

# Analysis of 3 RPS Robotic Platform Motion in SimScape and MATLAB GUI Environment

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## Abstract

This paper presents a novel system of robotic assistance, which uses an optimization algorithm for human-machine collaborative work. With this development, the path of a robot is calculated, avoiding collision with obstacles and people placed into its workspace, in order to reach an object. As optimization algorithm, the outside penalty method with the variants of absolute value and quadratic penalty is used, taking the location of the operator and a safety distance as restriction. To define the operation of the robot in a virtual environment, we use a plane parallel to the base of the robot, moving it at different distances in order to simulate the interaction with the operator.

**Keywords:** Optimization, robotics

## INTRODUCTION

The application of parallel robots has increased for tasks that demand high speeds, effective relationships between load and power, greater precision and efficient distribution of weight for a given object [1] [2], an example of this type of industrial robotics is a platform Parallel robotics with three kinematic chains and three types of articulation (3RPS) connected to a fixed base located at the bottom and generating positional displacements to a mobile platform. It is there when the development of control phases is determinant to manipulate the structure in this opportunity through the creation of a virtual simulation environment to control the platform built in a CAD system through a graphical interface, therefore to generate a quantitative and qualitative analysis of the prismatic and rotational movements of the 3D components.

An assembly of parts of the parallel platform is then generated by means of its CAD components in the SolidWorks software, the installation of the simulation and diagramming tools in Matlab with a detailed integration procedure of the two programs. Also development through testing the control block diagrams of each joint and the final set of the platform and in turn in each of its options through the tool Simulink, SimMechanics and Simscape Multibody to determine the most efficient For the controller. Finally, using another MatLab tool, GUIDE, creating the graphical interface and the programming code lines of each button that intervenes in the process [3].













Finally, the process of working in the virtual environment is expressed by controlling the simulation of the model in Simulink.

## SimScape Multibody

Simscape Multibody contains a library of blocks and simulation and control interfaces to interconnect Simscape plans with the Simulink environment. The Simscape blocks contains elements for modeling mechanical systems consisting of solid bodies connected by joints with translational and rotational degrees of freedom.

Simscape automatically configures reference systems and constructs a scheme with mathematical solutions used [3]. To understand the applied blocks, their function is detailed in Table 1.

**Table 1.** SimScape Blocks

Group	Block	Name	Description
Initial Parameters		World Frame	Construction of the reference point of the mechanical model. World Frame is the land of all mechanical links.
		Mechanism Configuration	Initial configuration of the mechanical and simulation parameters that will be applied to the whole mechanism, properties such as element gravity (9.81 m / s ^ 2) and Delta linearization (0.001) are configured.
		Solver Configuration	Defines the configuration values for the simulation, the parameters of consistent tolerance (1), solver type (Euler), sample time (0.001), linear algebra and memory capacity delays.
		Transform	Defines a fixed and rigid 3D transformation between two frames or for each kinematic extension. The components specify the translational and rotational parts for the model and its GDLs.
Platform Components (bodies)		Base Fija – B0012_1_RIGID	CAD converted into block representing the fixed base of parallel platform. It contains an input configured by the initial parameters and three outputs for the three kinematic chains.
		Actuador_x_RIGID	CAD converted into block representing the three actuators of the parallel platform. Composed of a cylinder, pneumatic piston, a servo motor and coupling parts. It has an entrance that connects with the rotational joint and in the outlet connects with the prismatic Joint.
		Pistón_1_RIGID	CAD converted into block representing the three pistons of the parallel platform. This element represents the displacement of the chain. Translational movement.
		Default_25_2_RIGID-Esfera	CAD converted into block representing the three spheres of the parallel platform. A piece that involves a movement of 3 GDL connected to spherical and rotational joints.
		Plataforma Móvil B0020_1_RIGID	CAD converted into block representing the mobile platform of the parallel robot. It connects through three ports corresponding to the sphere and in turn through the extensions. Translational and rotational movement.
Articulations		Rotacional	Rotational Joint to interpret the motion at angles between the actuators and the fixed base. Contains 2 connection points and 1 monitoring point.
		Prismático	Prismatic Joint to interpret the translational movement of the piston. It contains 2 connection points with the actuator and the piston, a monitoring point and a control point (input signal).
		Esférico	Spherical Joint to interpret the movement in 3 degrees of freedom of the mobile platform without restrictions.

