VSB - Technical University of Ostrava
Faculty of Electrical Engineering and Computer Science
Department of Cybernetics and Biomedical Engineering

Design of Control System based on Virtual twin
Návrh řídicího systému pomocí virtuálního dvojčete

2019 **BE. Keerthana Madehalli Janardhan Iyengar**

VŠB - Technical University of Ostrava
Faculty of Electrical Engineering and Computer Science
Department of Cybernetics and Biomedical Engineering

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Student:	**Keerthana Madehalli Janardhan Iyengar**
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Description:

1. Analyze industrial software tools available for a digital twin design.
2. Choose and describe a software tool suitable for a digital twin design in laboratory conditions.
3. Design a digital twin of selected laboratory workstation which includes 6-axes robotic arm. Specify workplace including safety zones and design trajectories of basic manipulation operations.
4. Make functional system analysis of proposed workstation processes.
5. Create basic PLC control application to control the digital twin. Use OPC UA communication standard for to establish connection between digital twin and PLC control system.
6. Perform verification and testing of created system.
7. Conclusion.

References:

[1] BLODYK, Gerardus. *Digital Twin: Beginner's Guide, 3 edition.* CreateSpace Independent Publishing Platform, 2017. ISBN 978-1978270138.
[2] PROUD, John F. *Master scheduling: a practical guide to competitive manufacturing.* 3rd ed. Hoboken: John Wiley, 2007, xxviii, 657 s. ISBN 978-0-471-75727-6.
[3] BRANDIMARTE, Paolo a Agostino VILLA (Eds.). *Modeling manufacturing system: from aggregate planning to real-time control.* Berlin: Springer, 1999, 215 s. ISBN 35-406-5500-X.

Extent and terms of a thesis are specified in directions for its elaboration that are opened to the public on the web sites of the faculty.

Supervisor: **Ing. Radim Kraut, Ph.D.**

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doc. Ing. Jiří Koziorek, Ph.D.
Head of Department

prof. Ing. Pavel Brandštetter, CSc.
Dean

Declaration.

I declare that this thesis was written by myself. I have listed all the sources and publications from which I drew.

Ostrava, April 30, 2019 ....

I would like to thank Ing. Radim Kraut Ph. D for help, factual comments on the work and helpful approach during the elaboration of my thesis.

Abstract

There is a need of drastic changes in the field of production from traditional manufacturing to smart manufacturing. Digital twin is the concept which is used for digital representation of a physical system. Digital twin is the key asset for smart factory production line. Production control and planning can be made precise with the help of digital twin in manufacturing process. In this project it is detailed more about how a digital twin system is designed as a parallel process in a production factory by doing palletization of products and transporting out on a conveyor using robotic arm and testing it under laboratory conditions and to specify workplace for the design.

Key words.

Digital twin, Virtual Commissioning, Visual Components, robotic arm, Programmable logic controller, TIA Portal, Open Platform Communication Unified Architecture, Control system, Works process, Conveyors, Pallets, PLC SIM advanced.

Abstraktní

Je potřeba drastických změn v oblasti výroby od tradiční výroby až po inteligentní výrobu. Digitální dvojče je koncept, který se používá pro digitální reprezentaci fyzického systému. Digitální dvojče je klíčovým aktivem pro inteligentní výrobní linku. Výrobní řízení a plánování lze pomocí digitálního twin ve výrobním procesu zpřesnit. V tomto projektu je podrobně popsáno, jak je digitální dvojitý systém navržen jako paralelní proces ve výrobním závodě tím, že se provádí paletizace výrobků a transportuje se na dopravníku pomocí robotického ramene a testuje se v laboratorních podmínkách a specifikuje pracoviště pro návrh .

Klíčová slova.

Digitální dvojče, virtuální uvedení do provozu, vizuální komponenty, robotické rameno, programovatelný logický regulátor, portál TIA, komunikace s otevřenou platformou, sjednocená architektura, řídicí systém, proces práce, dopravníky, palety, PLC SIM pokročilé

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List of used abbreviations and symbols

IOT	Internet of Things
PLC	Programmable Logic Controller
I4.0	Industry 4.0
OPC UA	Open Platform Communication Unified Architecture
RFID	Radio Frequency Identification
CAD	Computer Aided Design
API	Application program Interface
DT	Digital Twin
VC	Visual Components
2D	Two Dimensional
3D	Three Dimensional
HD	High Definition.
PLM	Product Lifecycle Management
OPC DA	Open Platform Communication Data Access.
HDA	High Definition Audio.
CATIA	Computer Aided Three-dimensional Interactive Application
IP address	Internet Protocol address
OB	Organization Block.
TIA Portal	Totally Integrated Automation Portal

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1. Introduction

Technologies are the key tool for manufacturing. In recent days it has been growing in an advanced manner because of their wide applications in many areas and mainly it’s been focused towards smart manufacturing. Manufacturing companies need to decrease their time and cost and make the manufacturing very effective. To achieve this there is a need for realistic designs of the ongoing production process and the interaction between the system and its environment –usually called a digital twin. Digital twin helps in smart manufacturing through collecting the data and processing it and by assessing the design of the product.

The objective of the project is to design a digital twin of a workstation. This is done by analyzing the software’s which are available to perform digital twin then choosing a specific software and designing a static layout. Functional system analysis is performed and a PLC Control application is created to control this digital twin approach. Once the application is created it is then tested and verified using OPC UA Communication standard.

2. Analyzing Industrial Software tools available for digital twin design

To perform digital twin in the form of simulated model there is a need of software to build the layout and test it using OPC UA. In this section is discussed about what is digital twin and what software's can be used to perform it

2.1 Digital twin

2.1.1 What is Digital twin?

With the increasing designing demands, more digital models replicating the real worlds of production are needed in order to bridge the gap between design and production. There was a time when the digitalization became popular and there was a need for digitization in the manufacturing process during the early 2000s.

Michael Grieves states that the digital twin, as a "virtual representation of what has been produced," is a "critical component of an enterprise-wide closed-loop product lifecycle" that reduces costs, fosters innovation, improves productivity, and ensures quality products. [4]

Digital twin- It is the ability to take a virtual representation of elements and dynamics of how IOT operates and lives through the cycle. It's more than a blueprint.

2.1.2 Why digital twin is used?

Machines used in the industry gets aged which leads to a lot of issues for users. Old machines need to be replaced with new equipment because the operation becomes slower and service becomes poor. Connecting machines and data sharing becomes a key feature once the old machines are replaced.

Another alternative can be to replace the parts which are damaged with the new parts or by changing the controller and fitting it with new Human Machine Interface (HMI) devices to fix it up with new behavior of the machines. These machines had to be taken off out of production in order to carry out these changes and then do the commissioning and testing and then use it during the production.

Using these machines, it is possible to collect a large amount of data and do the manufacturing in a smart way. The smarter production is by connecting the physical world with the digital world to enhance the speed of manufacturing and find better solutions in a liable manner. So digital twin is developed in manufacturing to bridge the gap between the physical world and the virtual world.

Physical world contains data for the manufacturing process which is transferred to the virtual world using sensors and then carry out the simulation, commissioning and validation. These data from the virtual world are then sent back to the physical world after the simulation process to make the necessary changes and perform the operation.

2.1.3 How digital twin is used in Industry?

A digital twin will influence the design, build and operation of a device that is constructed on a single lifecycle.

In Design phase- It includes the engineering tool, physical elements bringing together, physical materials, virtual elements, being able to collaborate together into a single facility of operational oriented design that is designed to bring out the highest quality product.

In Build phase- It is about knowing the tolerance level of a product and how it should be used for manufacturing the layouts in order to get the accurate results of the products made.

In Operation phase- Variation in the environment may lead to the change in the phase, where they have different tolerances and they drift so digital twin need to drift along with their products age and feedback. When done correctly not only facilitates the operation of the product but helps to facilitate better design and better manufacturing. [7]

2.1.4 Digital twin Applications

Design- To make sure if every part or product is perfectly efficient during this process, then 3D simulation can be performed and results can be observed. Simulation can be of any type like mechanically or electrically. With this, manufacturing becomes more effective in reducing time.

System tuning- Set of tasks can be performed with the help of digital twins like the transfer of data or any change in function which is related to electrical or mechanical simulation.

Automobile- In Automobile industry digital twin plays a vital role as it is being rapidly used in every industry. Digital twins are used for creating a digital replica of the production line in the automobile industry and then test the results thus reducing the cost and time of the real-time manufacturing.

Smart cities- Digital twin are widely used for planning and building the city, used for structuring the architecture, development and economic growth of the city.

Improving health- Using digital twin one can predict the illness of a real twin body based on their history and current activity. Using a digital twin, it is possible to get advice on how to maintain the health by tracking their food, activities and their day to day routine.

2.2 Virtual Commissioning

It is a process of replicating a real system in the form of a simulation model to create a factory and then to check the changes made in plant, test and control errors in the plant.

The proposed design consists of four steps-

a. Planning the whole process of simulation.

b. Physically building the process.

c. Theoretically checking the errors and logic.

d. Control the system and check for results.

A virtual plant may consist of devices like conveyor belts, robotic arms, other tools like assembly tools, etc. A virtual model can be done with two types which are creating a geometry physically or by kinematically modeling it. Virtual Commissioning is helpful because it reduces the effort and is time efficient but also since it needs to be controlled with actual devices like sensors, so it is a difficult task for designers to have a very good knowledge of control system and simulation.[1]

2.2.1 Virtual Commissioning on digital twin

It is the virtual representation of a physical product. Digital twin builds from physics-based models don't need to have a prototype to start using the digital twin.

Concept phase- When rapid iterations of a design are performed, there is a possibility to miss out some acceleration and dynamic loading so we use digital twin in this phase.

Other uses include-

- It can be used in the phase of development.
- It can be used for diagnostics and operations which can bring better design.
- It can be used with controller and also with hardware testing before physical commissioning on PLC code and hardware

Virtual commissioning in the context of a digital twin is joining together all the virtual system and doing a test of its operation before carrying it out on the real commissioning. When the system is connected to a digital twin it becomes easier for an engineer to do the test and validate the process. By using digital twin, the

Virtual commissioning cost is minimized and the risk to failure is also minimized. Downtime is reduced with the digital twin in the process of commissioning as it can predict issues at a very early stage and can be fixed easily.

2.3 Smart Factory Production Line (Industry 4.0)

The term I4.0 is the fourth Industrial Revolution which is present right now. According to the present status Industry, 4.0 is led everywhere. Before this generation, there were three other Industrial revolutions occurred (ref Figure 1). First Industrial revolution started in the 18th century which was mechanical production. In mid of 19th century, the second industrial revolution came into picture which was electrical production with some labor division, whereas in 1970 third industrial revolution called digital or virtual revolution took place where information technology and electronic revolution combined together to develop the production process in industries.[2]

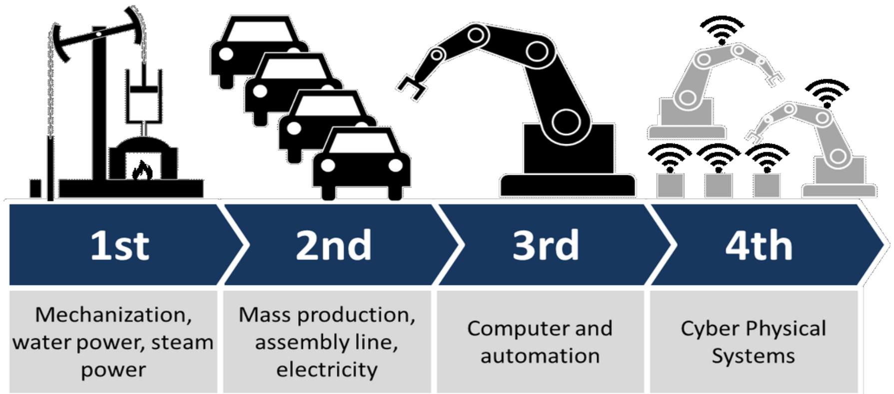


Figure 1 : Industrial revolutions including prior prediction [3]

With I 4.0 there comes plenty of opportunities for industries and also in the research field because it promises Industrial growth, effective production processes and design in various fields.

Humans are replaced with robots in this industrial revolution, the data to be entered manually is replaced with electronic transfer of information between processes, machines, and products. RFID chips are being mounted on every product and the whole production process is carried out. In the area of transportation of products, Optimized logistics and supply chain is present and automated transport is carried out from Production manufacturing till the warehouse of finished products. There can be wireless communication between machines to coordinate their respective movements for optimized production and utilization of space by reducing the manual burden.

Robots are being utilized for industrial manufacturing processes. They are now available easily for affordable budget and many organizations and companies are making wide use of it. It can be a service or industrial oriented robot with pick and place or for entire smart factory production robots have been an essential part for I 4.0.

2.3.1 OPC Communication Standard

OPC stands for Open Platform Communications. It was first identified in 1995 by automation players together with Microsoft back. From the past ten years, this is being used to communicate between the industries within the layer of automation.

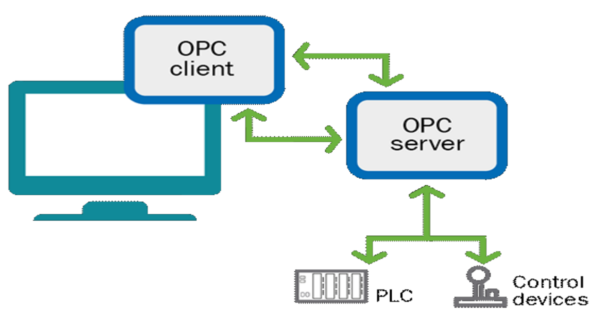


Figure 2 : OPC structure [11]

The OPC Foundation has set off a few protocols in the industry. These include OPC DA [Data access] allows accessing current data within the systems of control, OPC HDA [Historical Data Access] accessing historical data to support a long record of past data and OPC A&E [Alarms and Events] where the clients get access to all the alarms and events. OPC UA then found its new protocol later.

The first three Protocols of OPC did not serve the purpose of the connection, there was no connection between the value read in OPC DA or the value from the history in HDA or even the action is taken based on the value read. But the new protocol of OPC which is OPC UA serves this feature through which the actual value and the history and the events are related or interconnected within a unified space. An old specification provided just one hierarchy whereas the new protocol provides a multiple hierarchical division of data and supports new features for communication.[5]

OPC UA specifies an abstract set of services in and the mapping to concrete technology. OPC UA is not compared with API because it is only about the texts formats for exchanging of information. A communication stack is used on the client- and server-side to encode and decode message requests and responses. Different communication stacks can work together as long as they use the same technology mapping.

OPC UA provides services and mapping to technology through the data exchange. From Figure 2 the connection between OPC UA server and client is explained: OPC UA Communication stack consists of client and server stacks. OPC UA API is used as communication for client implementation. Service is defined previously and based on the requirements the client-side stack creates a request message. This message is sent from the client side to the server-side stack. The server-side stack then sends the message to server implementation using the OPC UA API on the server side. The OPC UA then realizes if the server side and client-side protocols are the same. The encoding of this data is done in either XML or UA Binary.

The encoding of the data can be done in XML or UA Binary. UA Binary specifies the serialization of data into a byte string. Message size is smaller in UA Binary hence it is a faster form of encoding than XML encoding. On the other hand, the XML encoding allows generic SOAP-clients to interpret the data in the SOAP message, whereas only binary string can be obtained using the UA Binary encoding.

