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# Virtual Commissioning with Process Simulation (Tecnomatix)

Luis Villagómez Guerrero[1], Virgilio Vásquez López[2], Julián Echeverry Mejía[3]

[1]ITESM CEM, levg@itesm.mx
[2]ITESM CEM, vlopez@itesm.mx
[3]ITESM CEM, jecheverry@itesm.mx

**ABSTRACT**

In this paper a virtual environment in Tecnomatix, which is the exact reproduction of a manufacturing cell was built. The virtual cell interacts with a Programmable Logic Controller (PLC) Siemens S7-300 which enables the operator to build and validate a PLC code inside the virtual model. This prevents any possible mistakes from occurring when the PLC code is implemented in the actual work cell. This manufacturing reproduction took place in Instituto Tecnológico y de Estudios Superiores de Monterrey, Campus Estado de México where the authors work. The first step in the design was to obtain the measurements of the components which are then designed in the NX software. Once the components are designed, the next step is to export them to a Tecnomatix software called Process Simulate. In one module of Process Simulate named Advanced Simulation it is possible to develop the 3D virtual environment and then introduce control information into that simulation environment. The platform built lets us test our programs, evaluate different scenarios, and check for the correctness of the control logic instead of taking risks on the actual equipment. The resulting control program was implemented into PLC Siemens S7-300. The OPC standard (OLE for Process Control) was used to build up the connection between the PLC and the virtual environments. Today, this virtual cell is used to verify their control program instead of testing it out in the actual work cell. The virtual prototype provides information that helps to prevent errors. An application of these concepts in the college classroom is proposed at the end of this paper.

**Keywords:** automation, virtual commissioning, Tecnomatix, process simulatation.

## 1. INTRODUCTION

Nowadays, the development of products and manufacturing processes are constructed in 3D virtual environments. This new tendency is called Digital Manufacturing. It is defined *"Digital manufacturing is the use of an integrated, computer-based system comprised of simulation, three-dimensional (3D) visualization, analytics and various collaboration tools to create product and manufacturing process definitions simultaneously."*[1].

Digital Manufacturing is the integration between Product Lifecycle Management (Product Lifecycle Management is a concept to describe the management of all the product's processes involved in their design, manufacture, distribution and recycle) software, and different design and floor applications. This strategy allow us to create entire manufacturing processes in a virtual environment. It comprises from the concept of the process to the adequate material, tools and line production management.

Tecnomatix[2] portfolio is divided in different products for a specific area. For example, ergonomics studios can be created in the software JACK (JACK is a software concerned with human movement and ergonomics. Nowadays, this software is developed by Siemens PLM), a complete factory design can be

[1] Siemens PLM Software, "Digital Manufacturing definition" Siemens AG, 2011. Available: http://www.plm.automation.siemens.com/en_us/plm/definition/digital-manufacturing.shtml
[2] Tecnomatix is defined as a "comprehensive portfolio of digital manufacturing solutions that deliver innovation by linking all manufacturing disciplines together with product engineering". Nowadays, this software is developed by Siemens PLM. Definition was taken from the website: http://www.plm.automation.siemens.com



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Fig. 1: AMATROL Mechatronics System (left) and Station #2 Gauging drew in NX Software (right).

developed in the Factory CAD (Factory CAD and Factory Flow are AutoCAD complementary software used to create and evaluate factory's layouts. Nowadays, this software is developed by Siemens PLM) platform, and a process production can be quantified in the Plant Simulation software[3].

On the other hand, Process Simulate (Process Simulate is a specialized software to create virtual environments, to test PLC programs, and to develop offline programs for robotics and manufacturing applications. Nowadays, this software is developed by Siemens PLM) was used to make a virtual environment for different manufacturing and assembly cells. Other different software were used in order to create an automation and control program of the system, to create or edit drawings with CAD software, specifically with the NX or CATIA (NX and CATIA are Computer Aided Design software. Sketches and assemblies of the 3D models were done with these software.) software (see Fig. 1), and to test the program in the virtual environment to communicate the Programmable Logic Controller (PLC, PLC is a specialized automation microcontroller conformed by 4 parts: CPU, I/O modules, the power supply, and the rack) with Process Simulate.

An AMATROL[4] Mechatronic System cell (see Fig. 1) is owned by Instituto Tecnológico de Monterrey, Campus Estado de México. The cell has seven independent stations (which can work in a collaborative way), and that have different tasks such as Pick and Place, Gauging, Indexing, Conveying, Assembling, Torqueing and Storage. The system is monitored and controlled by a PLC S7-300 (The PLC S7-300 is the family name for the Siemens PLC middle class. In this PLC you can connect different kinds of modules but the number of modules that can be connected is restricted by the rail).