Control Blocks		Conversor PS-Simulink	Block that translates the elements of second to first generation of Simulink to interpret data and signals. Used for angular monitoring of the rotational joint.
		Conversor Simulink-PS	Block that translates the signals from first to second generation of Simulink. It interprets the input data to move the piston to the prismatic joint.
		Bloques Constantes	Signal input. Enter the distance value of the three desired pistons through a control system.
		Display	Display to display the degrees of rotation of each actuator.
		Gain	Gain applied to control systems.
		Time Scope	Graph 2D to visualize the signal produced by the variation of the displacement of the pistons

**CAD Parallel Robotic Platform**

The CAD files are arranged to assemble a virtual structure that complies with the requirements of conversion to .xml file and send it to Simulink for its respective virtual control. The components that makes up the final assembly are distributed by subassemblies that make up unique pieces. These sub-assemblies are the fixed base, rotational part, the three actuators (cylinder, piston and servomotor), sphere and mobile platform [3]. The final assembly (Fig. 1) is obtained by means of the position relation types of the sub-assemblies as the standard concentric, coincident and parallel span ratios and the advanced distance position ratios and thus set up constraint parameters of the movements. With the position relationships the RPS (Rotational, Prismatic and Spherical) joints are configured that comprise the system. In order to generate the control blocks in MatLab and their respective simulation.



**Figure 1.** Visualization of the parallel robotic platform imported from the 3D model of the SolidWorks program

**Development of the model in Matlab / Simulink**

The CAD model assembled in Solidworks is exported to Matlab through a plug-in that interconnects the two platforms and in turn is directed to the Simulink tool. The conversion can be done for the two types of assembly of control diagrams

raised for devices of mechanical robots, these are SimMechanics and Simscape Multibody.

The development of the model applied in the two environments manifests the most efficient option to work the simulation, the later kinematic analyzes and the resolutions of mathematical equations that have as benchmark a series of tests executed in sub Assemblies that intervene in each of the three articulations that the model has and finally review the response that maintains the complete prototype before an environment of control and simulation [4].

**SimMechanics Block Diagram Development**

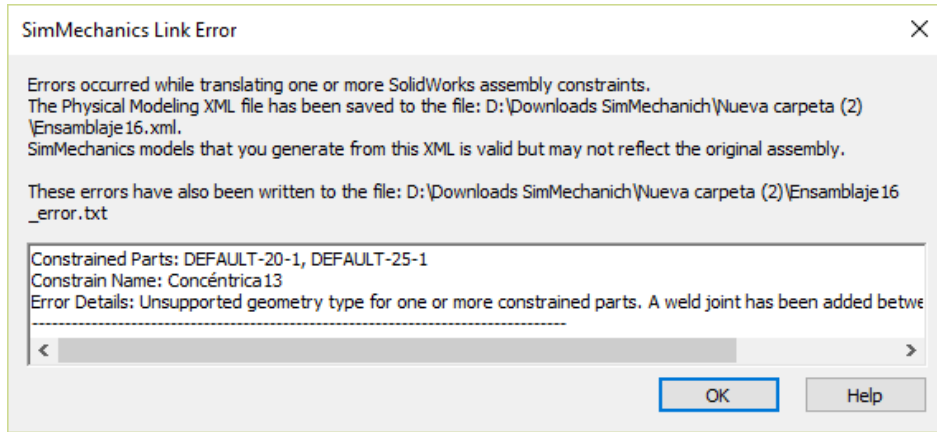
Simulations were performed with different sub-assemblies of the platform in SimMechanics (First Generation) to understand the software environment, to identify the function of each block, the time and objective of the simulation, prototype analysis, identify assembly problems of structure or position relationships made in SolidWorks, to mechanically detail the movements and failures of each piece, construction of control blocks to give displacement to the moving parts [2]. For this, the assemblies comprising the prismatic, rotating and spherical junction were taken as simulation, since they are the points of analysis to analyze the mechanics of the movement.