Designs for the production process can be two dimensional or three-dimensional descriptions. For a better picture can be shown as a two-dimensional picture using 3D rendering. There is so many software available for 3D designing or CAD modeling like Siemens NX, Solid CAD, AutoCAD, etc.

Any data given as input needs to be visualized by the software to get the closer look and this has to be monitored on a real-time basis through which the DTW can be realized. CAD software does not monitor the input data through simulation but however software such as Siemens PLM is able to do such function through a secure OPC UA communication.

The software solutions through digital twin can be realized and discussed in the following section.

2.4 Software Analyzation

2.4.1 Visual Components 4.1

There is a need for simulating the design and work area of a smart factory production line through visualizing it using the software. The visual component is used for this purpose as it is capable of material flow simulation with the help of a robot, system integration can be performed in the same platform as well. The visual component is cost effective and very faster means of a platform for displaying the virtual representation of a smart factory production line.

VC has its branches in Finland, Helsinki and has its control in Michigan, Lake Orion, and Munich, along with a worldwide partner network [6].

The function of VC can include offline programming and PLC ADD- on. The PLC connectivity can be used to connect with the external world to visualize real-time data and analyze this data and then do the testing and verification and see the results using simulation.3D create feature helps the user to learn the software and serve as a platform for operators to visualize things in real time.

The process of virtual commissioning comes into the picture when a product has to tested in the production line. There can be changes when the production process is commissioned so virtual commissioning is done to avoid such aspect and flaws are being determined before and thus reducing the whole process time.

Therefore, by integrating the process of virtual commissioning there can be plenty of time for engineers to design and visualize the whole production process and to complete the automation if the assembly line is ready

VC 4.1 has predefined libraries in their catalog. More than 35 brand robots are being introduced in the library which can count up to 1400 robots. Built-in features are present. It provides a powerful set of robotic tools for designing any model in the factory with the help of robots. Controlling the program flow defining the logical behavior of robot analyzing the scope and jogging of robots and collision features are present in robots.

Easy usage and the products can be customized or redefined for the user needs. Many companies use VC 4.1 in their production process which includes KUKA Sim, or Octopus which was developed by In-House solutions.

2.4.2 KUKA.Sim

KUKA.Sim is a software used for designing 3D models and then testify and simulate it for results. The library contains different KUKA robots that can be accessed with different geometrical structures and components. The components can be picked from the library and can be easily used for modeling. [12]

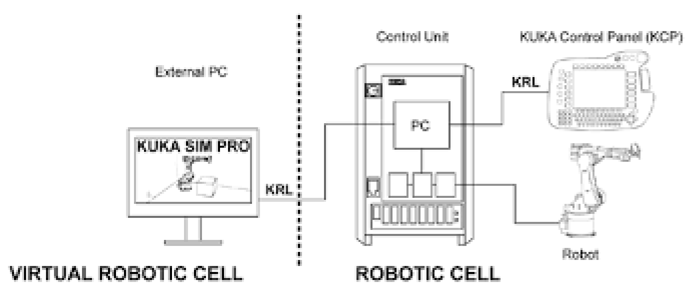


Figure 3 : KUKA.SIM PRO [13]

The component modeling can be adjusted for the project needs to be its height, width or any other spacing. From Figure 3, KUKA robot language (KRL) can be used for programming without the use of any other processors. Offline programming can also be done. KUKA. Office Lite programs can also be downloaded and worked within the software.

There are several features for modeling components which includes:

• Any physical system can be connected which can be an input or output signals including sensor

• Geometries such as conveyors, gripper heads, base or other machines and tools into their kinematic structure

• Controlling components is done using input or output mapping.

2.4.3 Visual Components 4.1 versus KUKA.SIM

KUKA contains a feature of importing CAD files into the workspace as well. It can include CATIA, V5, STEP. It can provide better CAD performance if it is of 64-bit application format. KUKA is basically running on Ethernet technology and uses graphical programming. Offline programming can be done using KUKA.Sim pro for a real-time application including a controller.

3D models can be exported to PDF formats in KUKA or even the animation forms can also be converted. It is similar to VC 4.1 in adjusting the component parameters based on the requirement needed. KUKA.Sim is similar to VC 4.1. but the VC4.1 catalog contains libraries of different robots and products from many different well-known brands whereas KUKA library is restricted to only have KUKA products.

It also is capable of doing OPC UA communication to communicate with the different interfaces like Beckhoff twin Cat, or Siemens TIA. But the OPC UA is not completely reliable as it is still being developing a feature in KUKA.Sim pro software. So comparatively VC 4.1 software gives a reliable standardization of OPC UA communication when compared with KUKA.Sim Pro.

2.4.4 Siemens Technomatix

Siemens Tecnomatix is mainly used as PLM software solutions for the whole process of manufacturing that contains information about planning, designing a static layout, performing the simulation and then doing testing and Verification. With Siemens Tecnomatix, businesses can improve their planning activity of a manufacturing process.

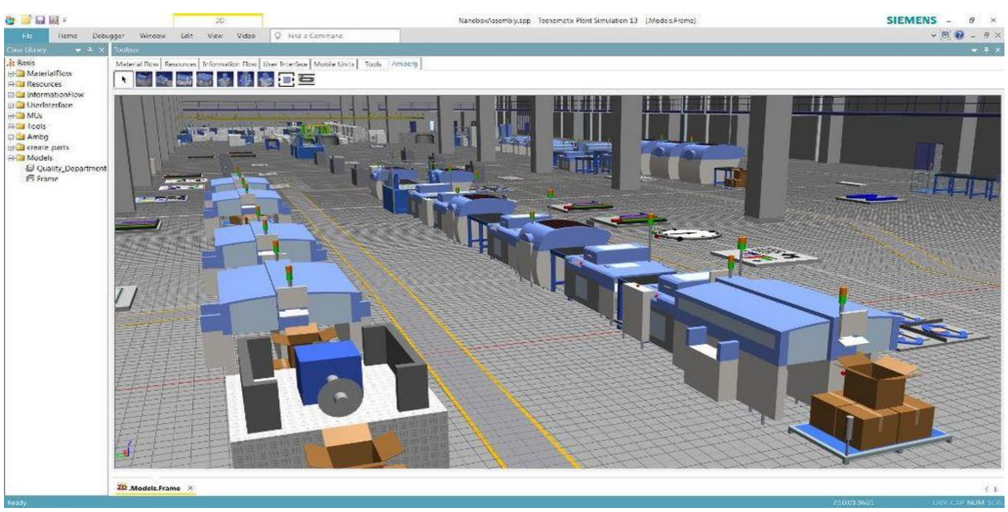


Figure 4 : Siemens Technomatix Plant Simulation [14]

Figure 4 shows that, Siemens Technomatix software is used for manufacturing process planning which includes modeling, testing, customization, optimization, and simulation. It is a component which eliminates the gap of designing materials and products to the delivery of finished products. The smart factory can be created using Technomatix plant simulation software effectively because the investment for creating a simulation of the production process is cost effective.

Simulation models are created using the application object libraries. The libraries can be extended using objects and any model can be designed using the tools available from the library. It has pick and place robots through which you can model the robots which perform such operations of picking and placing the objects.3D CAD models can be used for example and can perform modeling in the workspace. There is a bit memory allocation for improving the performance of CAD using the FACTORYCAD feature available in plant simulation software [10].

Robotics planning in the Technomatix is letting the user through a product life cycle management to design and do the testing and then simulate the robotics system. Manufacturers are able to access any amount of information or projects to increase the production level and can update the model and synchronize the automated designs. Engineers can discuss and take decisions while purchasing any products or designing any robots in order to decrease the error during simulation of the production process.

There is a Supervisory Control and Data Acquisition (SCADA) and Human-Machine Interface (HMI) system from Siemens, with functions for controlling automated processes and to collect real-time data in the production management of Technomatix. SCADA systems are used to control processes involved in the industry. These HMI and SCADA are used for specific functionality requirements and for a real-time HMI to provide a reliable solution.

2.4.5 Visual Components 4.1 versus Technomatix

In short, we define simulation as the production of data and visualization as the representation of data. Using 3D, we are able to visualize and simulate the whole manufacturing process as if they were being done in a real factory.

3D visualization and simulation are used to make the physical factory look real through these features. Different behavior and property of materials can be visualized using these features. However, both Siemens Technomatix and VC 4.1 are capable of doing simulation and visualization but there is a difference in the way it is done and which is more effective.

Technomatix plant simulation software has a drawback as it only provides 80 element flow objects that can be used for a student version software and there is a lack of designing a logical diagram of the process.

Using VC 4.1 there is a possibility for custom design of 3D models whereas it is not the case of Technomatix. Technomatix does not allow the user to program the robots in offline mode which is a major drawback. The main problem in Technomatix is that while adding and connecting elements. Only one element is possible to add when an icon is clicked. If the second element needs to be added, then the whole process has to repeat which is time-consuming.

Whenever there is any change made in the project it is not possible to go back to the previous version after the changes are saved. Therefore, there must be a copy of each version of the project for the user to refer it at any time but it is a very annoying task and also delays the task.VC 4.1 contains much optimized and effective use of libraries but the libraries in Technomatix need more customization and is not pre-defined.

3. Describing software tools suitable for digital twin design

3.1 Visual Component 4.1

• VC 4.1 provides a standardized simulation process by understanding the behavior of each element in the process.

• It is possible to upload any sort of files easily and there are graphic changes allowed in VC 4.1.

• There can be the simultaneous operation of simulation and programming and there is separate memory allocated for performing this. CAD files can be imported at a faster rate and can be converted for use in the simulation process.[9]

• There is maximum quality provided for the user interaction. Icons and the command window are easily available from the menu toolbar. User can also experience the 3D effect of rotating, zooming and visualizing in different angles.

The architecture uses the .NET framework with the use of PYTHON API. Any changes to the projects can be made very easy through the kernel. Display of the data is more flexible through rendering models and with any amount of shading and spacing the view is more accurate. New materials can be designed for the sake of simulation using X-RAY mode.

3.1.1 Visual Components 4.1 Premium Version

Work area modeling

Drag and drop menu makes it easier for the user to just drag the elements from the catalog into the work area to interface using plug and play. Speed, size and color dimensioning can be changed using the edit icon and there are almost more than 1300 industrial robots available from 25-30 brand automation industries along with other equipment like conveyors or grippers, etc.

CAD compatibility

Any 3D files can be imported and converted. These importing files can be prepared from different software's used for designing CAD models and visual components support cad files from any CAD vendors. These geometries imported will be the same one which is designed already and so there is no need for any other help to do the conversions or make changes with it as seen in Figure 5.

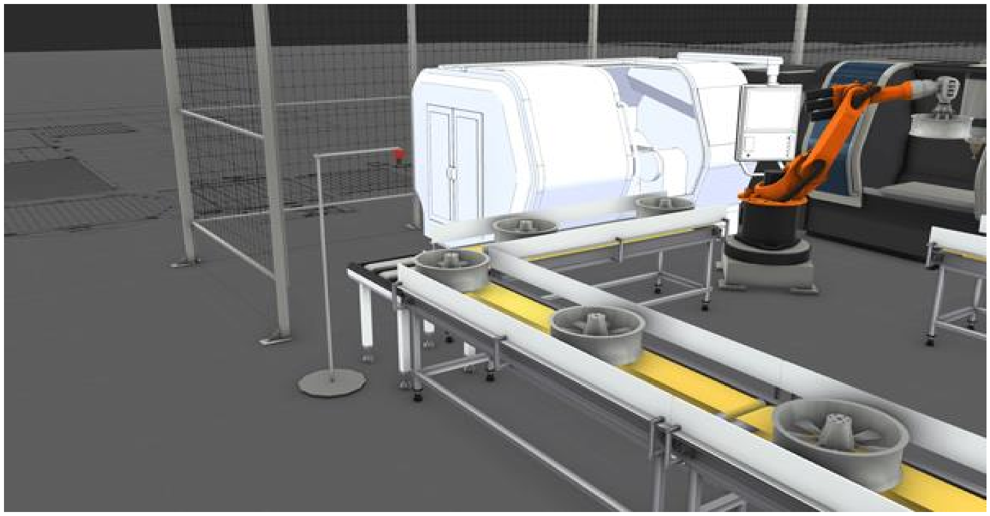


Figure 5 : CAD file imported to visual component [15]

Controlling the Graphics

When working with desktop any image can be easily clicked on the desktop and can use the same image directly into the projector even include video in HD quality.

Through Figure 6, 3D pdf can be generated for showcasing the zooming, or rotating or components and then used the same in simulation. It is possible to create 2D drawings with our dimensional requirements and then can be printed on a printer.

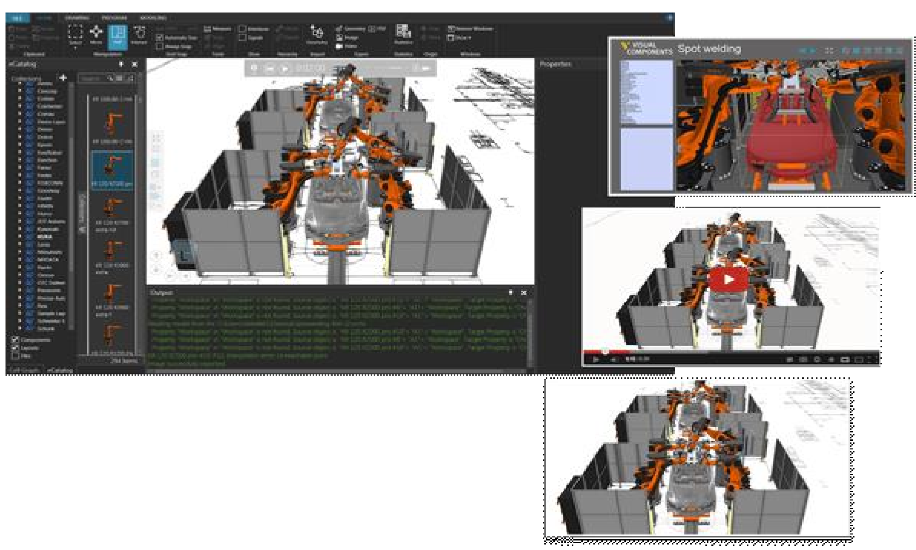


Figure 6 : Zooming and Rotating in VC [8]

Robotics supporting point cloud

Robotics is defined in a simple manner using standard tools for designing the robots. Point clouds in the form of geometry can be used to model the work area and do analysis with 3D dot clouds.

Support of OPC UA

OPC UA communication is made possible for 3D simulation and visualization using PLC for real-time process and then analyze the data and do the simulation. Virtual commissioning can be performed to verify and test the logic codes.

Statistical display

Simulation results can be displayed using statistical toolbars such as bar chart, column or pie chart. For further modification of the results, a special icon can be used to identify the problem and then make changes accordingly and then later these results can be exported into PDF'S or XLS formats.[8]

Modeling of components

Any component can be modeled very easily using the modeling tab. The component's geometry can be modified based on the requirement and can be made to even change the behavior and functionality for that requirement.

CAD models can be imported and we can change its function or the behavior or it is possible to even modify the structure which is already existing. So, it is possible to create your own library for modeling.

Components can also be modeled using wizard by quick inputs and activating.

4. Design of digital twin of selected laboratory workstation and specify safety zones

4.1 Idea behind the topology

The smart factory is the new trend in the industries these days. Production line plays a major role in the industry. Producing parts, transporting it or palletizing it and attaching or detaching of parts and so on are the major processes that can be seen in a production line.

