different CAD proposed model, improving their design, but conserving the robot's functionality.

2.2.5 CONTROL SYSTEM DESIGN

For design of control system it was necessary to select the actuators, for this selection we needed to take the dynamical model and search the torque and power consumption for the correct operation. Electric motors of type servomotors were used; since inside the selection characteristics that were looked for they offered high couple, they increased the precision, they originated less magnetic noise and of course their weight and consumption were low; what allowed an appropriate working of the manipulator's articulations. The types of motors used are two servo motors; those which they go located respectively in the base and the manipulator's arm. The servos are a special type of motors that are characterized by their capacity to be positioned in a quick way in any position inside their operation range. For their operation, the servo waits a train of pulses that corresponds with the movement to carry out.

The control system used in the robot is a system in open loop in global terms with an internal closed loop that guarantees the positioning of the servomotor and consequently of the robot's articulation, in the figure 10 the outline of general control is shown.

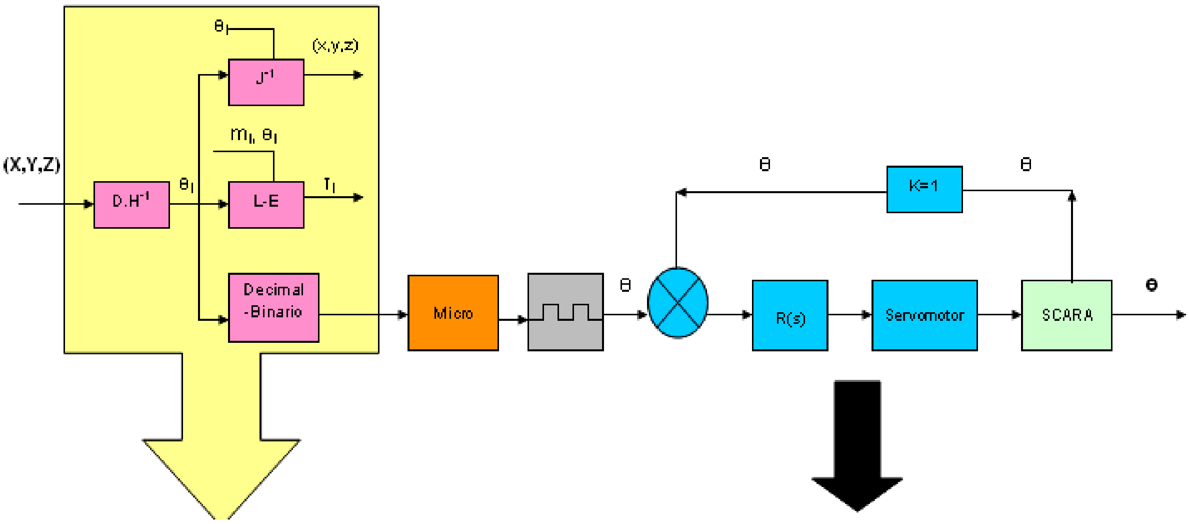

Figure 10 Block Diagram of control model.

2.2.6 INTERFACE CONTROL DESIGN

The interface was designed in Matlab allows by means of a graphic interface to know the position in which the Scara must be located in his work space; it is structured so that the user can call diverse functions inside a main program. Considering that the project looks for that the manipulator be a didactic tool for the user; this program serves as aid element, obtaining who the students can verify their kinematics and dynamics calculations, with the results that software generates. The user is the one who enters the angles of positioning of each articulation so that the manipulator arrives to the wanted position; otherwise it enters the value of coordinated (X,Y,Z), so that he is located directly in a given point. This is achieved by means of the Direct and Inverse kinematics described in two functions in Matlab that are included inside the main program. The program also allows to calculate the speeds to which the manipulator arrives to his final location. The calculation of Jacobian was used to describe one function in Matlab. Finally we could obtain the torque of each movement that makes the Scara in its two rotations and translations. This was achieved by means of the dynamic equations that were previously realized. The graphic interface is presented in the figure 11, which contains all the operations