The tests performed on the sub-assemblies containing the prismatic and rotational joints performed well in the simulations and with no errors in the respective conversions.

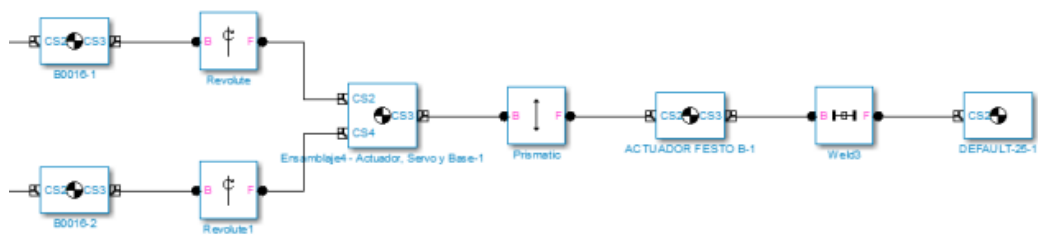
On the contrary, the spherical joint presented errors (Fig. 2a) in the conversion of the model to SimMechanics by not identifying the spherical block and therefore the program replaced it by a Weld block (Fig. 2b)

A solution is proposed by replacing the Weld block with a Spherical block in the Simulink window (Fig. 2c), obtaining unsatisfactory simulation results (Fig. 3).

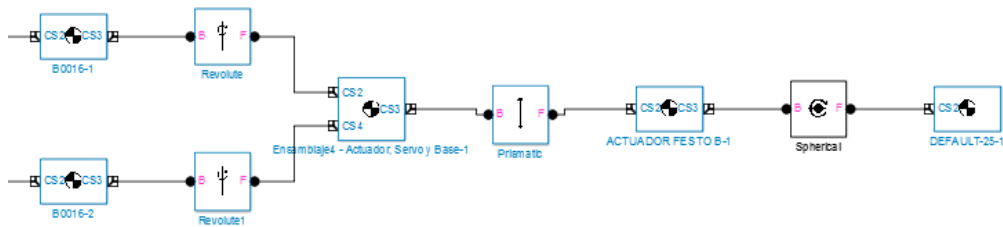
When presenting the above mentioned problem, the conversion of the complete parallel platform to Simulink is performed observing the same error, with no possibility of movement and therefore no virtual CAD control option.



(a)



(b)



(c)

**Figure 2.** Report of the error conversion (a); Blok diagram with welded articulations (b)



**Figure 3.** Unsatisfactory results of the simulation in the spherical joint

**Development in block diagram of Simscape**

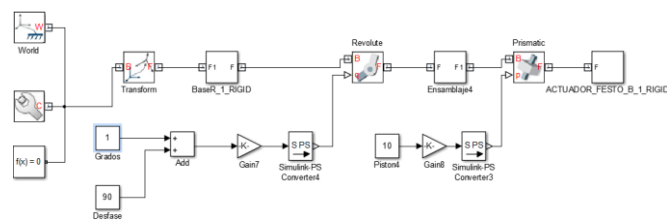
The tests carried out in Simscape, as in SimMechanics, are carried out on models derived from the general, and the respective conversions are made between the developer programs of the sub-assemblies that make up the platform to identify the corresponding articulation of a mechanical extension to its representation In block system and also to recognize the function of each block, obtaining results and

elapsed time of the simulation, prototype analysis, understanding of the new generation of blocks, understanding and application of the new parameter configuration, problem identification Of assembly in terms of the structure of each part or the position relationships in SolidWorks, mechanical details of the movements, failures of each part and construction of control blocks to generate displacement to the moving parts [3].

The described study is performed and analyzed in Simscape Multibody to conclude performance compared to SimMechanics. In turn, the simulation of the sub-assemblies comprising the prismatic, rotational and spherical joints, which comprise the points of analysis, is started.