It is necessary that all the processes carried out needs to be precise and easy to achieve. Conveyors become an important part in an automated industry as the products are transferred easily and in a safe manner. These products are then either picked and placed elsewhere or can be carried out to perform another process. In many industries we see robots performing the pick and place. Pick and place robots are very precise and the errors that can occur are very rare and minimal. It also increases the speed of the production line and increases the final quality of the production line.

A visiting company like brose helped a lot in coming up with topology to pick and place products and doing palletization. Pick and place robots are present to pick and place the car latches in a box and then humans are counting the products and are doing the packaging and transportation. But the same process can be made easier by doing palletization so that there is a count of parts and also it is able to save money and time. Labor work is reduced which in turn reduces the labor cost. Heavy materials or light products can be stacked with the help of pallets and can be moved easily with the help of robots or pallet jack. This, in turn, reduces the overall time of production, saves money and time as a whole and increases the throughput of production.

So, to implement such an efficient production, this project explains about the pick and place of products by robots and the palletization process and how it is being transported by a robot. A parallel process is carried out to reduce the time of production and there is no labor work.

4.1.1 Sequence of processes

- The main aim is to design the static layout which will contain a conveyor attached to the sensor where the main product is created and transported. The main product here is chosen to be a cylinder. At the end of the conveyor, the cylinder stops at the sensor point.
- The robotic arm 1 should pick this cylinder and it should place on the sensor where the pallet is created. A certain matrix is defined for the placing of cylinders and then this filled pallet with cylinder should be transported to the conveyor attached to it and the pallet should stop at the conveyor end exactly at the sensor point
- The robotic arm 2 will now pick this filled pallet with the cylinder and it moves on the robot floor track to place this pallet to the sensor which is at the end of robot floor track and then this pallet should be transported out.

The whole process is first designed as the static layout in VC and then the control code is programmed in Tia Portal and later tested and verified.

4.2 Static Layout Modelling

4.2.1 Adding process component

Works process (Figure 7) in VC is basically a sensor through which the product is being sensed and processed. Under the e-catalog, Panel go to works library and under visual component add the component called works process

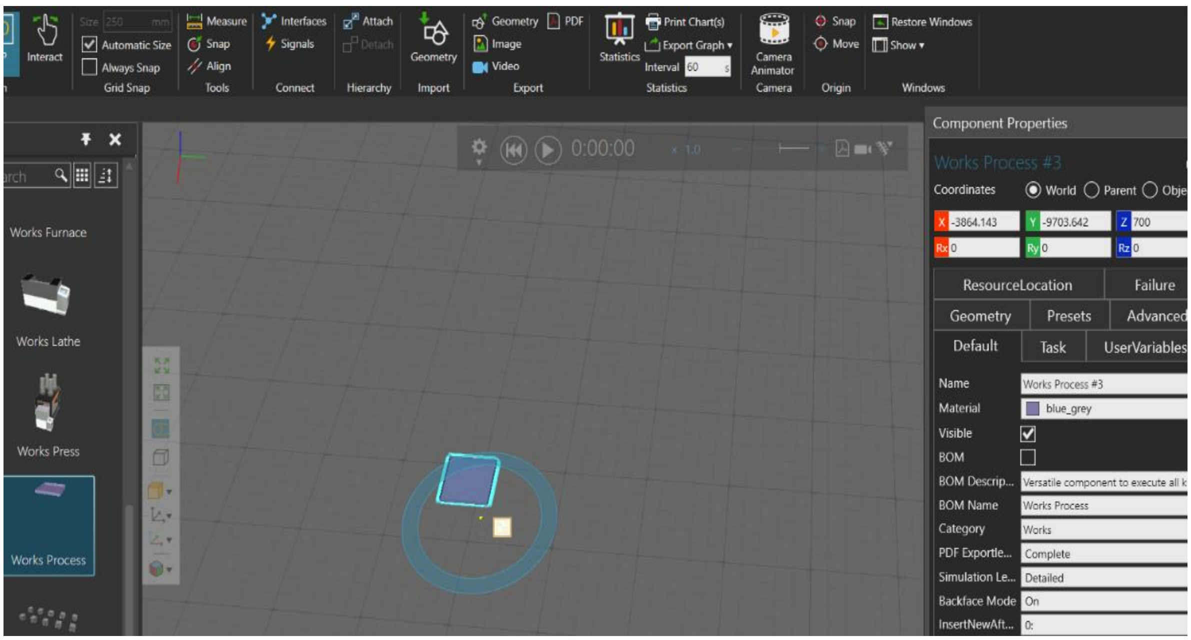


Figure 7 : Creating works process component

4.2.2 Adding cylinder and Defining Size

Under products and containers library select cylinder and drag it into the 3d world see Figure 8.

The size of the cylinder is changed under component properties of cylinder Radius to be 150 and cylinder height to be 200

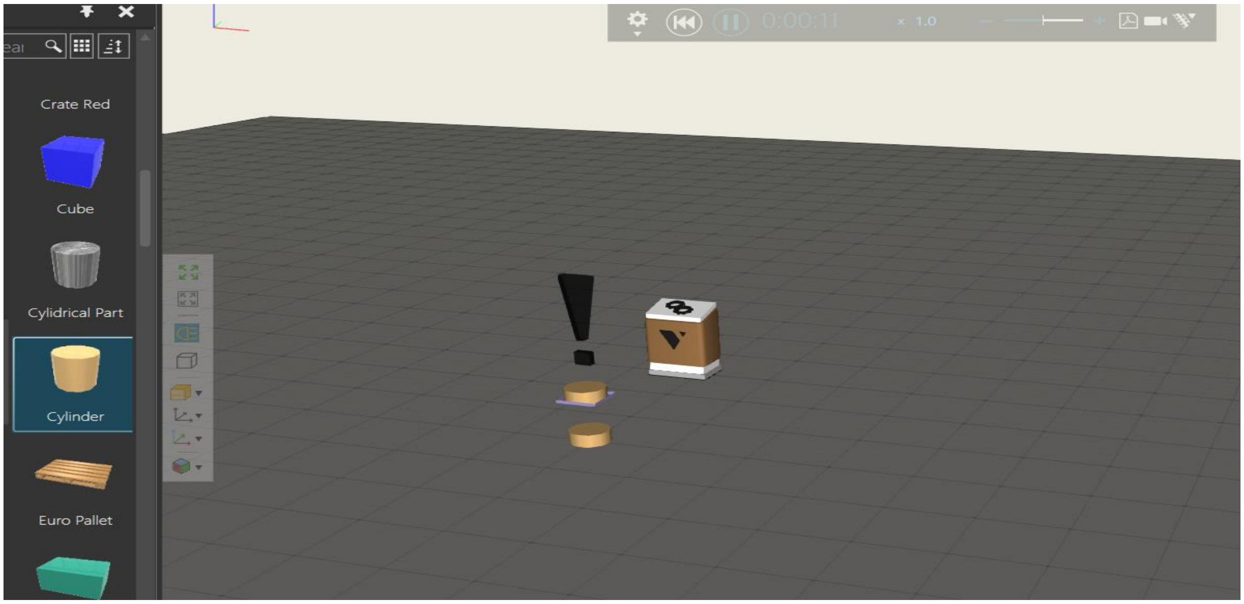


Figure 8 : Adding cylinder to the 3D world.

4.2.3 Conveyor connecting to works process

Conveyors are found in models by type library in the e-catalog panel. Using the PnP command, the conveyor is plugged with the process component. In the component properties under default, tab changes the conveyor type to be belt conveyor. (ref Figure 9)

Add a second process component to the other end of the conveyor and use PnP command to plug it into the end of the conveyor. Make the process component to look like a conveyor. In the component properties panel and in the geometry, tab selects the checkbox for ShowConveyor and clear the Showbox bar. At this point, the second process component looks more like a conveyor.

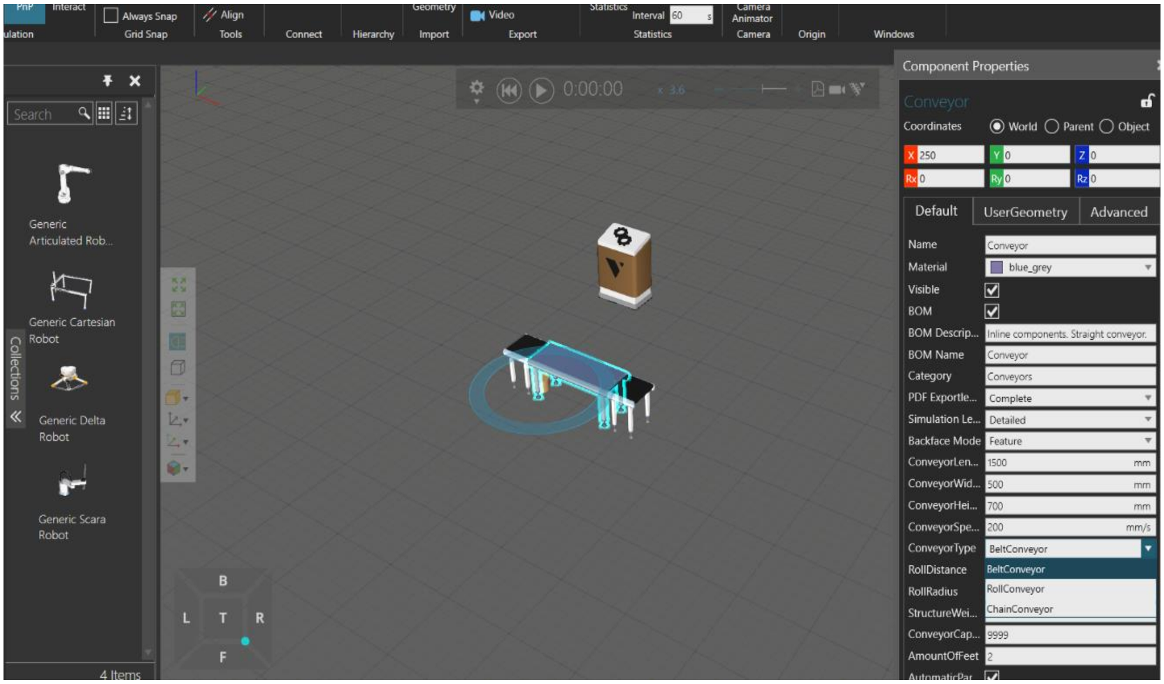


Figure 9 : Connecting conveyor to works process

4.2.4 Robot Modelling

Under Models by type, check for the option of works Resources and under that option select works robot controller and add it by dragging it into the 3D world. Go to the top menu and Align it to the end point of the second process component so that the robot placed on it is able to reach the second process component.

The works robot controller is added here to control the robot movements and trajectory. The control algorithm of the robot works by using a works robot controller for it.

Select Generic Articulated Robot under VC from robots’ tab which is under models by type panel. Use the PnP command to connect the robot to the robot controller. (From Figure 10) The green arrow indicates that the position where the robot needs to be placed. So, using PNP command move this robot in that direction and place it on the works robot controller.

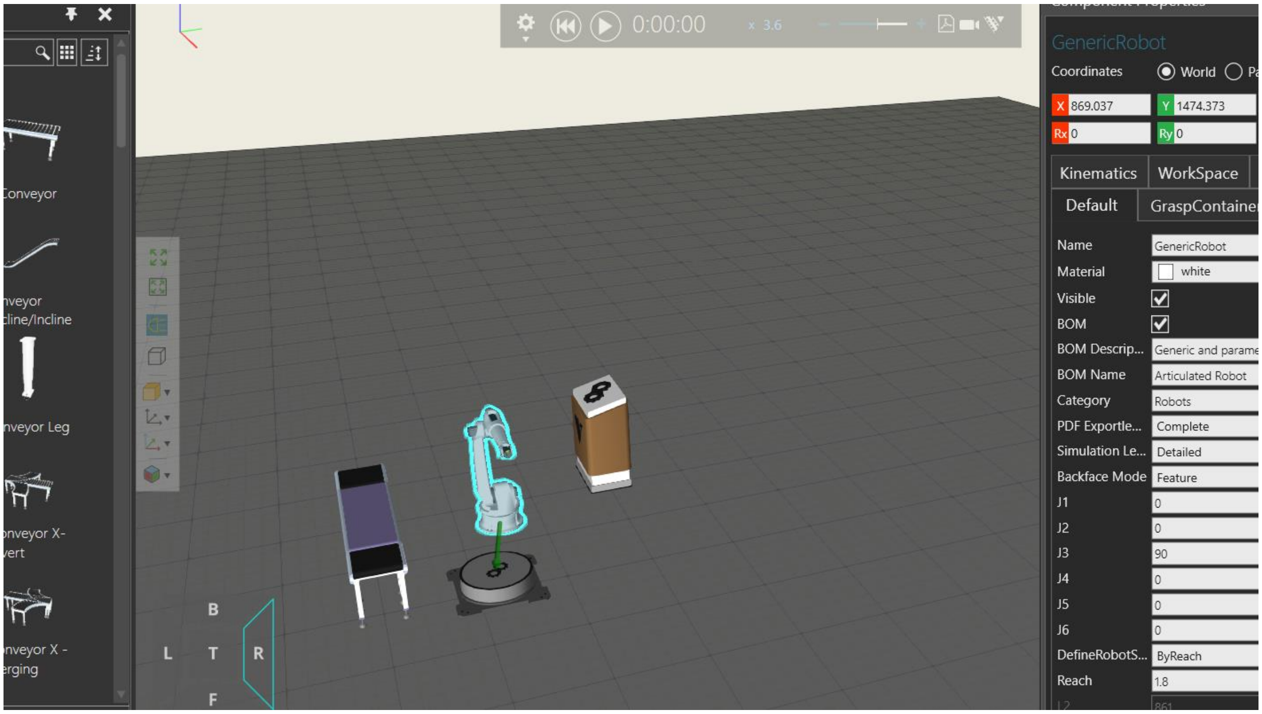


Figure 10 : Connecting robot to works robot controller

Add a tool to the end of the robotic arm. In the e-catalog, panel expand tools and from VC menu add a simple gripper.

Use the PnP command to connect to the end of the robotic arm and verify if the tool is connected to the robot. So, to verify that select the robot in the 3D world and then use the mini toolbar to activate the interact command and then interact with the robot's joint and the tool should move with it.

Using this simple gripper which is attached to the robotic arm it will now pick the product with its gripper open position and then closes the gripper to hold the product and then it again opens the gripper to place the product on another place.

Use the PnP command to connect to the end of the robotic arm and verify if the tool is connected to the robot. So, to verify that select the robot in the 3D world and then use the mini toolbar to activate the interact command and then interact with the robot's joint and the tool should move with it.

4.2.5 Adding pallet and Creating second conveyor.

The third process component is added to place the pallet. Under products and containers choose a Euro pallet and drag it into the 3D world. Third process component needs to be resized. So, change the C length to 1500 and C width to be 1000. Make this process component to look like a conveyor by the same process which was followed before.

Place this process component in such a way that the robot can reach the point where it needs to place the product. Select the robot in the 3D world and in the component properties panel to select the workspace tab and then select the envelope checkbox to see the area of reachability to the robot. Select the process component and move it closer to the robot so that it is easy for the robot to reach it. After this clear the envelope tab.

Select the first conveyor and then use the clone option to generate the conveyor and use the PnP command to connect the conveyor to the works process component which is creating the pallet and then resize the conveyor by changing its width to be 1000 now the layout would like shown in Figure 11.

