Selective Compliant Assembly Robot Arm (SCARA)

A benchmark design to kick-start learning Mechatronics designing

by Pravin Jethawa

Mechatronics applications have revolutionized industrial plants and control from past two decades. Pick & place, shift & insert robots have accelerated the production benches in past decade and would continue to do so.

The **SCARA,** acronym stands for **Selective Compliant Assembly Robot Arm** or **Selective Compliant Articulated Robot Arm,** is benchmark design to kick-start learning Mechatronics designing. It is 3-axis robot and can move to X-Y-Z co-ordinate within their work envelope. By virtue of the SCARA's parallel-axis joint layout, the arm is slightly compliant in the X-Y direction but rigid in the 'Z' direction. SCARA robots are used in assembly operations where the final move to insert the part is a single vertical move. This is often called "vertical assembly". They are very common in pick-and-place, assembly, and packaging applications. The electronic printed circuit board industry, in particular, uses large numbers of SCARAs for placing semiconductor ICs and other components on the circuit boards of computers and related equipment.

Modeling Saves Time

Modeling the Mechatronics application using software can save a lot of time of engineer and can help in fine tuning of control parameters.

We know in any robotic design, the desired robot trajectory is achieved with electronic feedback control. The simulation is performed and results are incorporated to show various analysis performed during modeling phase.

Comparing the desired and achieved trajectories along with induced oscillations in position coordinates due to improper selection of electronic and mechanical parameters can be verified and tested way before implementing it.

This article is been written with all the work performed in 20-Sim, modeling and simulation package available from Controllab, Netherlands.

Mechanical Structure

Inspecting picture reveals that robot has a base with arm that can move in the horizontal plane and a load that can move vertically. The robot is modeled using four bodies which are connected by joints. Between the base and the first arm, a revolute joint is mounted, which can be actuated and indicated by the torque T. Between the first and the second arm an identical joint is mounted. Between the load and the second arm a prismatic joint is mounted, which is also actuated and indicated by the force F.

The physical robot is decomposed into its constituent elements as shown in fig.1

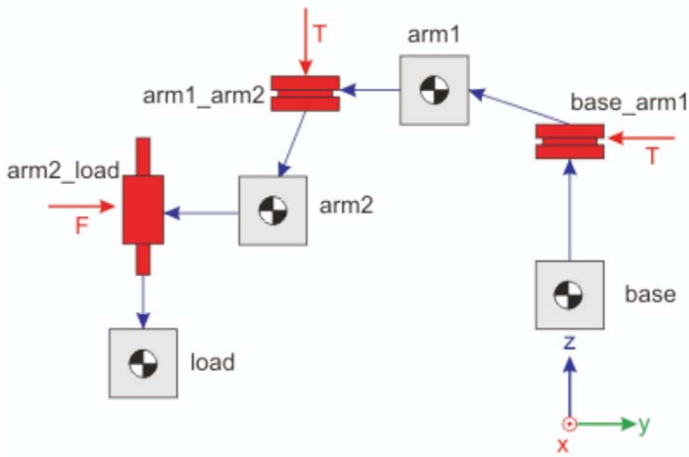

Figure 1: Freebody diagram of scara robot

Freebody diagram consists of joints, bases, arms, torques and forces. The modeled robot is created in 3D Mechanics Editor toolbox available in 20-sim. 3D-Mechanics supports CAD drawing for mechanical designs and also facilitates importing CAD designs from other CAD tools. The geometrical parameters and the mass and inertia's used in the design drawings of the Scara robot is shown in fig. 2

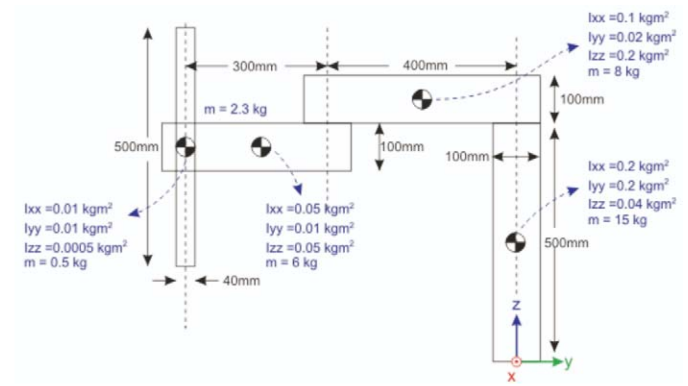

Figure 2: Design details of Scara Robot.