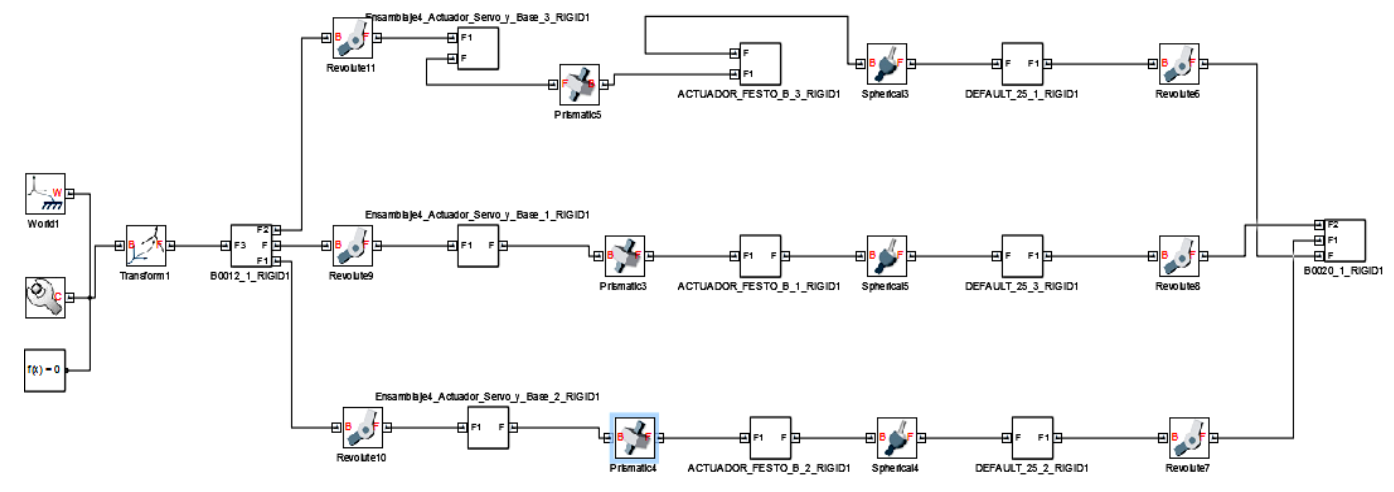
– Prismatic and rotational assembly

The prismatic articulation is analyzed in the displacement of the piston through the actuator cylinder and the rotational one through the gradual movement of the actuator with reference in the fixed base when effecting a movement of the three kinematic chains. When executing the conversion, a block diagram is obtained and the joint for the simulation is previously configured. In addition, a control input with a numerical value (Fig. 4) is designed to allocate the displacement of the piston and the actuator in the simulation (Fig. 5).



**Figure 4.** Control block diagram for prismatic and rotational assembly.

– Spherical Assembly



**Figure 6.** Initial block diagram of the parallel platform.

– Displacement of the pistons:

The construction of a control block to provide movement to the actuator pistons through a numeric value or input signal shown in centimeters which indicates the path of the part by the cylinder and in turn the translation of the movable platform [3].

On this occasion, there is no problem with the conversion of the model, the diagramming of the control is satisfactory in terms of assembly and parameters, the sphere is kept on its axis. Therefore, the simulation is done with the complete platform.

**Parallel Platform in Simscape Multibody**

The model is constructed in block diagram (Fig. 6) after the conversion of each piece into Simulink language without generating errors while maintaining relationships and position constraints.