## 2. DEVELOPMENT

For this paper, the AMATROL Mechatronics System, Station #1 Pick and Place was taken as an example of virtual environment development, test, and application. The steps were followed in order to create and implement a virtual environment. The steps are named: characterizing the system, computer aided design, virtual environments, testing the virtual environments, and virtual environments as a monitoring systems. Following there is a detailed description of each step.

**Characterizing the systems:** In the event that the physical system is already manufactured, the purpose of the system and the normal operation sequence must be known. A connection map between signals and the PLC is required. On the other hand, the drafting of the principal components must be done.

Station #1, where the work piece is picked and transported to a specific location, has three pneumatic actuators that work in 3 different axis. The Pick and Place sub process has two double effect pneumatic cylinders that move on X and Z axis and one double effect pneumatic cylinder, in the gravity feeder, that moves on the Y axis. These actuators are activated by electro pneumatic 5-ports-2-positions valves. All of the cylinders have limit switches to detect an initial and final state of the piston rod (see Fig. 2a and 2b below).

The process that takes place is Station #1 can be represented as depicted in Fig. 3 below, which

[3] "Plant Simulation is 3D, object-oriented, discrete event simulation software that allows you to quickly and intuitively build realistic logistics models". Nowadays, this software is developed by Siemens PLM. Definition taken from the website: http://www.plm.automation.siemens.com

[4] Amatrol creates innovative, interactive learning solutions for industry and education to equip people with the skills to master technical systems, solve problems and adapt to a rapidly-changing workplace. Definition taken from the website: http://www.amatrol.com/about-us/

shows the electric, pneumatic. and electropneumatic diagrams.

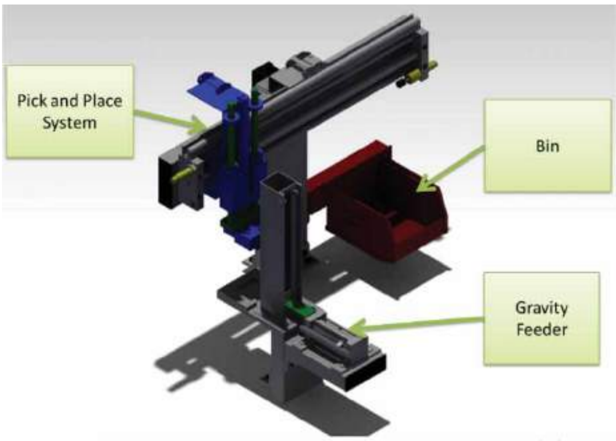


Fig. 2a: Pick and Place system: sub process division.

There are two special sensors in Station #1. The optic sensor, located in the Gravity Feeder base, is used to detect if there is a work piece or not in the feeder. A differential pressure sensor, located in the Z-axis, is used to detect if the work piece was taken by the Pick and Place subsystem (See Fig. 4 below).

In order to produce a product successfully, Station #1 (see Fig. 5) must follow a series of steps called the Normal Operation Mode. If these steps are not followed, the process might present deficiencies. The steps in the Normal Operation Mode are:

- The feeder pushes the work piece to the pick-up point, when the star button is pushed.
- Z-axis extends to pick up location.
- Vacuum generator turns on.
- Feeder retracts.
- Z-axis retracts.
- X-axis extends.

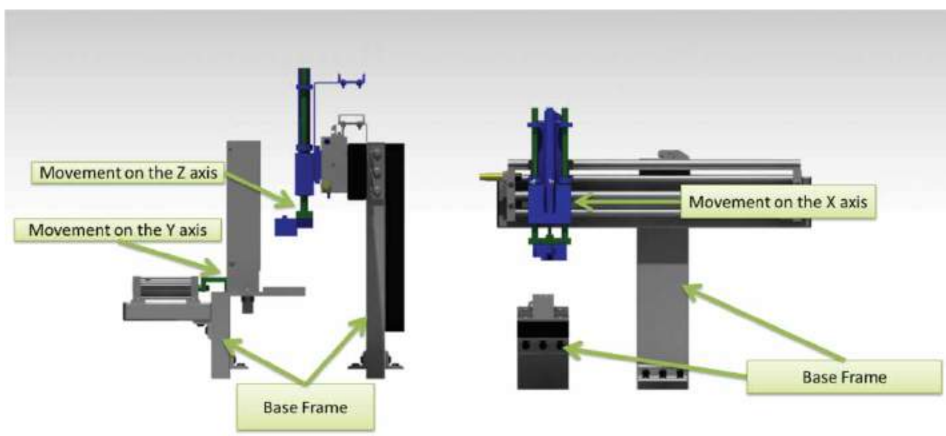


Fig. 2b: Pick and Place system: static and dynamic links.