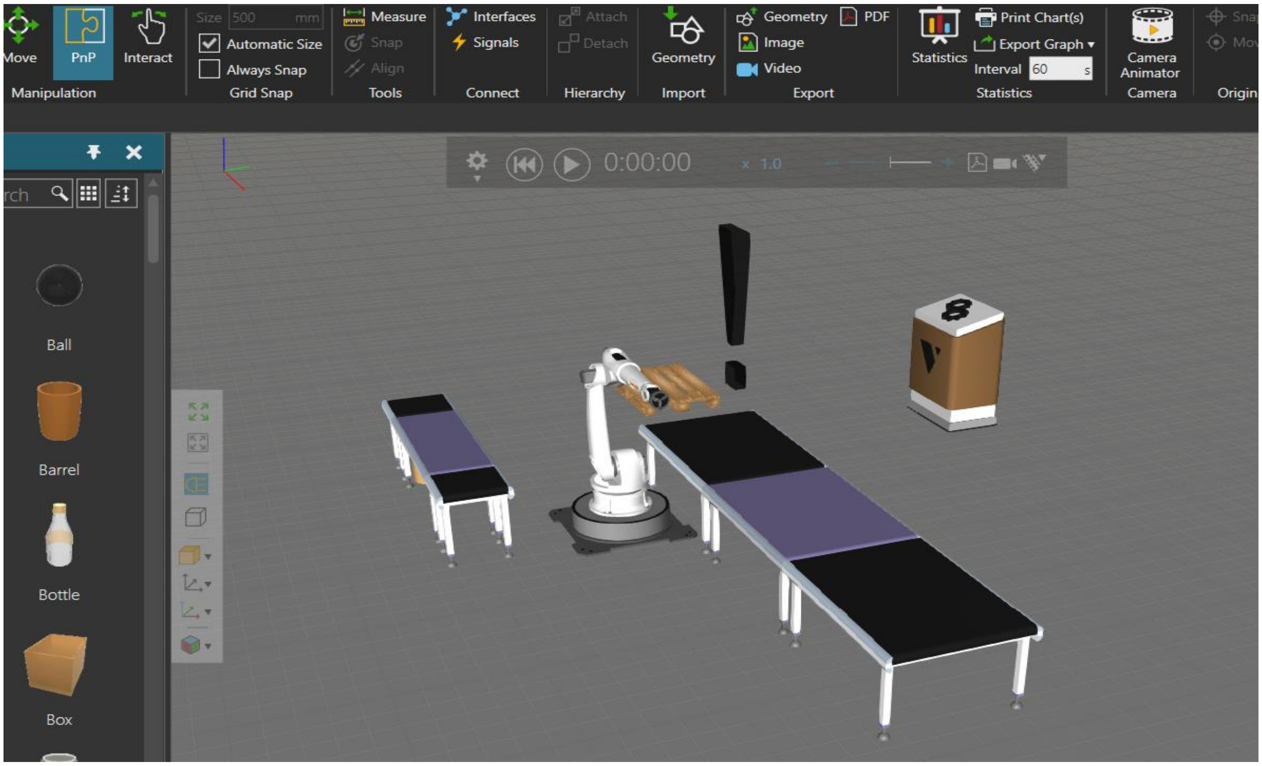


Figure 11 : Adding works process and cloning conveyor.

4.2.6 Teach robot to Pick and place

Tool frame is needed for the Gripper. Under the programs tab and use the jog command to select the robot. Turn on the tool's frame under the 3D world toolbar and click the frame type and select the checkbox of robot tools. Tools frame and the imported tool from the gripper is highlighted and it is called Gripper Tool_1. Under the Jog panel click the tool drop down menu and we can see Gripper Tool_1 in it.

Select the second process component which gets the cylinder and in the component properties panel create a task called 'Feed' and then select the 'All' checkbox. Define the Tool Name that the robot uses to pick the product and type it as 'SimpleGripper' in that bar. Select the second process component which gets the cylinder and in the component properties panel create a task called 'Feed' and then select the 'All' checkbox. Define the ToolName that the robot uses to pick the product and type it as 'SimpleGripper' in that bar.

From this, it is understood that it is not needed to assign it to the robot. The robot manager with the task controller automatically knows that the process component with the pallet needs the cylinder or a component with that product id. The robot will know that it was assigned a feed task for feeding the component with the product id of the cylinder to any other process component which needs and is within its reach.

4.2.7 Repositioning of cylinder on the pallet

Select the cylinder and use the move tool and move the cylinder up and then to adjust it to a location hold on the shift key and pick a point on the cylinder and then drag the component with that point onto another location and the snap it to the edge point which is the top face of the pallet. Press the escape key to exit out of this snap command. Use the move tool to reposition it for the cylinder to be placed initially. Save this location of the cylinder for future use by selecting the Teach Location under the component properties panel. Also, select the checkbox 'OnlyContainedComponent'. The pallet and the cylinder location will be stored with this option. Now after running the simulation, we see that the robot places the cylinder at the location that we specified.

4.2.8 To place more cylinders on the pallet

Under Tools group use the measure tool and under the measure task manager snap type select the bound option and now select the upper corner point of the cylinder and then draw a diagonal and then select the bottom corner point and the X, Y and Z indications are shown. Under the component properties panel select the task as 'NeedPattern' and the property we need is a cylinder and the AmountX to be 4 and the AmountY to be 4 and AmountZ to be 1.

4.2.9 Connecting a robot floor track

The works robot controller is added initially and is positioned in accordance with the works process where the pallet stops (Figure 12). Robot floor track is selected from robot positioners library under models by type, and using PnP command plug the track into the controller. Using move command rotate the robot floor track by 90 degrees along the Z axis.

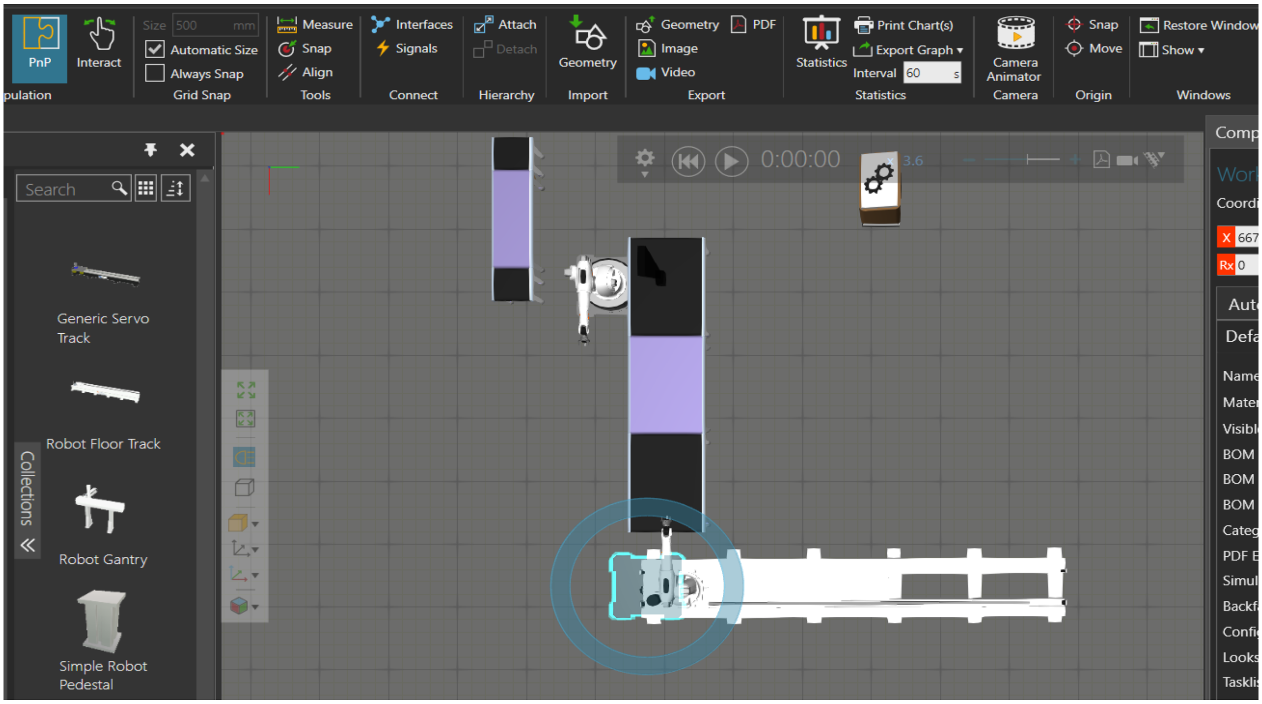


Figure 12 : Creating a robot floor track for second robot and aligning it.

Plug the Generic articulated robot from the VC menu to the platform track and then test the connection by clicking the robot and then turn on the interact command. When we interact with the platform on the track the robot also moves with it. From the top view position, the track in such a way that the robot is able to access the pallet filled with cylinder

4.2.10 Transfer this pallet to another process component with conveyor

Select the process component where the pallet should stop and now create a task ‘Feed’ and ListofProdId as ‘Euro Pallet’ and then we need to select the robot controller to assign this task to the robot. In the component properties panel under default, tab go to the Task list and add that Task Name defined in the previous step.

Create a process component with conveyor to the other end of the track to transfer out the pallet. Create a ‘Need’ task and ListofProdId as ‘Euro pallet’ and create the task. Select the robot controller and change the Joint Force and JointSpeed to be 100% and in default tab under configuration to be Front Above No Flip.

4.2.11 Safety Zone and Factory Equipment.

There should always be a safety whenever there is a robotic arm present. This safety zone is provided by adding fence and boundaries. There is also other factory Equipment added to make it have a factory look. The final layout is as shown in Figure 13.

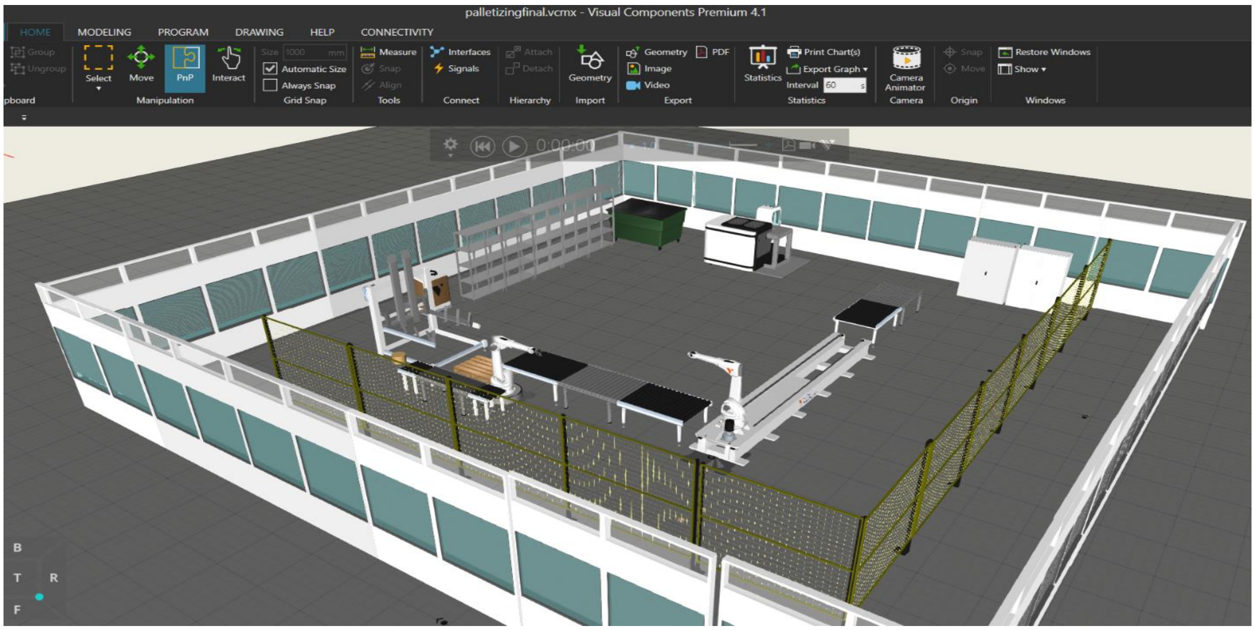


Figure 13 : Final Static layouts in VC 4.1

5. Functional System Analysis.

5.1 Main blocks of the static layout.

Sensors: They are used to sense any physical entity and then respond to it as an output with some signal identification. In this digital twin different sensors are used which collects the information and processes with the help of signal.

Conveyor: These are designed to move or transport materials from one location to another. There can be heavy or light materials. Based on the type of materials different type of conveyor belts can be used. There can be gravity conveyors are powered conveyors. In this digital twin design, belt conveyors and roller conveyors are used as it is used to transport light materials from one place to another.

In Total there are three conveyors being used. Conveyor 1 is for transportation of cylinder. Conveyor 2 is for transportation of pallet after the palletization process and the third conveyor is to transport out this filled pallet to another process.

Robotic Arm: It is a programmable machine which is able to function like a human arm. It has six axes and can be said to have 6 DOF. It can be used for various purposes like welding, construction, palletization, pick and place of objects, assembling, etc. In this project, robotic arms are used for picking and placing the product and also to perform palletization. An articulated robot is used in the layout as it is easier for the robot to reach any place and pick or place the product easily.

Pallet: It is a wooden or plastic or metal piece of structure to load the materials on its surface uniformly. pallets are mostly used in industries to store the goods and then carry it using a lift jack, front loader, a robotic arm or by any other jacking device.

Gripper: These are objects attached to the end point of a robotic arm in order to grasp any physical object and close it to hold the object and then release it by opening the gripper. Here a simple gripper is used to pick and place the cylinder and pallet. It works just like a human hand to pick and place from hands.

5.2 Implementation of sensors.

There are three stages in the process where sensors are needed at each functional stage. First is creating and transporting the cylinder. The second stage where the sensor is needed is for the creation and transportation of pallet. The third stage where a sensor is needed to transport out the filled pallet to another conveyor.

5.2.1 Creation of cylinder and transportation.

Sensor 1: This sensor is needed to sense the creation of the cylinder and once it is created then the cylinder is transported.

Sensor 2: This is needed at the end of conveyor 1 to stop the cylinder at the sensor point for robot 1 to pick the cylinder.