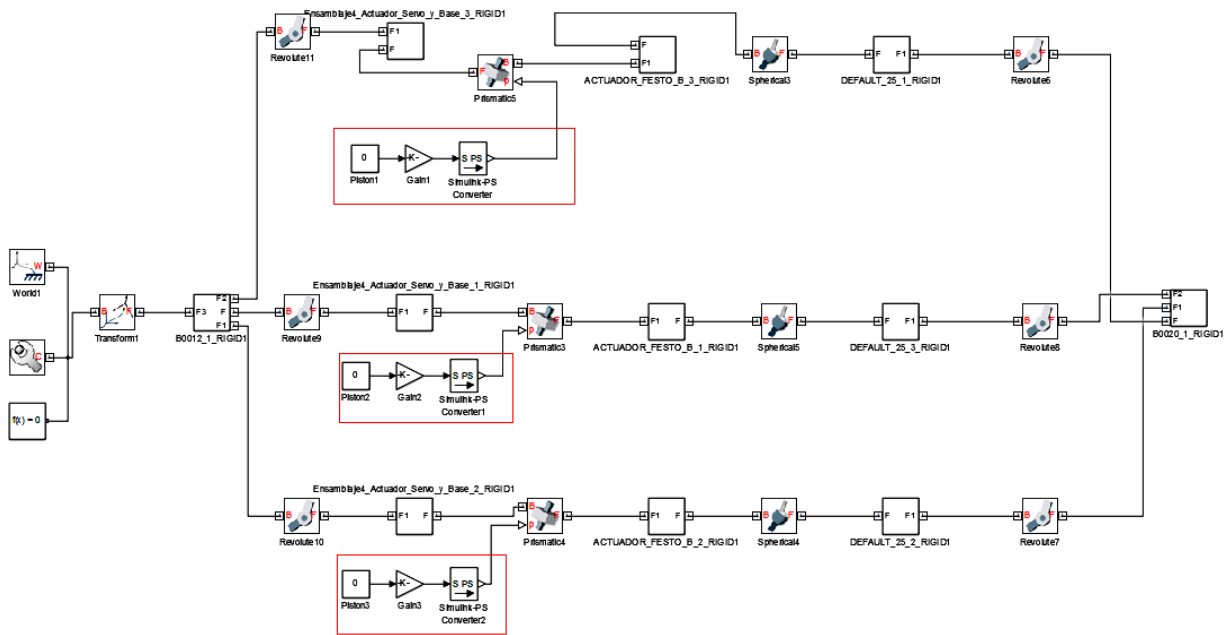
In the previous figure we observe each block described in section 2 of the article and also the joints that comprise the 3RPS systems, from left to right is located the rotational ball joint, then the prismatic joint and finally the ball joint connected to the mobile base.



**Figure 5.** Simulation for prismatic and rotational assembly.

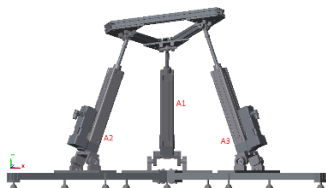
The control only applies to the prismatic joint since for the rotational joint it is not necessary to control a directed movement because the system through its kinematics moves autonomously. For the configuration in the prismatic block, an input is set for proper control.

The new control scheme (Fig. 7) has the numerical input, gain and converter blocks from Simulink to Simscape.



**Figure 7.** Diagram of blocks with control of the three prismatic articulations of the parallel platform (marked areas)

The simulations were performed to determine assembly errors or missing data to then record the results by entering an input value in each of the three Blocks available and observing the displacement of the piston and the virtual structure in general in the simulation [3] – Displacement Piston1 (A1): 5cm, Piston2 (A2): 10cm, Piston3 (A3): 15cm (Fig.8)



**Figure 8.** Simulation 1: Virtual control of displacement of pistons and actuators

Another simulation exercise is shown below:

– Displacement Piston1 (A1): 10cm, Piston2 (A2): 35cm, Piston3 (A3): 10cm (Fig.9).

Some restrictions are considered and for this the ranges to be taken into account in the entries for the displacement of each actuator and not to produce errors in the stability of the structure are established the following conditions are established:

1. The lower value should be approximately greater than or equal to one-third of the mean value, ie equal to or greater than 0.3.
2. The mean value should be approximately greater than or equal to one-third of the largest value, ie equal to or greater than 0.3.

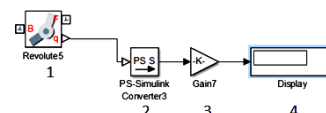
If either of these conditions is not met, the simulation of the system is erroneous.