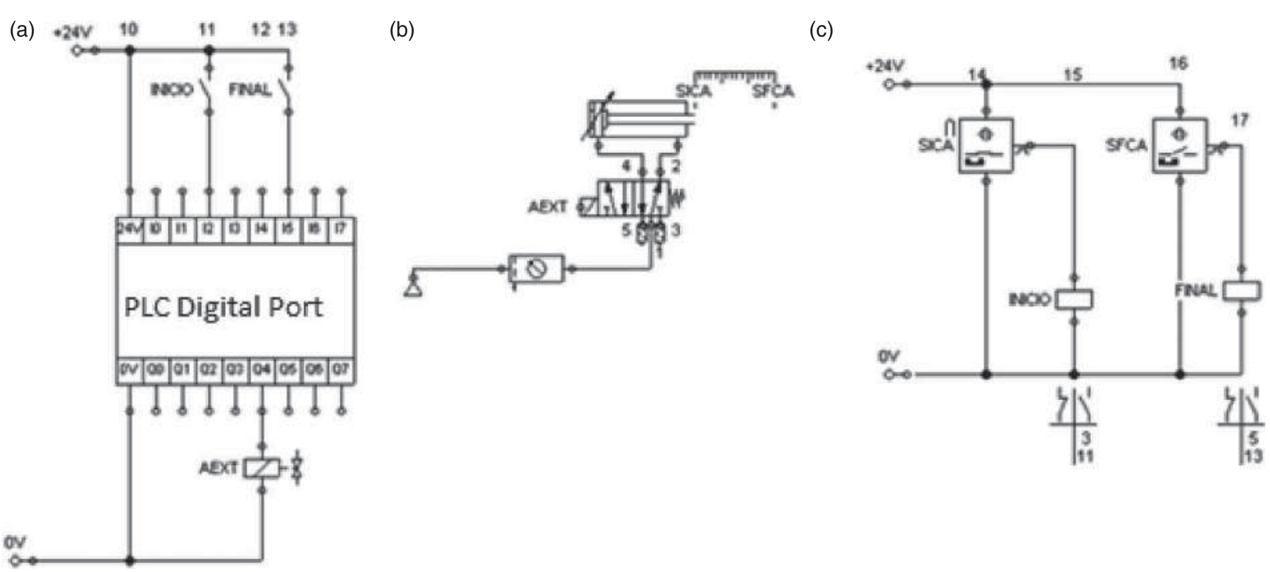


Fig. 3: a) PLC I/O example diagram. b) Pneumatic example diagram. c) Electric sensor diagram.

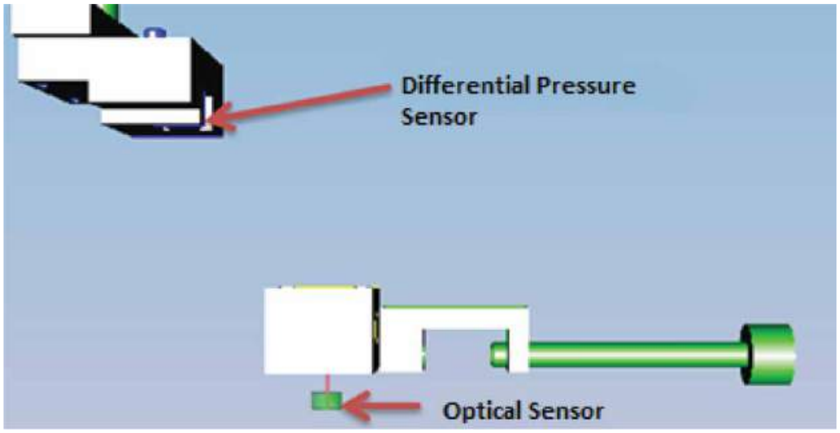


Fig. 4: Optical and Differential Pressure Sensor location.

- Z-axis extends.
- Vacuum generator turns off
- X-axis retracts.
- Cycle ends

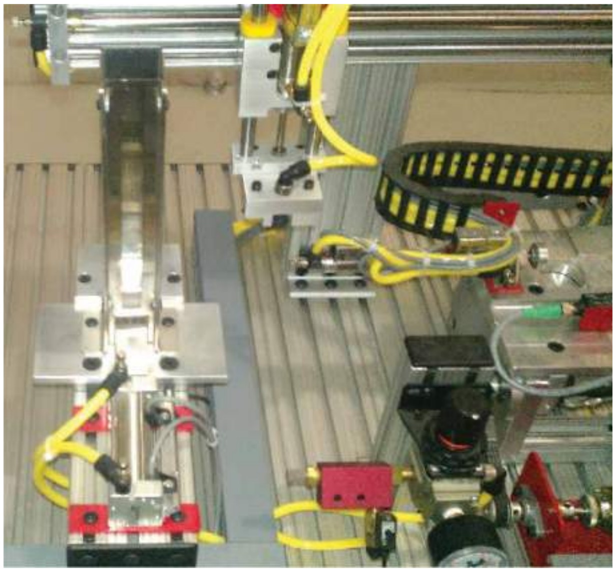

Fig. 5: AMATROL Mechatronics System. Station #1 Pick and Place.