5.2.2 Creation of pallet and transportation.

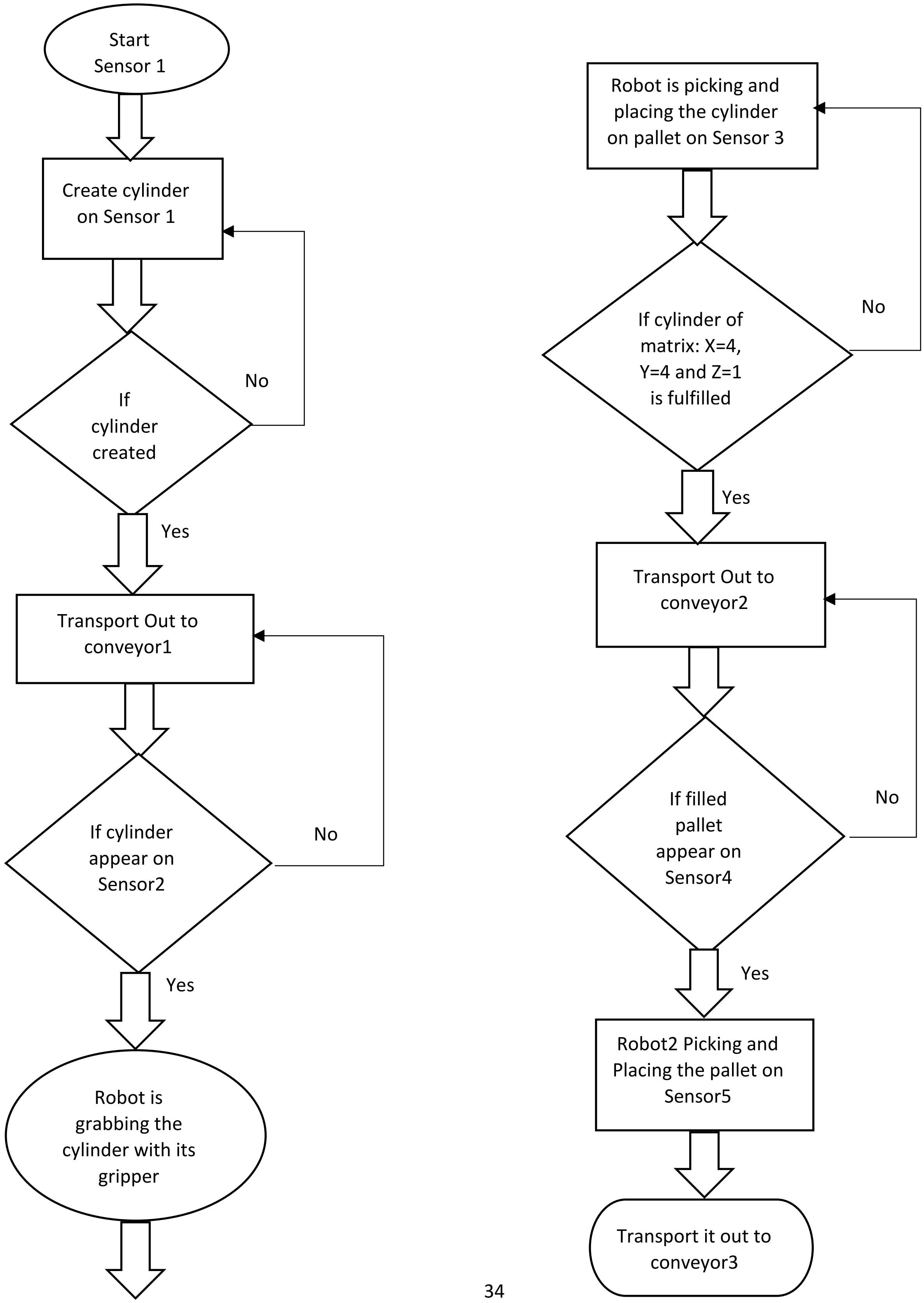
Sensor 3: This is needed to Create pallet on it and to sense if all the cylinders are placed to do transportation.

Sensor 4: This sensor helps us in knowing that the filled pallet has reached the sensor point and once it reaches the pallet stops for the robot 2 to pick.

5.2.3 Transportation of pallet to conveyor 3.

Sensor 5: This sensor senses if the filled pallet carried by the robot is placed on it. If it is placed, then it transports out on to the conveyor

5.3 Flow Chart of the process.



5.3.1 Creation of cylinder.

Input should be provided to sensor 1 to create a cylinder and the action should be the output which is the creation of a cylinder. If sensor 1 is true that is if its value is 1 then the cylinder is created else cylinder is not created.

5.3.2 Transportation of cylinder.

If the cylinder is created, then this cylinder needs to be transported out to conveyor 1 and then it appears on sensor 2 attached to the conveyor. If the cylinder appears on sensor 2 then its value becomes 1 then the robot can pick the cylinder. If the value is still 0 then it goes back to the previous process and the cylinders are transported until it reaches the sensor 2.

5.3.3 Palletization.

Sensor 3 should be provided with input for the pallet to be created on it. If it is true, then the picked cylinder is placed on this pallet. A matrix of X=4, Y=4, and Z=1 is defined. Total of 16 cylinders are placed and then transported out. If the defined number of cylinders are not placed, then the process continues until all 16 are filled and then it is transported to the conveyor

5.3.4 Stopping the pallet.

These filled pallets appear on sensor 4 and the sensor 4 value becomes true that means pallet is present on the sensor and it can be picked up by robotic arm 2. If it is 0 then the pallet is still being transported and it hasn't reached the sensor point.

5.3.5 Robotic Arm 2.

The input is given to the second robot to pick the pallet and it then picks and moves on the robot floor track and then the places it on sensor 5. Sensor 5 then becomes true and gets an input that pallet is placed and it now needs to transport it out on to the conveyor. If it not true that means, there is no pallet present for transportation.

6. Creating Basic Application

6.1 Defining variables

Tag table from TIA Portal is used for defining the variables. Each input, output and memory bits have defined value and it is then called in the Main OB program.

Variables are defined for each component in the TIA portal. Using these variables, the process is controlled and these variables are then paired with the variables from VC and the testing is done.

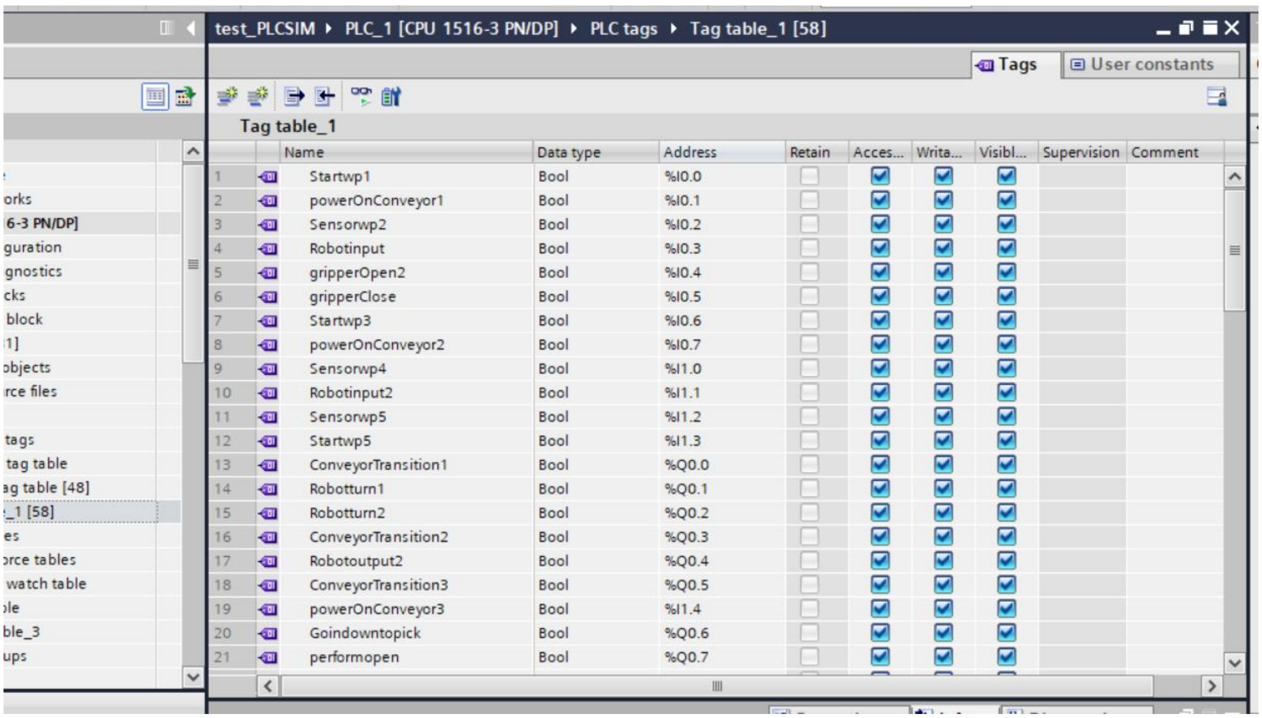


Figure 14 : Defining tags in TIA Portal

Main OB is the main organization block program, where the logic of the whole process is being represented in the form of ladder builder. Inputs and outputs are represented in a horizontal line called rung. Right side always starts with input and it must end with an output.

6.1.1 Cylinder creation and transportation

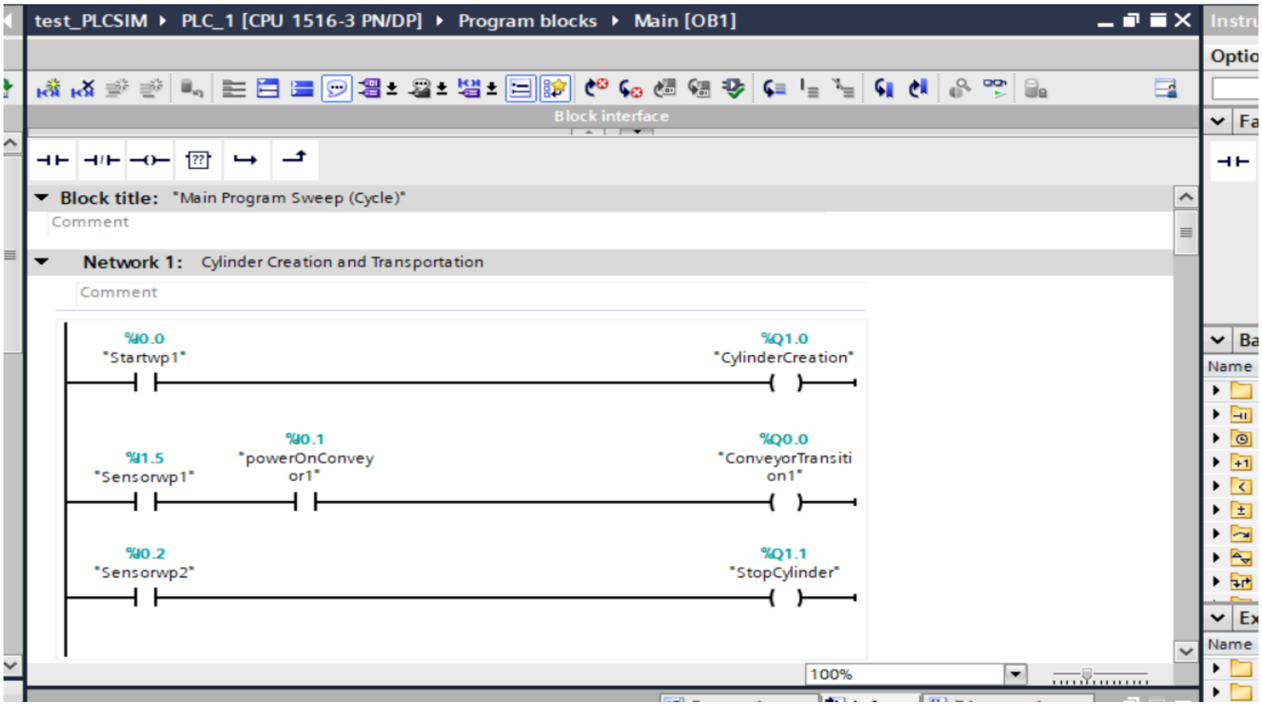


Figure 15 : Network for cylinder creation and transportation

In this stage, the Variable ‘startwp1’ is used for starting the works process and the output is the creation of cylinder represented with an output variable ‘CylinCreation’. If the cylinder is created, then it needs to transport out the cylinder.

If the input variable ‘Senswp1’ is true it explains that the cylinder is present on that sensor and it can be transported out. Variable ‘PowerOnConv1’ input variable, becomes true for conveyor1 after the cylinder is created. For transporting the conveyor ‘ConvTrans1’ is defined.

So, when the output variable ‘Convtrans1’ is true then the cylinder is transported out on to the conveyor.

‘Senswp2’ is the input variable defined to provide input to a variable to stop the variable at the second work process. Once the part arrives on the second works process then ‘Senswp2’ becomes true then the Output Variable ‘StopCylin’ denotes that the cylinder is stopped on the sensorwp2.

6.1.2 RoboticArm1 Operation

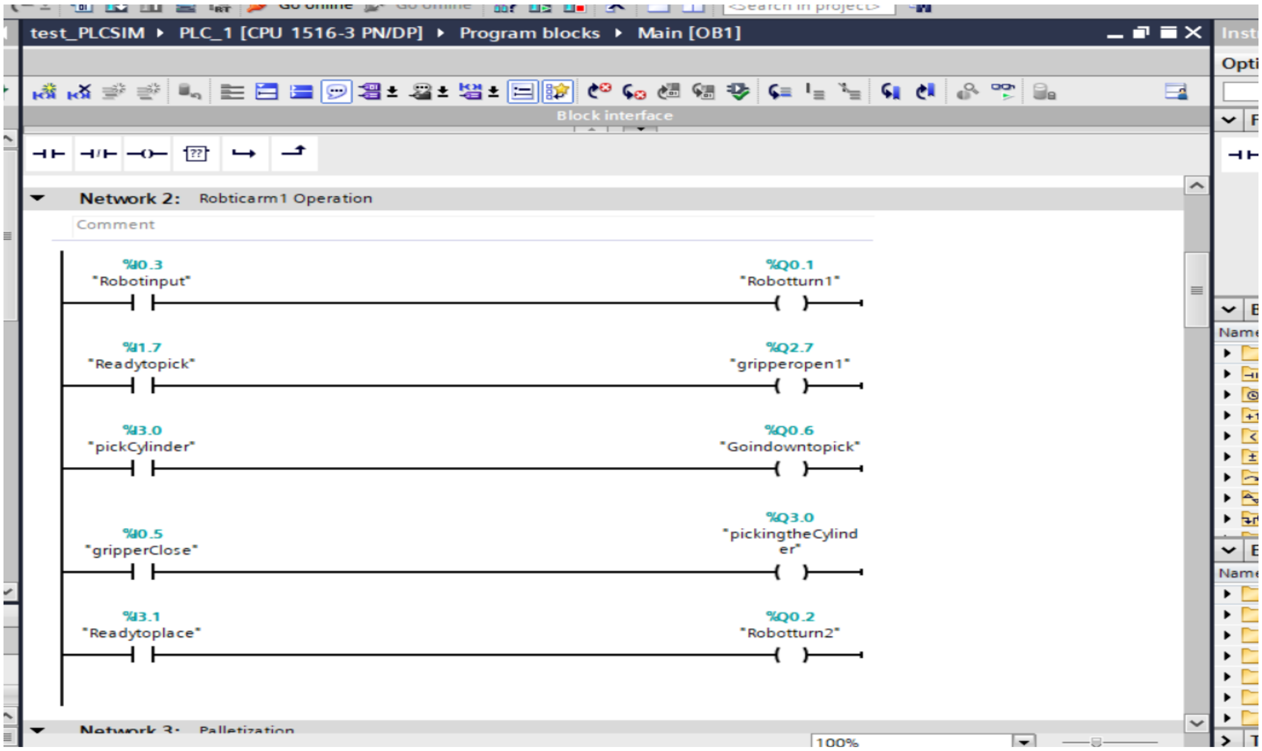


Figure 16 : Network for roboticarm1 Operation.

'Roboin' is used to provide input to the first robot to get ready to pick the part. 'Robturn1' is defined as an output variable. Once 'Roboin' is true then the robot needs to perform an action that is it takes a turn and get ready to pick the cylinder. Now it needs to Open the gripper which is the input 'Readytopick' and is performed with an action of 'gripopen1'.