A 3D Mechanics model of the Scara robot is developed in 3D Mechanics Editor as per the mass and inertia properties of the specs sheets. The dimensions of the Scara robot are rather small which is formulated by scaling of available default bodies in the 3D Mechanics Editor. Bodies are connected with appropriate joints to assemble SCARA. Joint connections with links were examined by ghost facility of 3D-Mechanics editor. Arm motions have been validated by moving all three arms of manipulator in appropriate direction. The mathematical model describing robot kinematics & associated dynamics is generated using auto code generation facility of 3D-Mechanics editor. It is based on coordinate transformations and uses port Hamiltonian approach model conversion. It has generated scenery file that will aid in animating SCARA. Thanks 20-sim for saving labor. The structural design of SCARA Robot is shown in fig. 3.

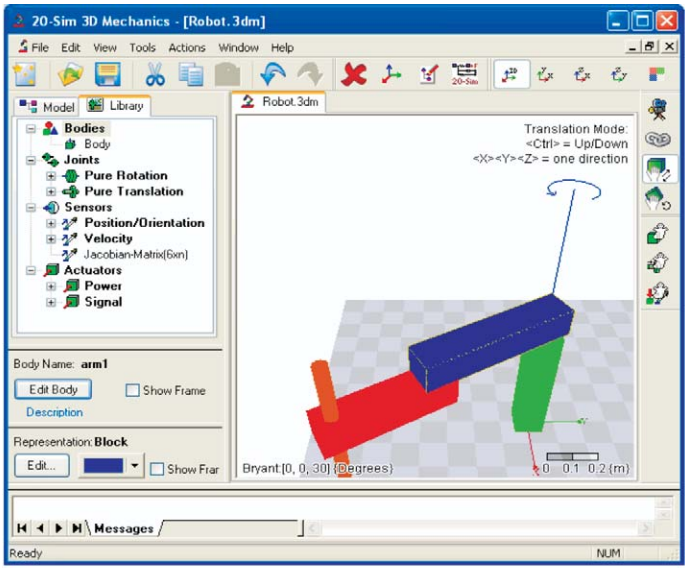

Figure 3: Structural design of SCARA Robot

Electric drive is required to move robot arms. Three separate drives are used to actuate robot joints. The rotation joints are driven by electrical motors modeled by ideal torque sources with gearboxes by calculating moments. The translation joint is driven by an electrical motor also modeled by an ideal torque source with a spindle. The motors are controlled by PD controllers, which compare the desired motion given by motion profile generators with the actual position of the robot.

Parameters	Values
Kp (proportional constant)	1
tauD (derivative constant)	0.05
Beta	0.1
Gear ratio	0.001
Pitch Radius Spindle	20mm
Lead angle of the spindle	50mrad

Table 1: Drive Parameters.

The actual position is being sensed by the position sensors and that is further proportionalized by the constant K and feedback to actualize the desired set point generated by motion profiles. The complete electric drive system is shown in fig. 4

The simulation model that was used to simulate the Scara robot is shown in the fig. 5. Robot model has three input ports one for the arm base_arm1 joint, one for the arm1_arm2 joint and one for the arm2_load joint. All 20-sim model has input and output ports which allows power to flow across system components.

The grey square with the local name robot is generated with the 3D Mechanics Editor. It represents the mechanical structure of the robot in mathematical form with all necessary coordinate transformations. Designed system model is simulated using 20-sim simulator to verify the model equations. Causality has been checked with *analyze causality* facility available in 20-sim. Model has been validated by changing various parameters in both time domain and frequency domain.