**Computer Aided Design:** The NX and CATIA (It is not necessary to work in both software. The sketch and the assemblies can be done in NX, but in some cases, the drawing's developer can use CATIA for this task but file translation is required) software were used to create the computerized drawing of the components of the entire system. The models were drawn in a 1:1 scale. The manufacturer's blue print was not implemented or required, as the operator of the system measured the actual work station.

The Sketching and Assembly modules of both software were used to create the sketch. All parts of the project were divided in two categories:

*Static link:* components that will not have any movement nor a specific function in the virtual environment. For example: fixtures, bases, rails, shafts, and motors. All of these parts can be done in one assembly or sketch.

*Dynamic link:* components that have movement or a specific function in the virtual environment. For example: sensors, pistons, platforms, grippers, clamps. A sketch or assembly must be done for every dynamic part.

All of the drawings or assemblies must be converted into a .JT extension file. This transformation can be done directly in NX or another Siemens 3D drawing software. This JT file is then put into the Process Simulate software. Process Simulate only works with this open format because it needs to convert a JT file to a COJT file (see Fig. 6).

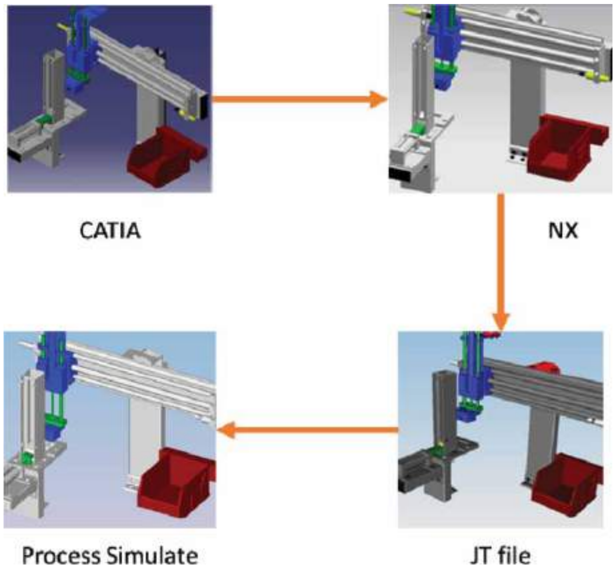


Fig. 6: AMATROL Mechatronics System. Station #1 Pick and Place in different CAD formats.

**Virtual Environments:** The next assumptions to create a virtual environment were made:

- All sensors and actuators were characterized and their operation modes are known.
- Velocities and accelerations are assumed as constant values (software's limitations).
- The process works with digital (input and output) signals. That is, there are only two values: 0 or 1.
- The purpose and normal operation are known by the virtual environment's developer.

The Advance Simulation layout was used to create the virtual environment. The Kinematics Editor and CEE (Cyclic Event Evaluator) tools (Kinematics Editor is a specific tool to create and evaluate kinematics chains of a system. The CEE is an evaluator that runs in Process Simulate in order to evaluate the behavior of the virtual environment) were used to connect the links and joints (represented in Fig. 7 below as rectangles and arrows) and to test the virtual environment respectively.

The division of the components into static and dynamic links were discussed in the previous section. The purpose of that is to simplify some steps in the kinematics representation in the Process Simulate program. For example, the station's components were divided in 3 elements that are the Pick and Place sub