Now the robot needs to go down to the cylinder position and pick the cylinder. So, the input is 'PicktheCylin' and the action performed is that it is going down to pick represented with output variable 'downtopick1'

Now it needs to pick the cylinder so then the variable 'gripclose' is given as input and when it is true, 'pickingtheCylin' variables becomes true indicating that the robot has now picked the cylinder.

'Readytoplace' input is to indicate that the robot has now picked and is ready to place, so when it is true the output variable 'Roboturn2' is executed for which the robot makes a turn to place the cylinder on the pallet.

6.1.3 Palletization

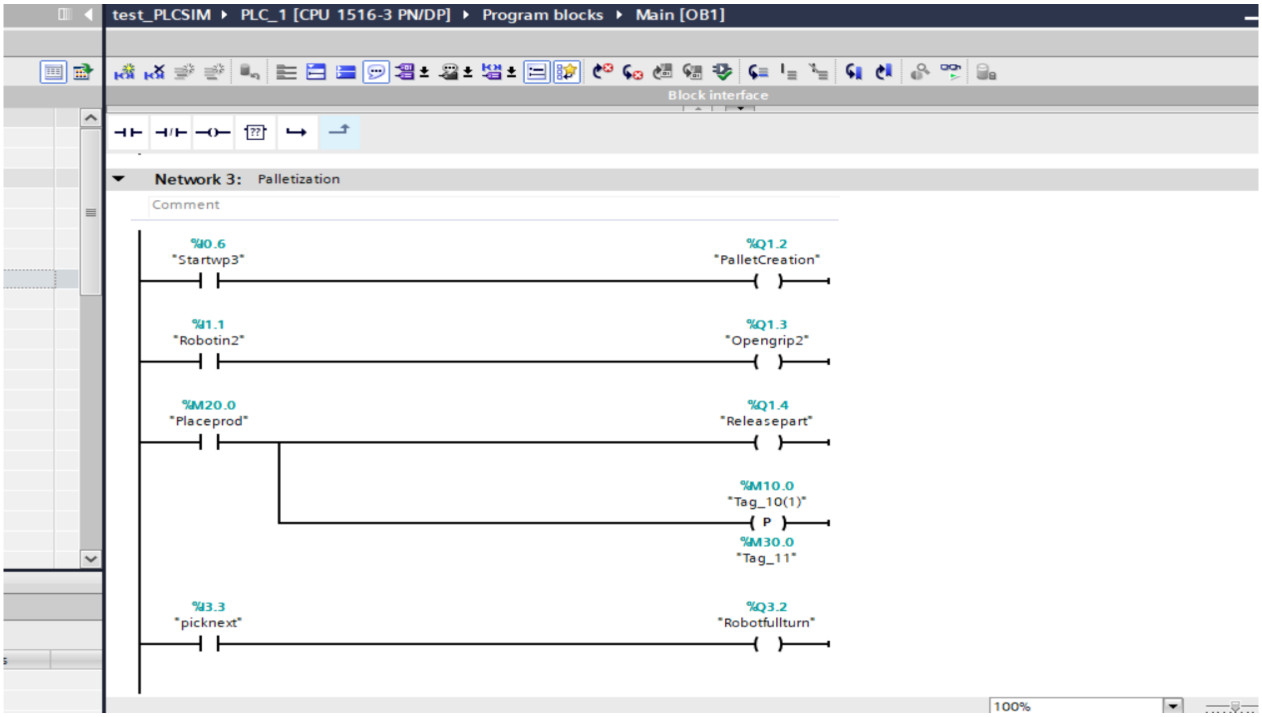


Figure 17 : Network for palletization.

Once the first robot picks the cylinder from the second works process and is ready to place on the pallet, ‘Startwp3’ variable is true and the pallet is created with ‘PalletCreation’ variable

Now there is a need for input to the robot as ‘Robotin2’ to perform an action of opening the gripper and placing the cylinder on the pallet with output variable being ‘opengrip2’

‘Placeproduct ’is to indicate robot to place the parts but with a specific position which is being indicated with a memory bit. If the value in the memory bit is 0 then the robot places the part in the 0Th place and then there is an incremental logic to increment the memory bit to the next level and cylinders are placed on the pallet according to the value in the memory bit.

Once the cylinder is placed then the robot turns with the action being ‘Robofullturn’ it turns back to pick the next cylinder and the cycle continues.

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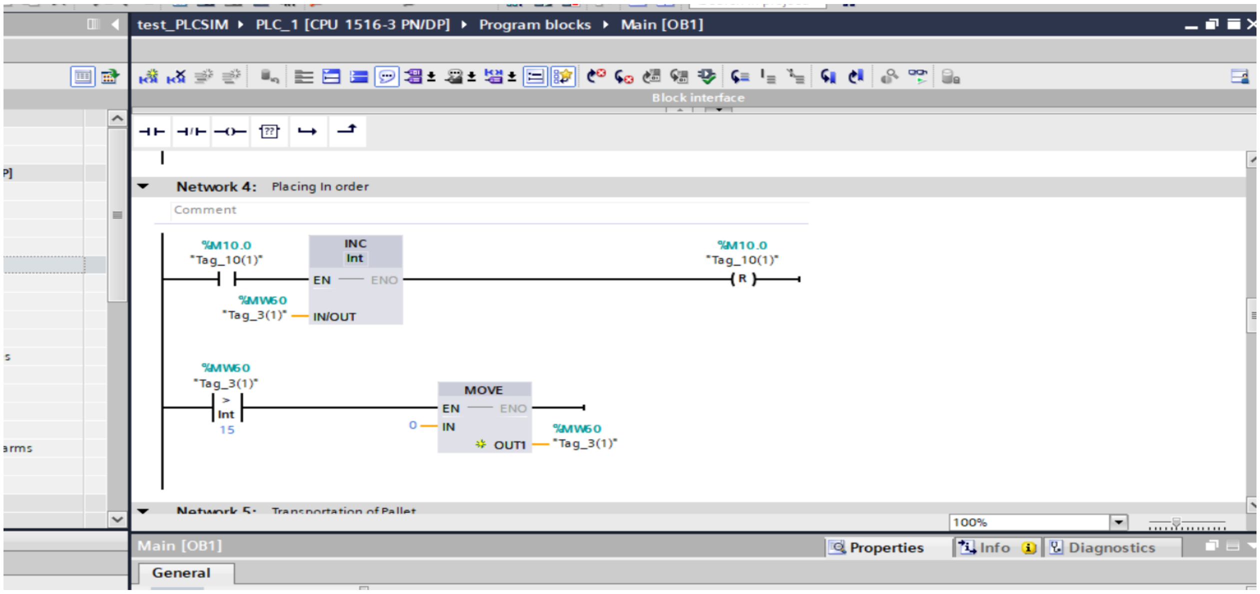

Figure 18 : Network for palletization logic.

The pulse is created in order to control the palletization of cylinder according to their order. A pulse is created with a memory bit starting from 0 initially and then when it is true the Increment math function becomes true and the memory value gets incremented by one and so on until it reaches the value 15. Then the value is reset and it starts counting from the beginning and it continues.

6.1.4 Transportation of pallet

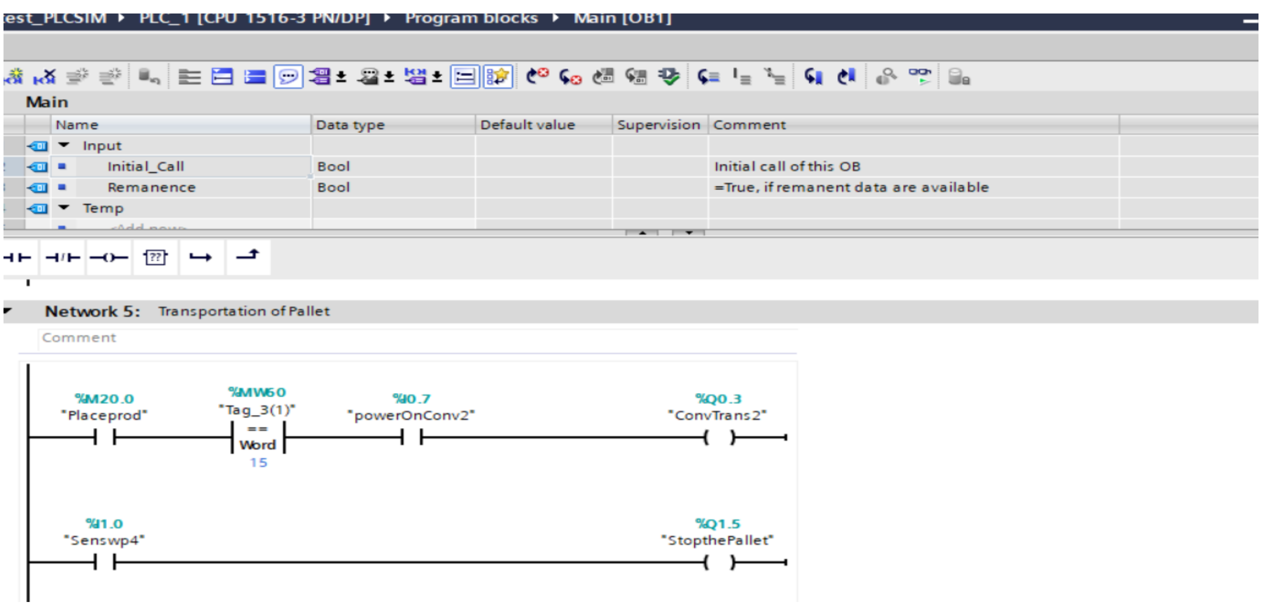

Figure 19 : Network for transportation of pallet.

Once the memory bit is 15, which means all the cylinders are placed on the pallet the 'PowerOnConv2' becomes true and is ready to transport out the cylinder and the action being indicated with variable 'ConTrans2'.

'Sensorwp4'variable denotes that the filled pallet is on the fourth works process and it can be picked up by the second robot. 'StopPallet' action is performed to stop the pallet in the position to be picked up.

6.1.5 Placing the filled pallet in the last stage

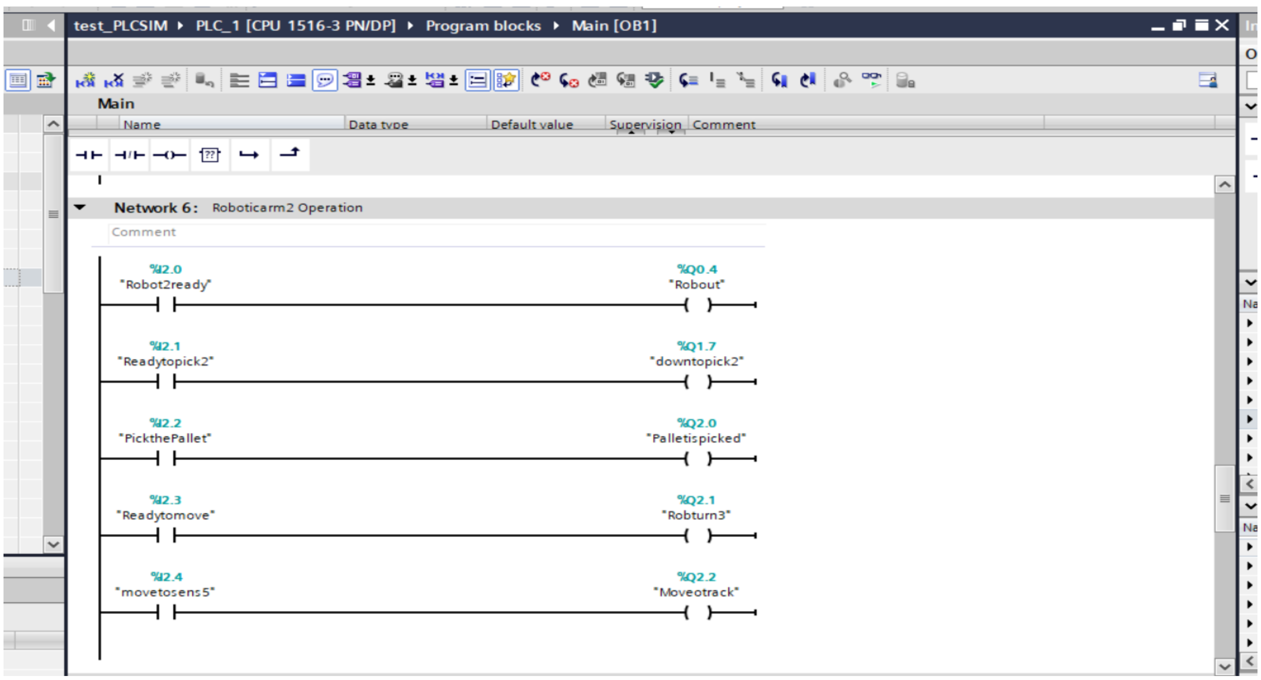

Figure 20 : Network for placing the filled pallet.

'Robot2Ready' is giving input to the second robot to be ready to pick the pallet and 'Robout' variable becomes true and the robot makes a turn to get ready to pick.

Then the robot needs to go down to pick the cylinder then input is given to pick the pallet and then the robot makes an action through 'PalletisPicked' variable. The robot is ready to carry it and move on floor track and it makes a move along the track with the variable 'Moveotrack'.

6.1.6 Transportation of pallet on third conveyor

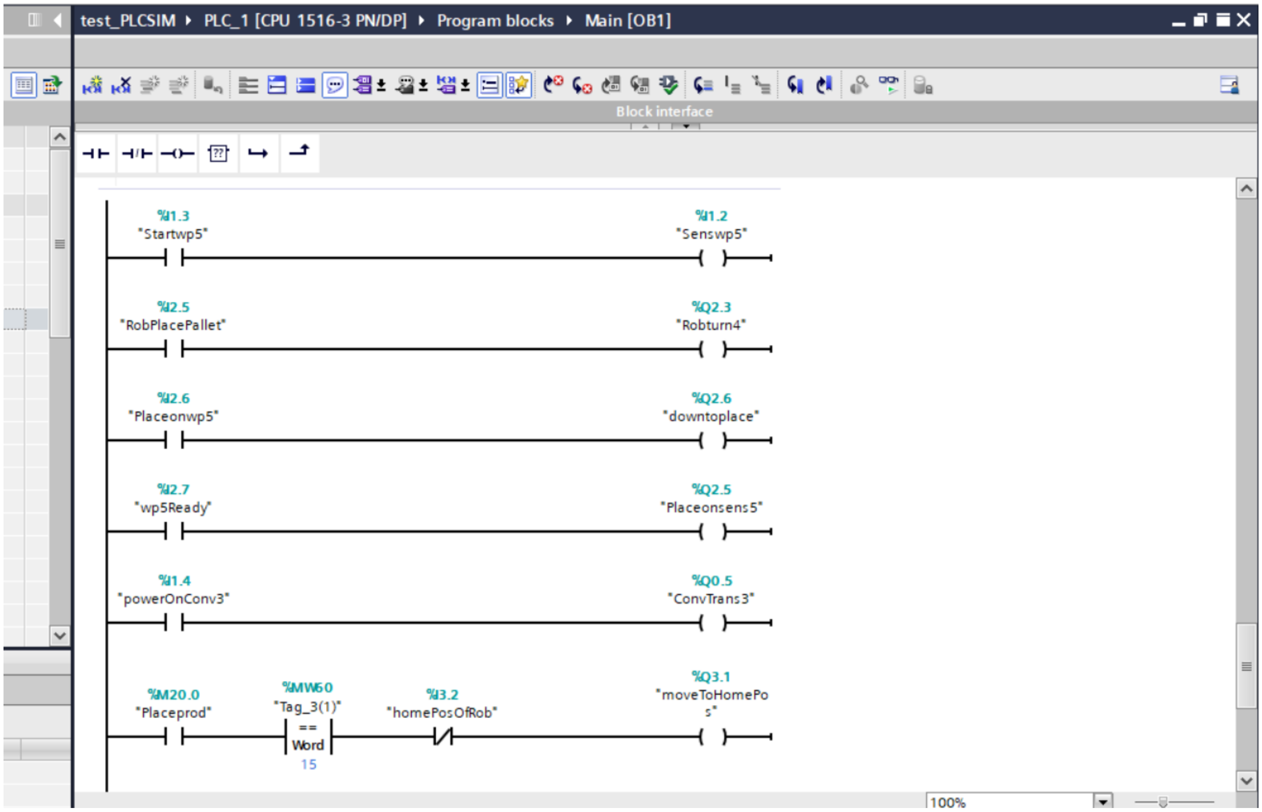

Figure 21 : Network for transportation of pallet on the next stage.