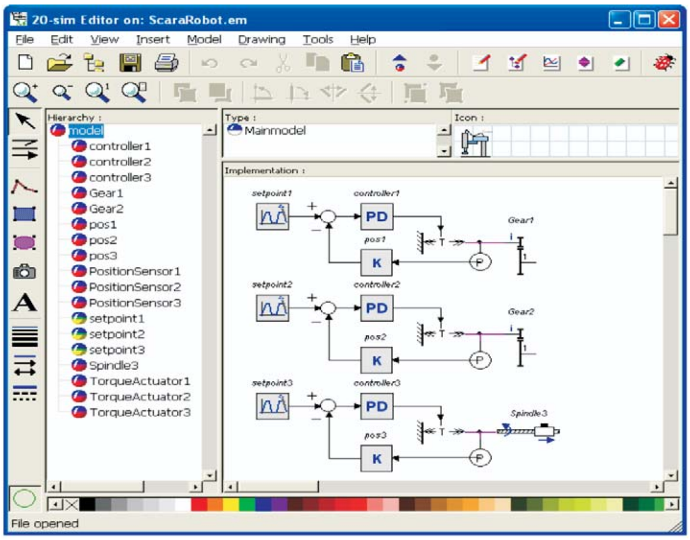

Figure 4: Electric drive assembly of SCARA Robot

We have used the 3D Animation Toolbox available in 20-sim to show an animation of the mechanical structure. One can export the structure to a scenery file, which can be loaded in the 3D Animation Toolbox while simulating the full model. All joints have an initial value, this may know from the joint properties dialog while design Scara in 3D-Mechanics. During analysis model, some joints may have been twisted. So we have used the current (twisted) configuration to generate a 20-sim model for the current configuration or reset it to its initial values.

Kinematics associated with Scara Robot has been observed during the simulation. Robot trajectory was changed by changing the setpoint parameters to change the robot movement. Motion was analyzed in perspective as well as XY, YZ and ZX direction by choosing other cameras option. The full working model of Scara Robot is available in ScaraRobotSimulation.em file from the Getting Started folder in demonstration version of 20-Sim available from Controllab Products B.V., Netherlands.

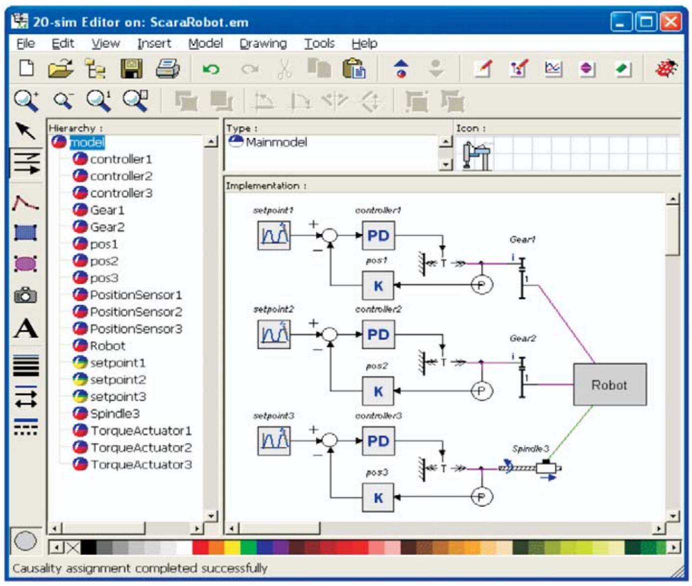

Figure 5: Simulation model of SCARA Robot.

Simulation results are given in the following figures. All the results were taken with Backward Differentiation Formula (BDF) simulation method out of all supported methods with absolute and relative tolerance of 1e-005. It shows three setpoints and corresponding positions of three arms. Positions of arms were in good agreement with desired setpoint as shown in fig.6.

The controller parameter was changed to check model integrity. By changing derivative time constant of all three controllers; model has shown a bit of oscillations as depicted in fig. 7.

Moment of Inertia of arm2 i.e., I_{zz} was changed to observe effect of increased mass of manipulator arm on model and it has produced vibrant oscillations in desired motion of robot as shown in fig. 8.

From animation we realized that robot arm has physically crossed the limit by showing reverse motion of arm2 which is non-trivial as shown in fig.9. Where as figure 10 shows the animation scenery model for simulation purpose.

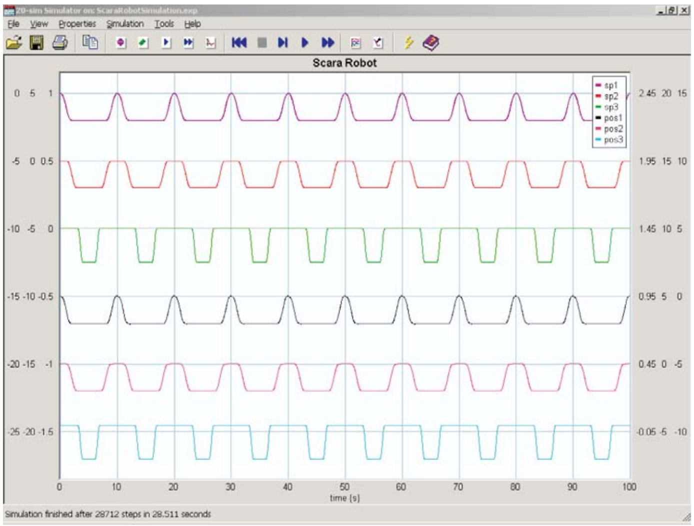

Figure 6: Simulation Result showing setpoints and achieved position of three arms.