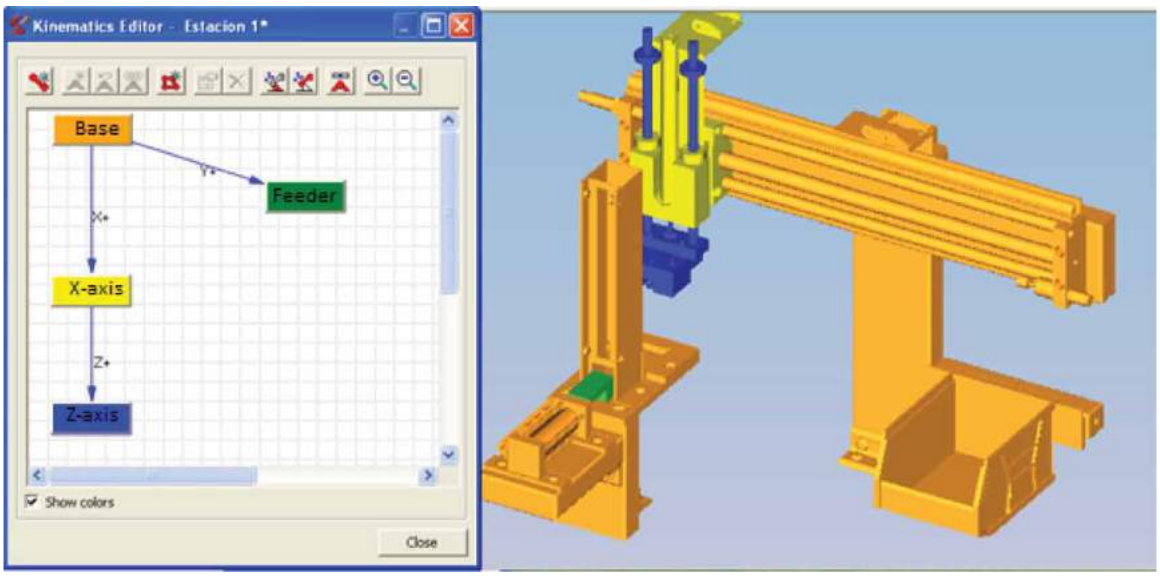


Fig. 7: Station #1 kinematics representation.

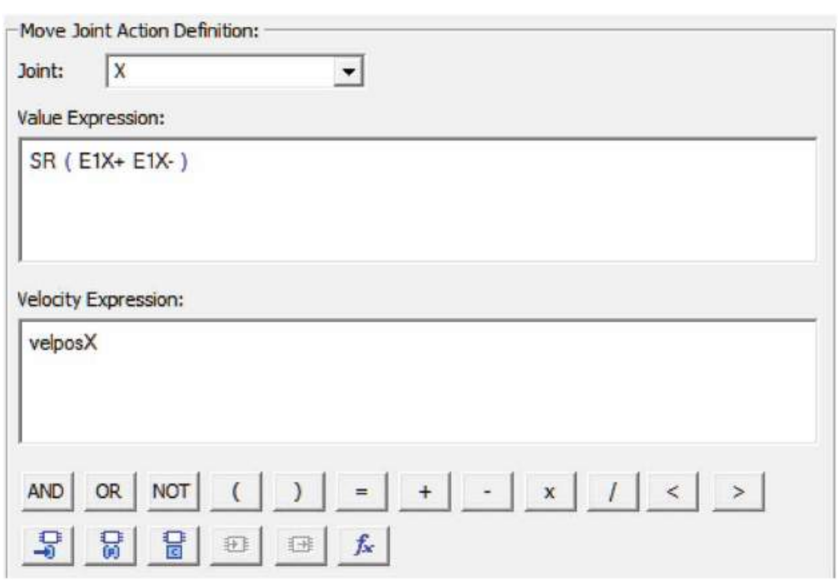


Fig. 8: Move Joint Action Definition dialog box.

process, the Gravity Feeder, and the Base Frame (with the bin). They can be seen in Fig. 7 below.

Using the previously shown axis layout (see Fig. 2) and using the Kinematics Editor we created four links (see Fig. 7). One link represents the static components of the system (base frame and bin) and it is shown in orange. A second link was created for the feeder (green). The third and fourth links are associated to the X-axis (yellow) and Z-axis (blue) movement of the Pick and Place subsystem.

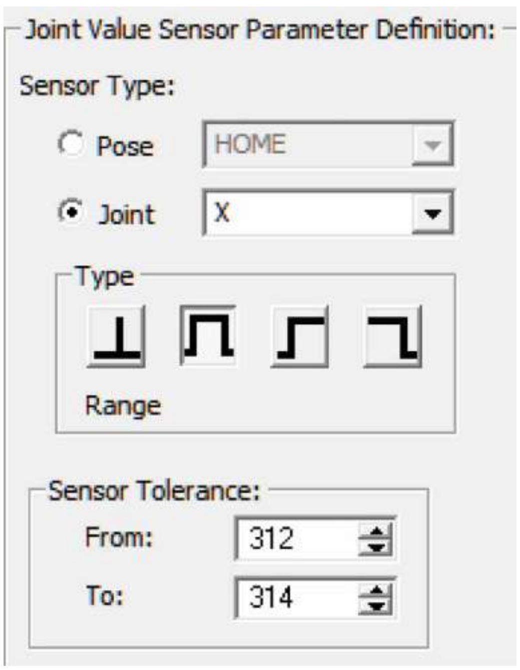


Fig. 9: Joint Value Sensor Parameter dialog box.

The prismatic movements of the joints, which move in relation to the base link, are represented by blue arrows in the Kinematic Editor. The editor allows us to place movement limits, associated with the physical restriction of the pneumatic cylinder's rod.