‘Startwp5’ is given as input for the fifth works process and when it becomes true it is now able to sense anything placed on it. ‘Senswp5’ is true when the filled pallet is placed on the fifth works process. Now it needs to transport out the pallet to the conveyor attached to it.

‘RobPlacePallet’ is given as input to the robot to get ready to place the pallet and then it makes action by making a turn ‘Robturn4’, Then the robot goes down to place it and places on sensor 5 indicated by ‘Placeonsens5’

‘PoweronConv3’ makes it ready to transport out the pallet and the output variable ‘ConvTrans3’ becomes true and the pallet is transported out on it. The robot remains at that position until all the cylinder is filled and the pallet appears on sensor 4. Once it appears then the robot comes to the home position to pick it up.

6.2 PLC SIM advanced.

PLC SIM advanced is helpful for simulation of the entire control code without being actually connected to the real PLC S71500. Using this simulation process the errors are detected at an early stage and can be corrected before connecting it with real PLC S71500. HMI device can also be connected to the virtual simulator.

Benefits of PLC SIM advanced:

Commissioning can be performed easily and in a faster way.

It reduces the production time as it can detect faults at an earlier stage.

Can be used and tested even if there is an absence of real PLC S71500.

Configuring PLC SIM advanced:

- Start the PLC sim advanced. Here select PLCSIM Virtual Ethernet Adapter mode.
- Select TCP/IP communication with Local.
- Specify the Instance name, any name can be specified here but should be unique every time.
- In the IP Address column, we can define the local host IP address as 127.0.0.1
- Provide the subnet mask as 255.255.255.0
- The default gateway should be similar to the IP address.
- Run time manager checkbox should be enabled.
- Then start the process and now the PLCSIM Virtual Ethernet Adapter is turned on and is identifiable.

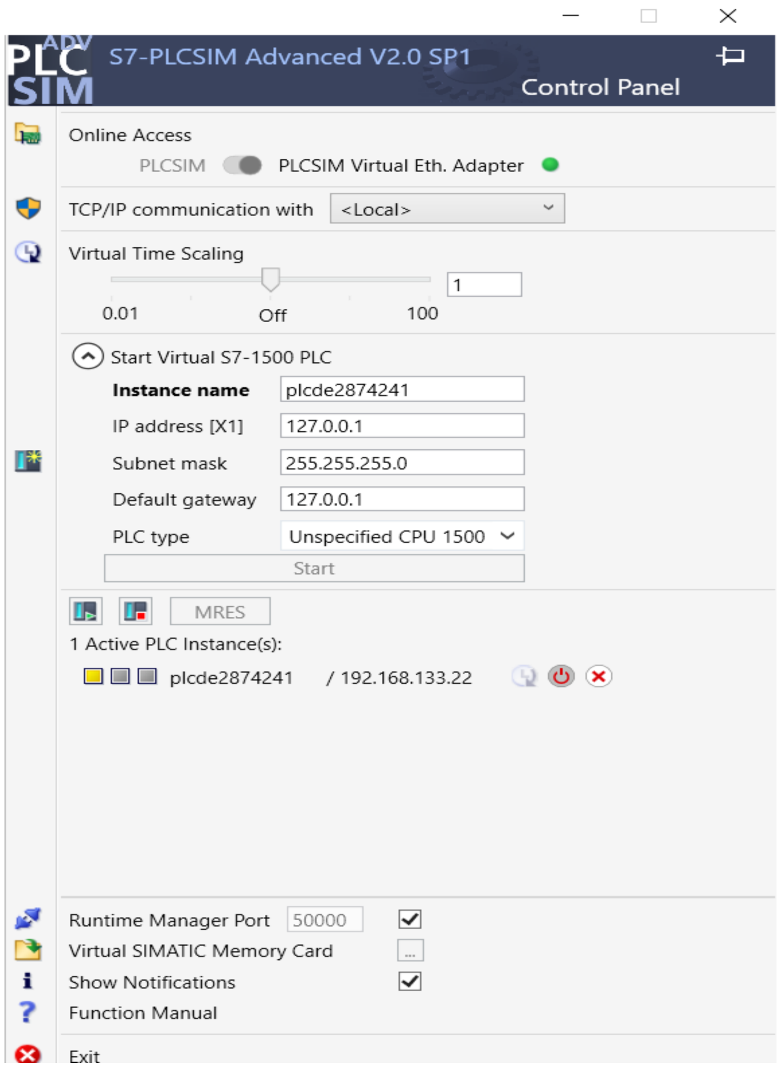

Figure 22 : Starting the PLCSIM advanced application for simulation

7. Testing and Verification of Created System

To test the PLC code that is being modeled it needs to be connected with VC and it has to be used to control the process in VC.

7.1 Connecting Siemens TIA portal and PLC SIM advanced

7.1.1 Activating OPC UA Communication standard

Under General tab, Select OPC UA and in the server, section select Activate OPC UA server and also specify the IP address in the properties panel.

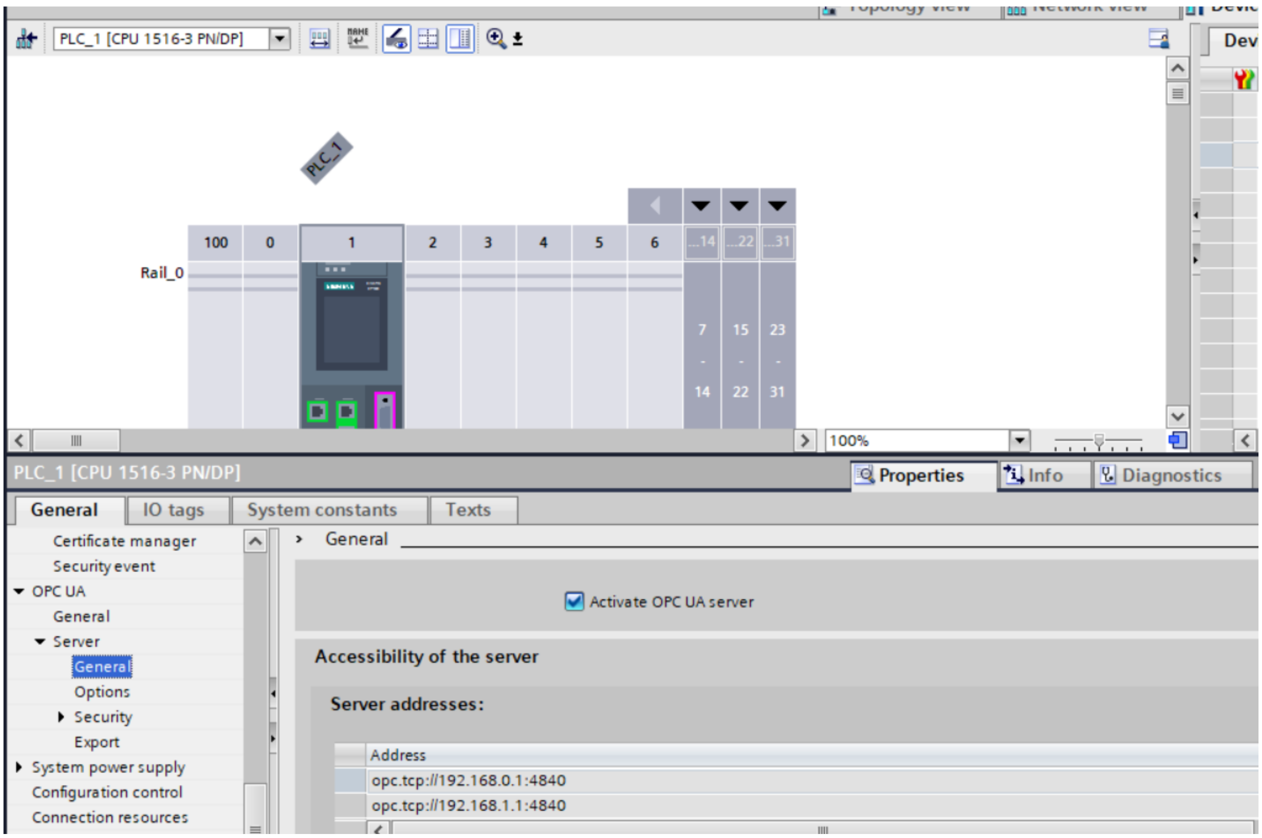

Figure 23 : Activating the OPC UA connection and specifying the address

Another requirement is to make ensure that the simulation is supported in TIA PORTAL. In order to confirm this. Open the project in TIA portal and right click on the project and then select the Protection tab.

Under Protection tab ‘Support simulation during compilation’ checkbox should be checked for the program to be compiled.

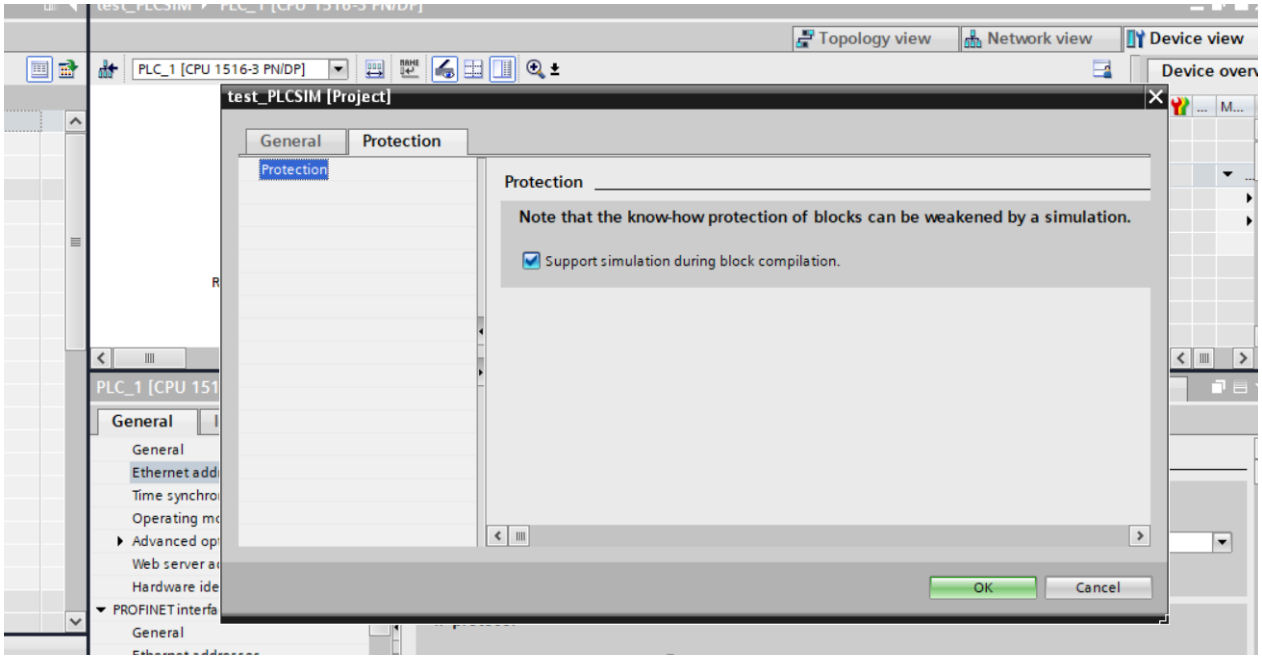

Figure 24 : Simulation boxes is checked for downloading the program.

7.1.2 Downloading to PLCSIM advanced.

The PLC needs to be loaded and connected with PLCSIM advanced to go online and test it. It must be an S71500 or ET200SP PLC to connect to PLC SIM advanced.

If OPC UA communication needs to be tested, then it is necessary to use PLC SIM Virtual Ethernet Adapter:

• The initial step is to click on the PLC in the Device Configuration menu and then click on download to the device.

• Select the type of interface that needs to be connected and specify the PG/PC interface as Siemens PLCSIM Virtual Ethernet adapter.

• Select the interface slot as a direct slot at 1 X1.

• Now the PLCSIM will be visible and then it would ask to add an IP Address to the PLCSIM Virtual Ethernet adapted and once added, then load the program and finish it.

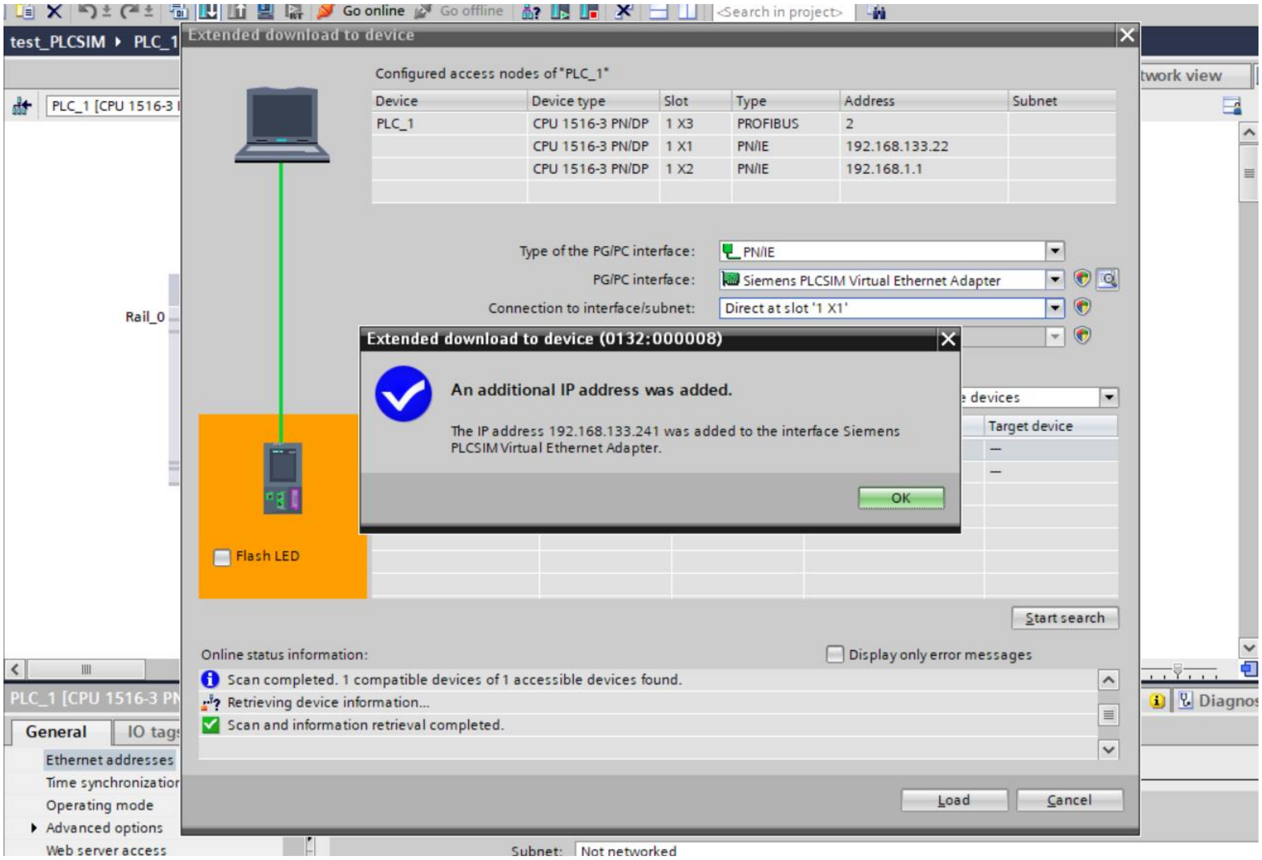

Figure 25 : Downloading the program to the PLC with the specified IP address

• Once the PLC connection is established, we can go online and check for testing the control application program.