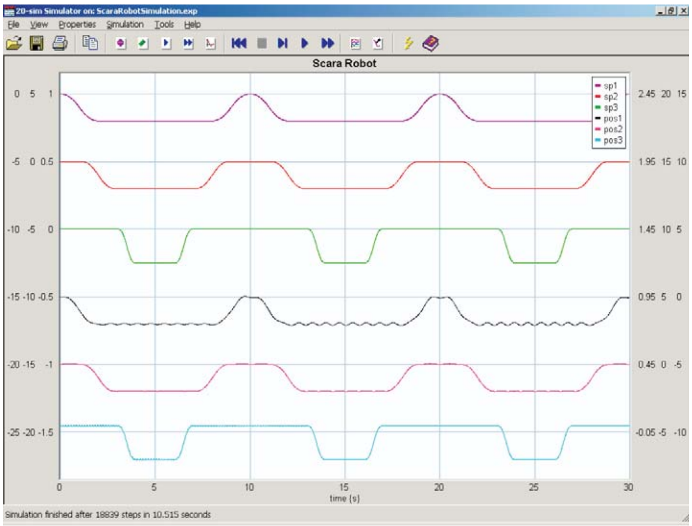

Figure 7: Changing derivative time constants of all three controllers resulted in clam oscillation

Conclusion

This was an attempt made to model Scara robot before its implementation seeking for exact parameters to avoid traditional trial and error design methodology aiding powerful modeling and simulation package 20-sim. Thereby we observed that modeling & simulation can help in saving development time by using efficient and easy to use package like 20-sim.

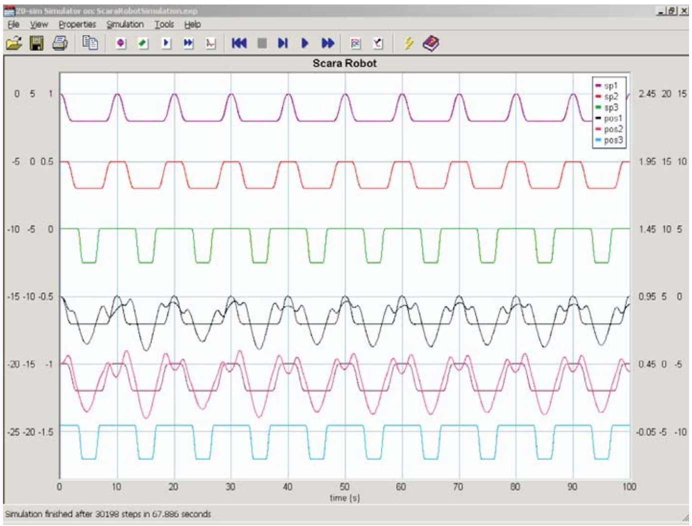

Figure 8: Induced Oscillations due increased in moment of inertia

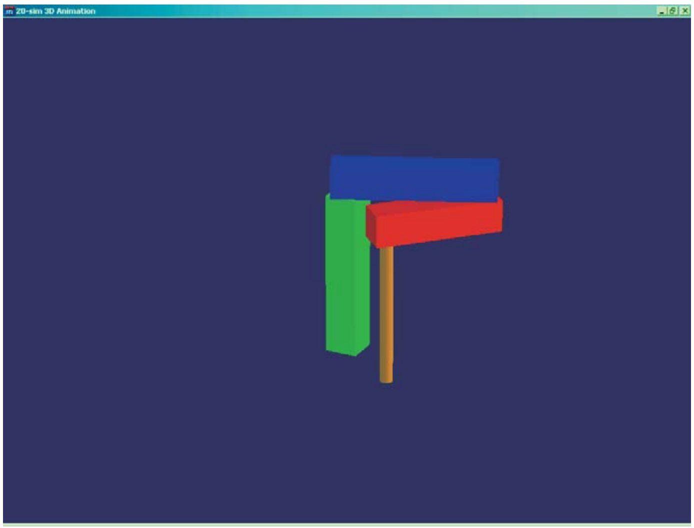

Figure 9: Animation showing unwanted traced position of robot arm due to increased in moment of inertia

Figure 10: Scara Robot in 20-Sim's 3D simulation window