It is easy to see that the feeder moves independently from the Pick and Place subsystem. The Z-axis has a dependent movement which is attached to the X-axis movement. If the X-axis moves to the final position, the Z-axis will move with it, but if the Z-axis moves, the X-axis will remain static.

The next step is to define an internal logic block. This block describes the activities that would be done by the virtual environment. For example: In the physical system, the PLC program sends a signal in order to move down the Z-axis. Then the Z-axis must perform the action instructed by the control system, and go to the end of its rod.

In the logic block some parameters are introduced to make this action possible as if we had been working with the physical system. Input and output signals are created in the logic block to specify the signals that are required or delivered by the virtual station to the control system.

At the same time, we create an action that is called "Move Joint Action Definition" (see Fig. 8) and its parameters are:

- Joint: It defines which link will be moved.
- Value Expression: It is a logical condition. If this condition becomes true, the joint will perform the movement.
- Velocity Expression: It is a constant value. It can be an unsigned integer or real. This parameter also describes the direction of the movement (positive or negative).

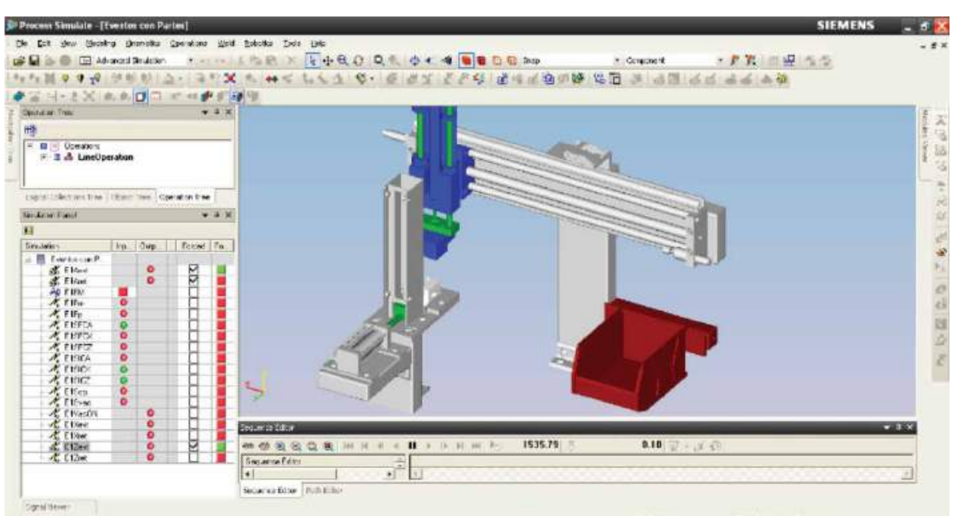


Fig. 10a: Virtual environment evaluated with CEE.

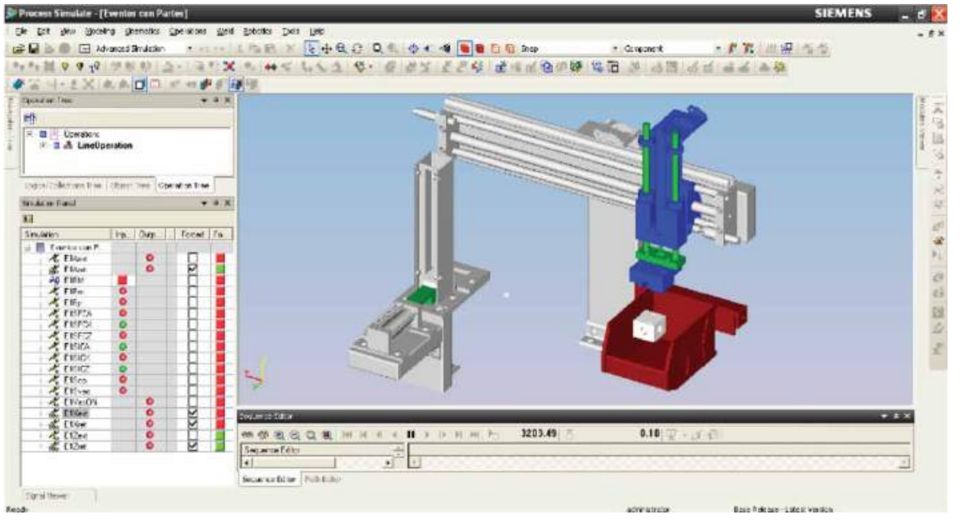


Fig. 10b: Virtual environment evaluated with CEE.