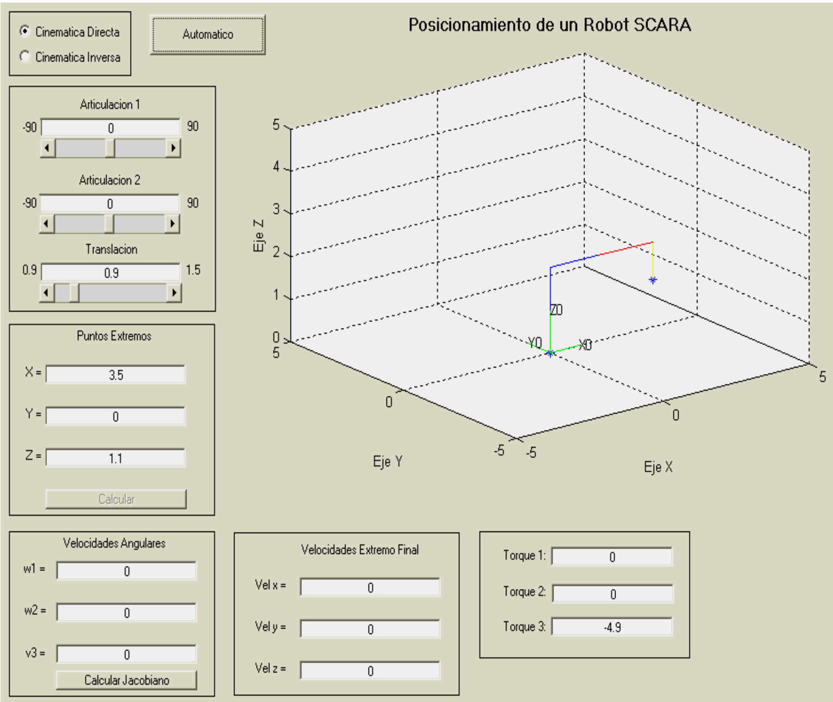

Figure 11. Interface of control.

2.2.7 ELECTRONIC DESIGN

The electronic design included a selections of microcontrollers for to drives the servomotors and the design of one card of data communications, the selected microcontrolers were the PIC 16F873, the PIC18F84, and a card of data communications takes the dates of the parallel port to master microcontroler. Once selected the type of microcontroller to use and well-known the electronic operation of the actuators it is come to develop the card of data communication. From the three used microcontrollers the PIC 16F873 takes the function of master, whereas both remaining (PIC 16F84) they are used like slaves within the process. The software made in matlab allows to send the signals of the angles of binary way to the actuators through parallel port; so that they modulate this type of signals must be sent first a the microcontrollers, who convert a signal train of pulses (PWM) so that the servo ones capture them, they activate and they manage to execute the operation. The masterful microcontroller is who directly receives the sent signals from matlab and has the following responsibilities:

The first signal that receives must send it to actuator 1 so that this one executes the action. Figure 12. The second signal that receives must send it to the first PIC 16F84 (that works like slave) so that it takes it to actuator 2 it activates and it conducts the corresponding operation. Figure 13. The third signal that receives must send it to the second PIC 16F84 (that works like slave) so that it leads it to the motoreductor that activates per times for which it lowers and it raises respectively. Figure 14.

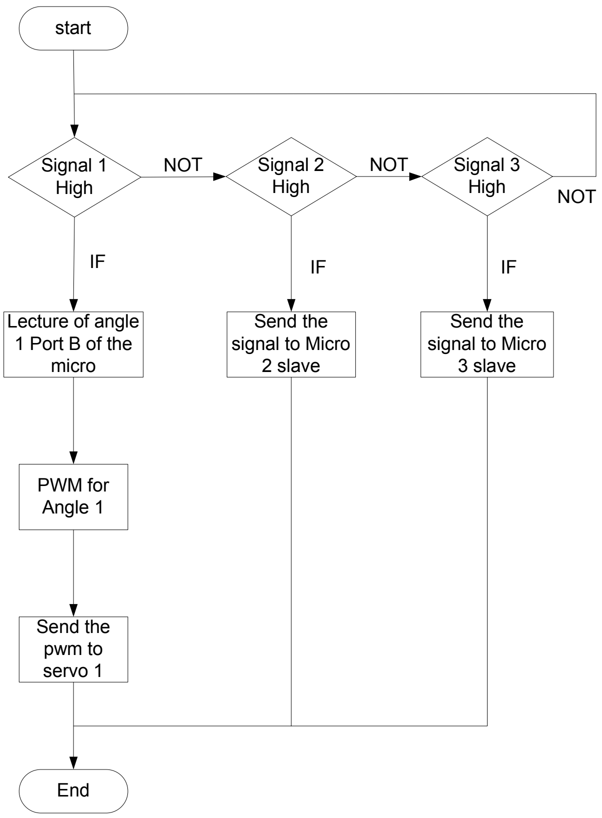

Figure 12.

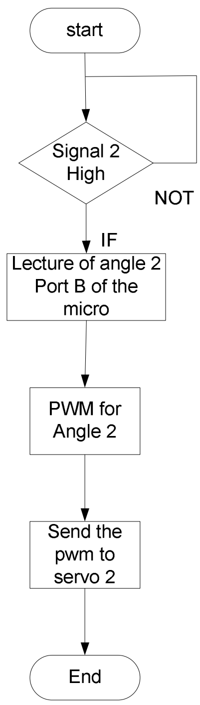

Figure 13.