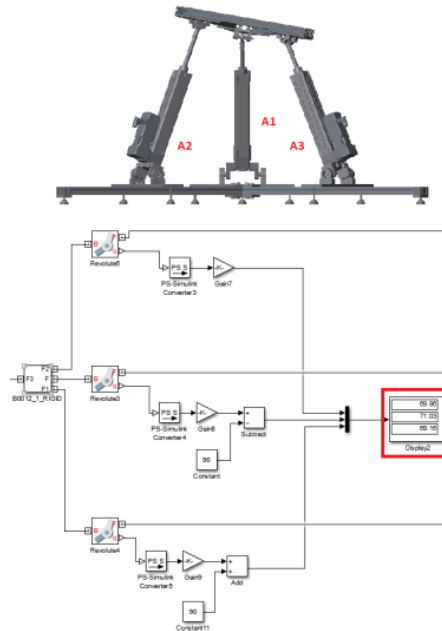
**Figure 9.** Simulation 2: virtual control of displacement of pistons and actuators

– Rotational joint monitoring The displacement of each piston takes into account the sensing or monitoring of the degrees of inclination that each actuator possesses due to the incidence of another mechanism and how it responds to its position. The reference point or starting point is taken from the base of each subassembly actuator [3].

To do this, an output is configured to the rotational block to connect a monitoring system (Fig. 10) composed of a PS-S converter, a gain block to convert the radian units to degrees and a display for each of the three joints and observe the displacement in degrees of the actuator before the prismatic movements (Fig. 11).