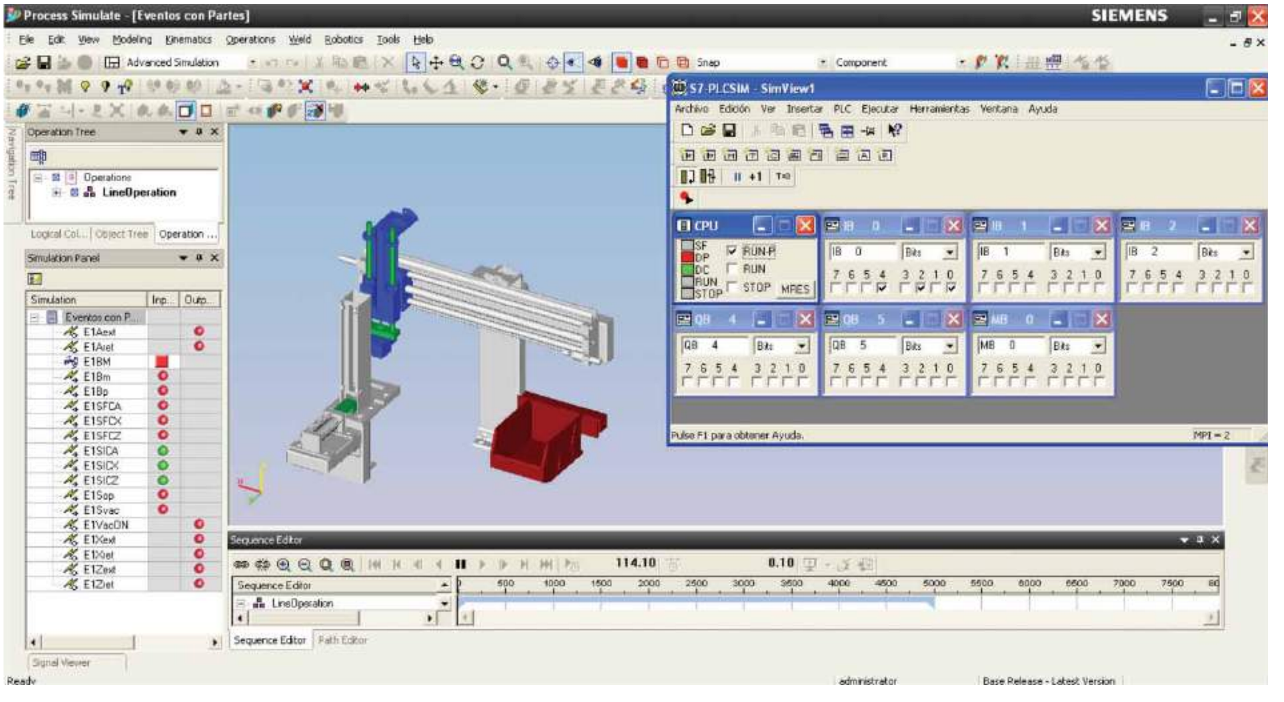


Fig. 11: Process Simulate and PLCSIM integration.

The limit switches of the system are introduced in the same logic block as a "Joint Value Sensor". The Joint Value Sensor Parameter Definition dialog box (see Fig. 9) requests some parameters like:

Sensor type: The joint sensor type is chosen to measure a specific joint.

Type: If the joint moves within a specific range (see sensor tolerance in next bullet), it changes its logical value. It can be a pulse, range or step. The most commonly used type is the range type sensor.

Sensor tolerance: When the joint moves within the range of the sensor, the logic value of the sensor chance from zero to one.

There are additional sensors in the process of creating a virtual environment, such as the optical and differential pressure sensors which are photo electric sensors in the Process Simulate software (See Fig. 4 above) but will not be discussed in this paper.

The Following steps after configuration of the virtual environment is to connect the signals form the logic block to the control system.

**Virtual environment Test**: After the logic block is finished, a test of the virtual environment must be done. The Cyclic Event Evaluator (CEE) is an internal logic evaluator, which can simulate the logic state of the signals that were created in the Process Simulate software.

These signals come from the logic block and photoelectric sensors. Using the Simulation Panel, the signals can be forced to a different logic state. In Fig. 10a and 10b below, different states of signals are shown.

If joint movements and sensor detection are right, the next step is to verify a PLC program. Step 7 GRAPH (S7 GRAPH allows us to develop a Sequential Function Chart (SFC) in a function block that will be downloaded to the PLC) was used to develop a PLC program using the GRAFSET methodology for sequential processes.

Using the PLCSIM (PLCSIM is a simulator that allows users to test PLC programs and communications. It is developed by Siemens AG) software, the PLC program can be integrated with Process Simulate. As it is showed in Fig. 11, different sensors and actuators signals are exchanged between Process Simulate and PLCSIM.