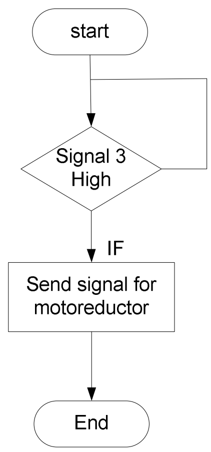

Figure 14.

The Electronics associated to control system was simulated in mplab fr the microcontroler and circuit maker for make the electronic card, circuit maker works how CAD and CAE for the electronic case the figures 15 and 16 show the model in circuit maker.

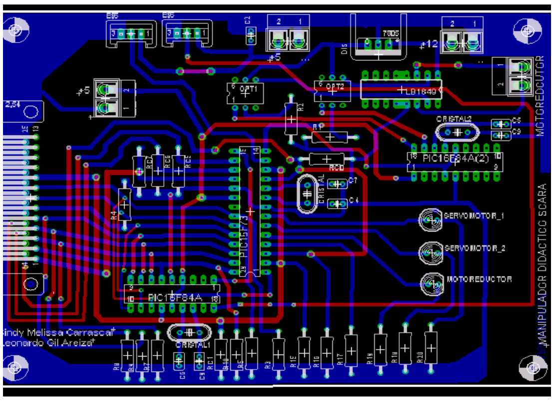

Figure 15 CAD for electronic Card

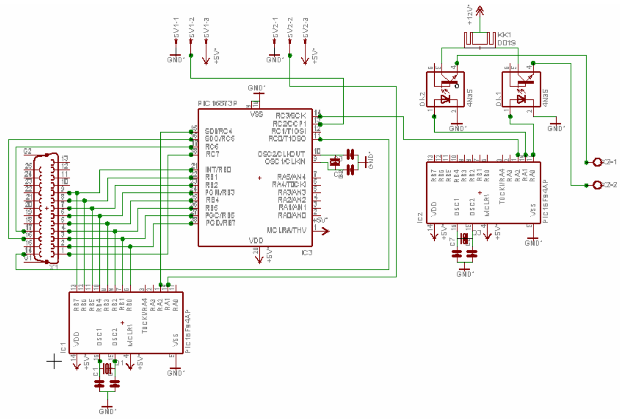

Figure 16 CAE for electronic model.

2.2.8 PROTOTYPE

The prototype of robot SCARA is presented in the figure 16, the geometry of robot was selected for increasing the inertial forces, and observe their effect, in the figure 16 too can observe the acquisition data card or communication card develop in this work.

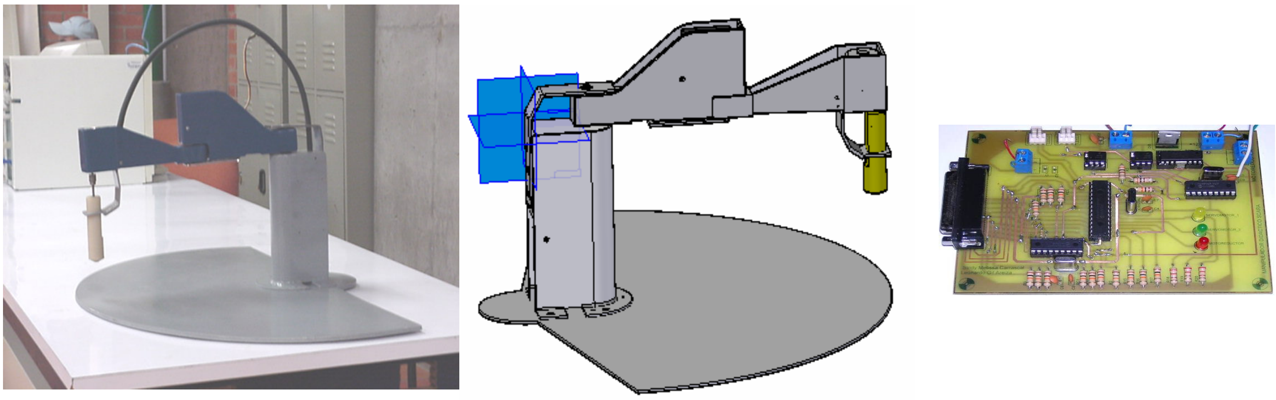

Figure 16, Prototype of robot SCARA

3 CONCLUSIONS

with the present work you outlines and it proved a methodology of mechatronic design that includes specialized tools of engineering software, the methodology allowed to have a virtual model on the one which to make tests and changes in the design, evaluating the influence of the same ones in the different areas of the mechatronic, being able to reduce the time of the robot's development and avoiding possible errors before their construction, the final prototype includes a system of control point to point PTP and an end off.

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