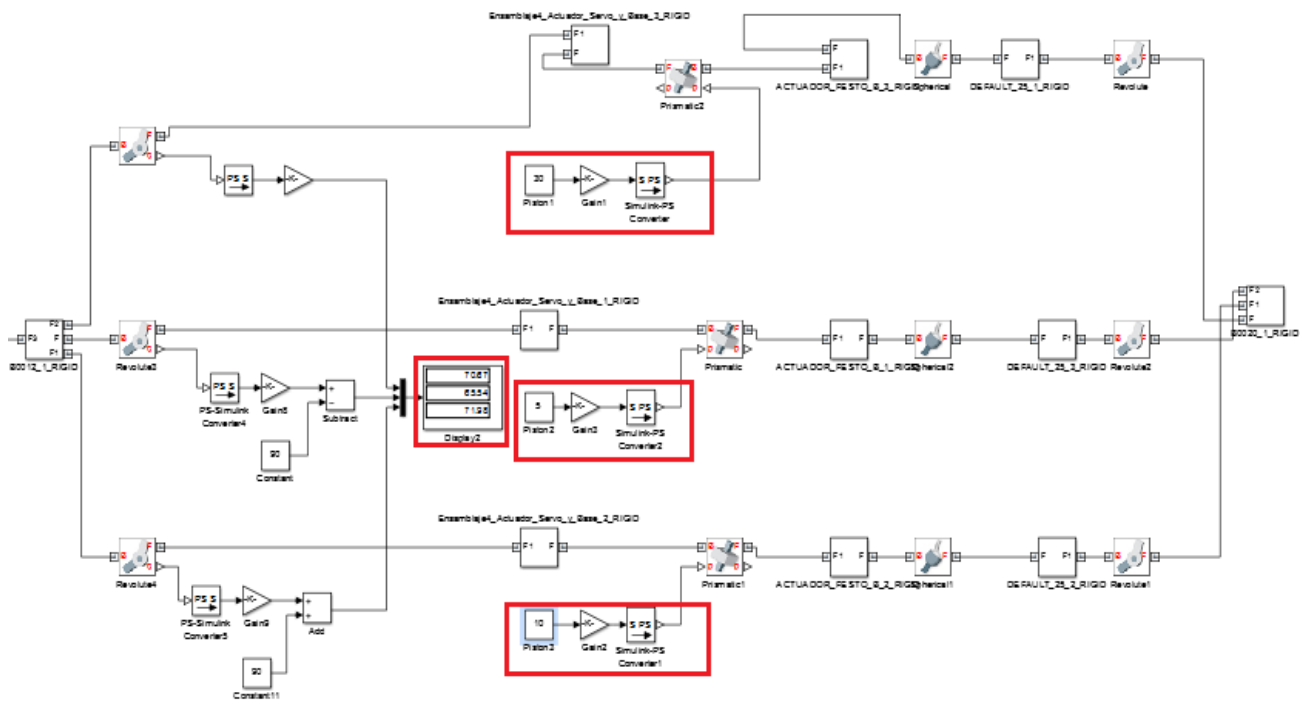


**Figure 10.** Monitoring diagram for the rotational displacement of each actuator



**Figure 11.** Rotational simulation and monitoring.

The block diagram of the parallel robotic platform (Fig. 12) is constructed and simulated to integrate with the graphical interface identifying the control and sensing points.



**Figure 12.** Diagram of final control blocks of the parallel robotic platform.

The design of a user-friendly and user-friendly interface was developed through Matlab's GUI graphics platform which, through the programming of buttons, text boxes and sliders, controls the simulation in terms of the desired distance for the user Displacement of the three pistons of the virtual platform

assembled in blocks in Simscape Multibody and Simulink and with a previous treatment in the points of analysis, ie the mechanical joints of the 3RPS robot. This complements the structure of the virtual simulation environment [5].



The graphical interface is constructed and detailed in Figure 13.



**Figure 13.** Graphical Control Interface of the Platform

The graphical environment is conformed as follows [3].

1. Load the model, in this part you will find three buttons.
  - Browse: Find the model path in Simulink, the file must have extension .mdl
  - Remove: Cancels the configured file.
  - Load: Load the model for its respective model by configuring the initial state and the communication and assembly parameters.
2. Shifting control of the actuators, each slider represents the user-guided movement of each platform piston from a minimum value 0 (left end) to the maximum value 35 (right end). The user manipulates these status bars to update the data that is sent to the Simulink environment and thus to the simulation.
3. Start button, Run is the start signal to start the simulation process. When searching, loading and running the block model in GUI runs the automatic simulation of the system and with the movement of the slider move the desired piston. In addition the simulation parameters correspond to the time it is configured in INF (Infinity) at a simulation speed of 64x to increase the transmission speed and visualization of the synchronization between interface and simulation. Also change the Consistency Tolerance value of the Solver Configuration block in the Simscape model from  $1e-9$  to 1.

#### Boot procedure

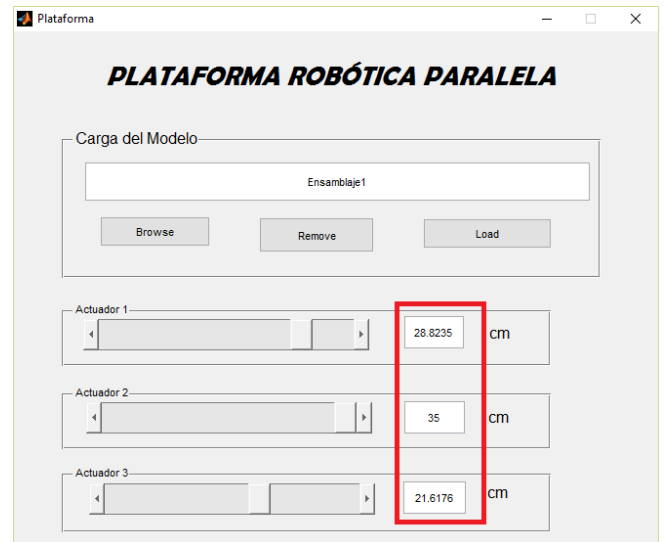
1. Save the Simulink model, Assembly1 in extension .mdl
2. In Matlab open the folder containing the model to be controlled in the Browse Folder.
3. Select the editor's simulation button.
4. The GUI interface is displayed. Click on Browse and look for the stored model. Open
5. Press Load to load the model.