**Virtual Environment used as a Monitoring System**: After the PLC program in the virtual environment works efficiently, the program is downloaded to the physical system and it is tested. The virtual environment has accomplished its purpose and now it can be used as a monitoring system (see Fig. 12 below). The connection between the physical process (specifically the PLC S7-300) and Process Simulate can be done by the Siemens OPC software.

These five steps (characterizing the system, computer aided design, virtual environments, testing the virtual environments, and virtual environments as a monitoring system) allow us to establish a methodology and an effective understanding of how to create and to use a virtual environment in the manufacturing process.

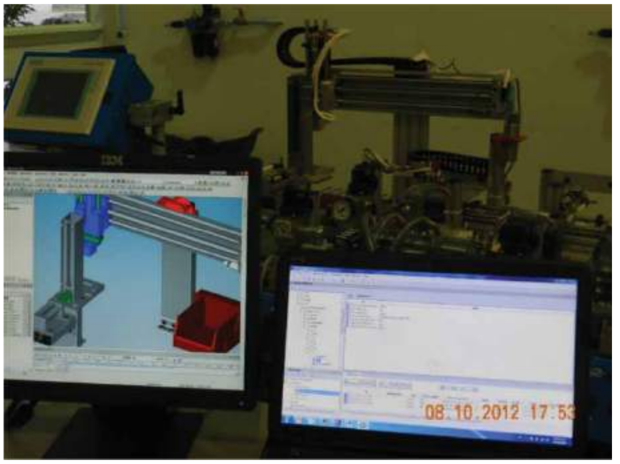

Fig. 12: Process Simulate, OPC Scout and the Physical process.

## 3. USES IN THE INDUSTRY

It is well known, that virtual environments helps manufacturers to reduce time and costs when a new manufacturing line is designed or implemented. Some successful cases report a reduction ofabout 60% in time and 40% in costs[5]. These cases are reported by industries, where almost every process is automated or robots are involved.

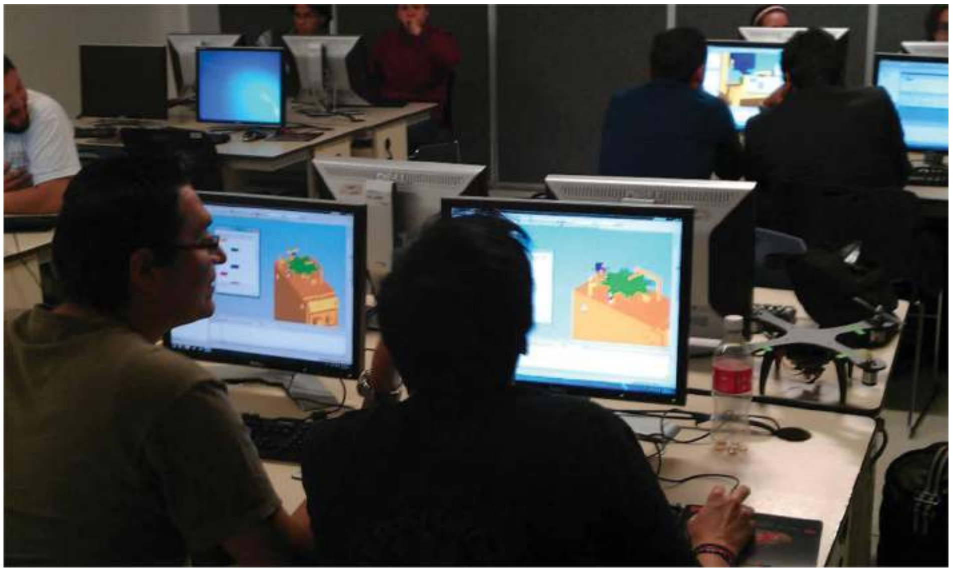

Fig. 13a: Students working with Process Simulate

[5]Study cases can be consulted in the Siemens PLM website: http://www.plm.automation.siemens.com/en_us/products/tecnomatix/tecnomatix11/index.shtml

Fig. 13b: Students and their virtual assembly cell.

## 4. FURTHER APPLICATIONS IN EDUCATION

The process described in this paper has been used as the Advanced Industrial Automation final project, for mechanical and mechatronic engineering students in the Instituto Tecnológico y de Estudios Superiores de Monterrey, Campus Estado de México. Students were asked to perform a characterization, to create the 3D drawings, PLC program, development, and implementation of a virtual environment of five AMATROL Mechatronics System modules (see Fig. 13a and 13b). The principal concepts of digital manufacturing and the application software (Step 7, NX, Process Simulate, and OPC Scout) was taught as part of the curriculum.

## 5. CONCLUSIONS

Virtual environments not only help manufacturers to decrease design and production times. Academia can use virtual environments in order to teach automation, control and manufacturing topics, reduce incidents in the equipment or create virtual environments as a substitute of physical processes.

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