**Figure 14.** Load of the model

The current values are loaded into the control system.

6. Click on the RUN button
7. The Simscape simulation window is noted.
8. Open the model in Simscape.



**Figure 15.** Visualization of the current state

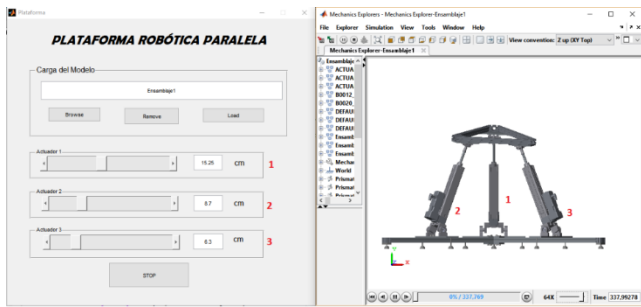
Now it is possible to control with the Sliders the movement of each actuator and in turn of the whole mechanism in the three degrees of freedom.

#### Virtual Environment Simulations

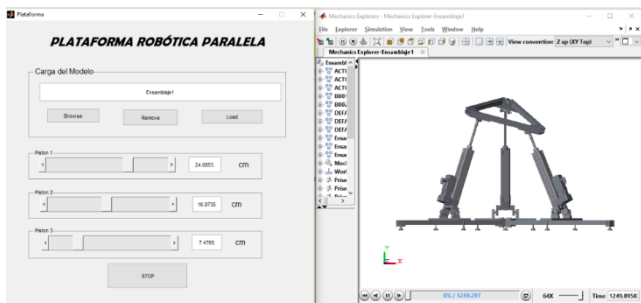
The virtual environment of the parallel robotic platform is based on a model converted from a CAD software to a block diagrams scheme in Simscape Multibody where it is designed, corrected, assembled and are attached control and monitoring stages at the mechanical points of movement And in turn is directed from a graphical interface that displaces the pistons by



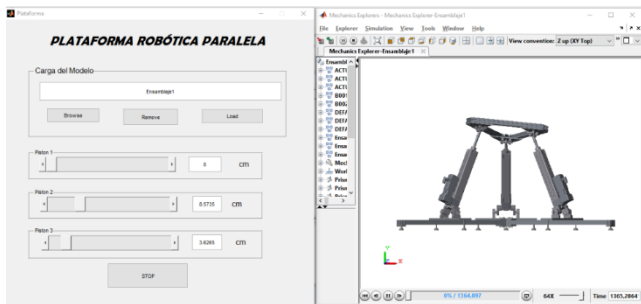
means of the simulation start of Simulink [3]. The results obtained are detailed in Figures 16, 17 and 18.



**Figure 16.** Simulation 1: Virtual Environment. Graphical interface (left) and simulation environment (right).



**Figure 17.** Simulation 2 of the virtual simulation environment.



**Figure 18.** Simulation 3 of the virtual simulation environment.

## CONCLUSION

Analysis of 3 RPS Robotic Platform Motion in SimScape and MATLAB GUI Environment Figure 18. Simulation 3 of virtual simulation environment.

Simscape Multibody presents a complete tool for mechanical robotic models making developments in their kinematic extensions comprising the mathematical solution to the movements of joints and parts of the system. The integration of computer-aided design programs and developers for control

analysis and implementation facilitates the work of modeling different robotic types.

The result is the implementation of the virtual environment of the parallel robotic platform through the complete three-dimensional assembly of the structure divided into sub assemblies, a block diagram with the corresponding joints and pieces, a graphical control interface with the simulations Of test that verify the operation and the times of response by means of the development of the software involved in the analysis of the specific zones of articulation, in order to provide greater ease to the user in the manipulation of the virtual model.

It also generates routes that detail from the installation of the systematic tools to the control of the simulated platform through the graphical interface.

It is proposed as future research to establish mathematical models that deepen the study of inverse kinematics before the different positions acquired by the mobile zone and the development of applications for research purposes as therapeutics that contribute to the community.

## ACKNOWLEDGMENT

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