• All the variables are defined in the watch table and can be monitored to see if the proposed logic works perfectly without any errors.

7.2 Commissioning using watch Table

Once the Program is complete, it can be tested and controlled using a watch table. In the watch table, all the input tags are copied and then each input tag is modified to 1 and the outputs are tested using this.

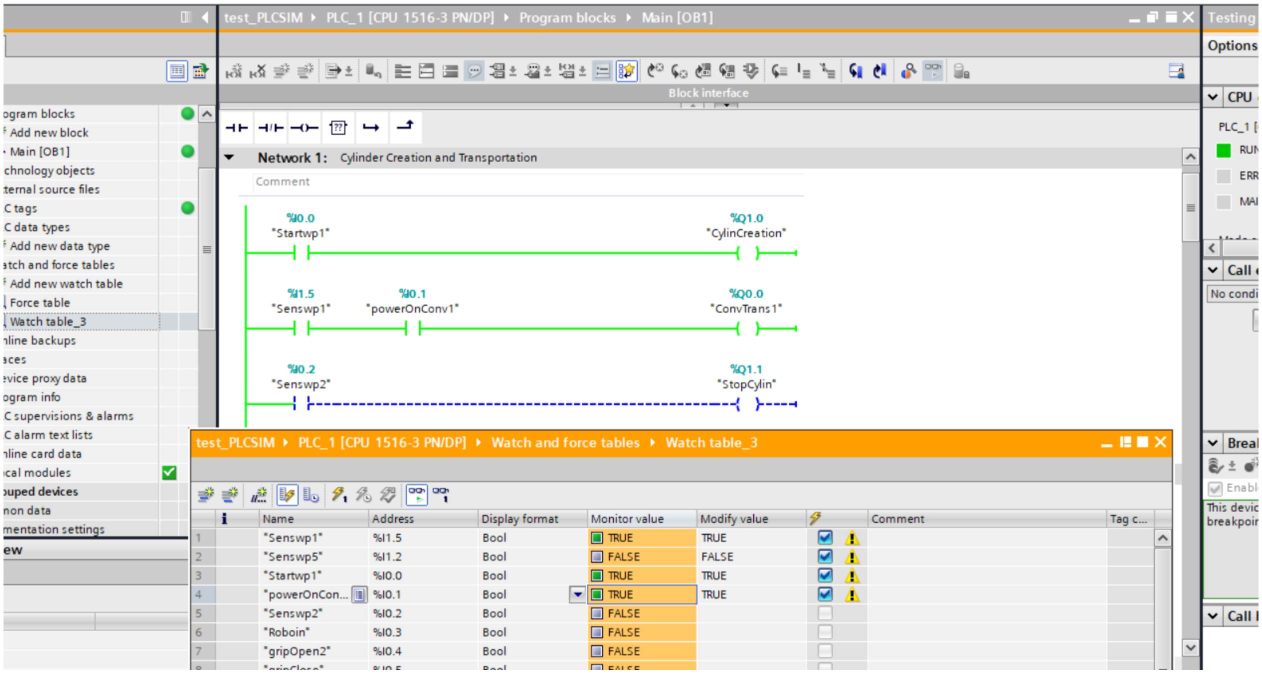

Figure 26 : Monitoring inputs using watch table.

When the input variable ‘Startwp1’ is modified to 1, then the input tag in the main OB turns to green indicated that it is active now and the corresponding output becomes true and turns to green. Also, the variable Startwp1 becomes true in the watch table.

In a similar way, all the networks are tested and checked if the logic is working perfectly without any errors.

7.3 Connecting TIA portal and Visual Components

TIA portal and VC needs to be connected and communicating with each other in order to control and test the process. This is done with the help of OPC UA.

• In the VC software, open the project and go to file and options.

• Under Options go for add-on and in connectivity options enable it and click ok.

• Now restart the application in order to launch the connectivity. Once the application is restarted it is ready for the connection. In the connectivity, tab click on OPC UA and then add server

After the server is added click on edit connection to define the server address. In the server, address tab defines the IP address matching the address specified in the TIA portal. It has to be defined as opc.tcp:// and then followed by the IP address.

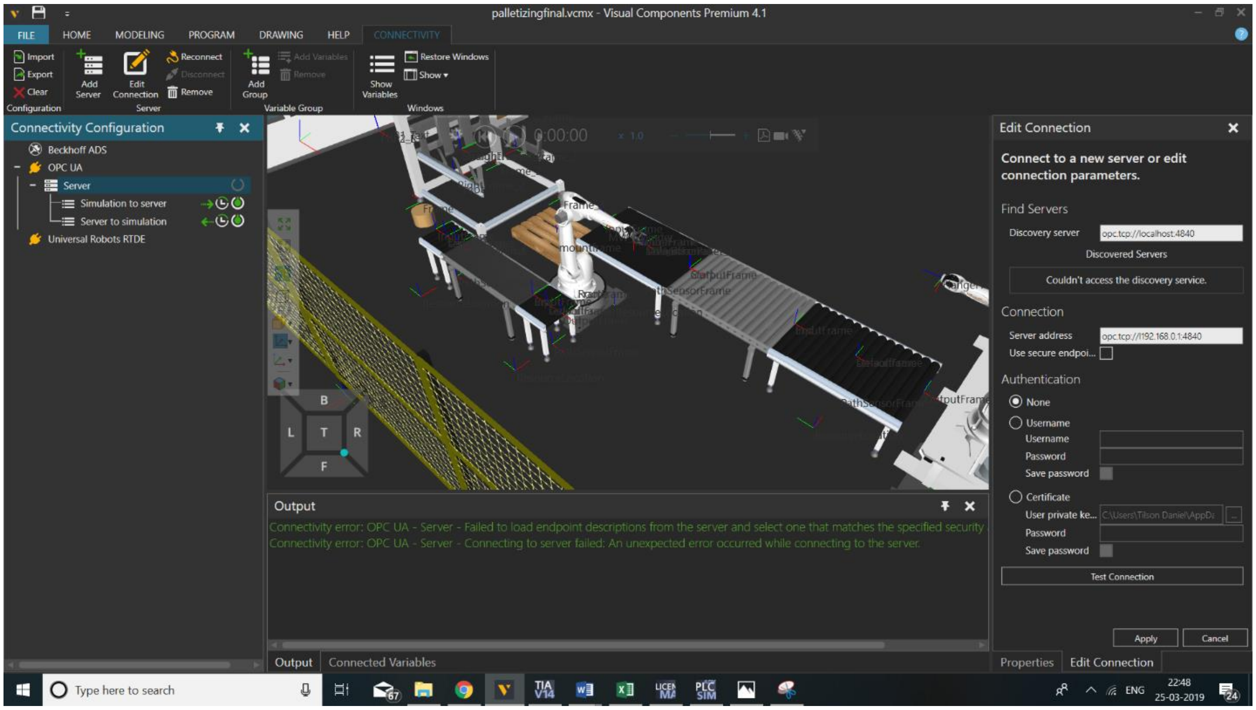

Figure 27 : Specifying the server address to test the connection.

Then test the connection and click ok. It means the connection was succeeded. But after this, the connected option would show false. To make it true we need to turn on the green button on the server tab which means now the connection is established and the server is ready.

7.4 Adding and Pairing variables for testing

Variables from the TIA portal needs to be paired with the variables in VC. Every component in the Visual component layout has signal variables. These variables denote the signals or processes that can be linked

Simulation to the server is selected and then the variables are added. Similarly, server to simulation is selected and the variables are added

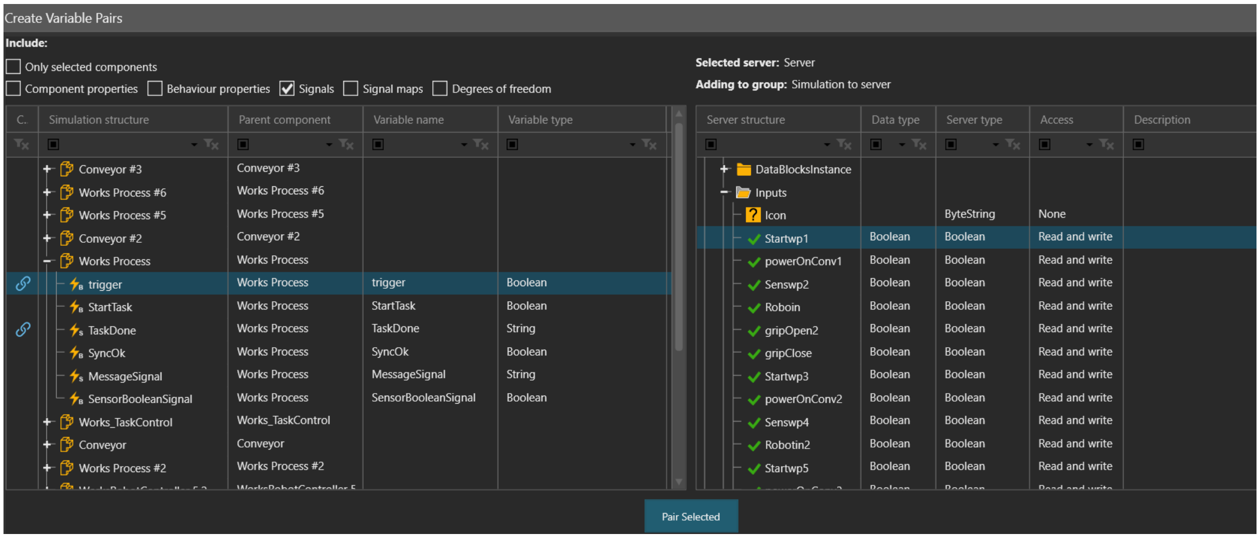

Figure 28 : Pairing variables of VC 4.1 and TIA Portal.

From Figure 28 it is seen that the trigger variable of first works process component from VC is being paired with Start wp1 of Tia Portal network code. The trigger is the initial signal to start the process and Start wp1 represents the same, so these two variables are selected and then this pair is selected. This pair gets added to the connected variables list.

In a similar way all the of VC and Tia Portal variables are matched and pairs are selected and connected. Now all the similar variables are paired and the control of Visual Component project is done using TIA portal via OPC UA communication.

As the process is being executed the results can be seen through the status of the variables. When a variable becomes true it means that part process is being executed now and when it is false the process is halted. (see Figure 29)

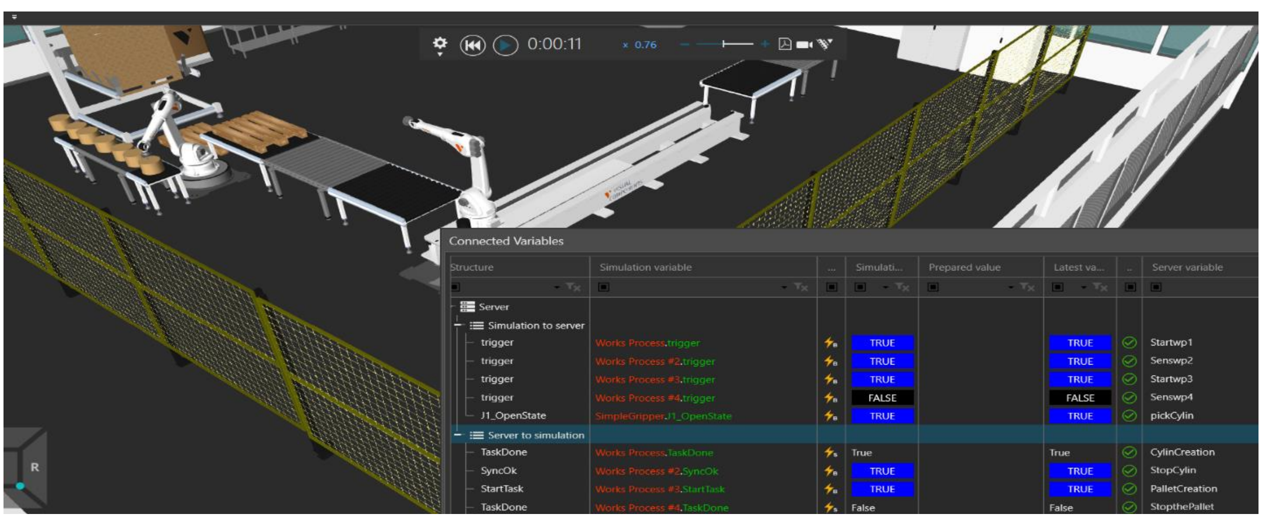

Figure 29 : Variables Controlled and tested using OPC UA communication

8. Conclusions

8.1 Findings.

- Provided a simple idea of a digital twin by using a simple cylinder as a product.
- Used Robotic arms to make the process run in a faster way and this process has 0 labor cost.
- Palletization carried out for placing products in a defined manner and to keep a count of it.
- Virtual commissioning is carried out to make it much easier to detect faults at an early stage before doing the real commissioning.
- With the help of this, one can easily control the process from anywhere by just having a control device without actually being present at the spot physically.

8.2 Suggestions.

- Visual Components software can be useful in a larger production line where there is n number of processes being carried out.
- It is easier to model using visual components because of its drag and drop feature and also because of its wide list of library options.
- This process can be implemented in an industry for their product line and the product can be anything chosen accordingly based on the industry. For example, in a car manufacturing company the tires can be transported and palletized and can be carried away for performing different process during car manufacture.
- The digital twin approach can be used in real industry automation segment, be it construction for designing building site, brick by brick construction and then modelling each component or assembling and removing of components etc. can be done at a greater speed and the designers who are behind the layout modeling and also the programmers who are behind the coding and commissioning process can perform the digital twin at an early stage and check for errors if present and then can also remodel it and configure it before using it in real time automation. This saves a lot of time well in advance and chances of errors that can occur is minimized.

8.3 Conclusion.

A digital twin system is designed as a layout in which there is a parallel process in a production factory. To perform this digital twin, VC premium 4.1 was chosen and the statistical layout is designed. The main aim was to create a cylinder and it was then picked and placed by a robot, which is basically palletization of products and transporting out on a conveyor. The second robotic arm picks and places on to the next conveyor and the process continues in a loop.

This whole process is controlled using logic code designed in TIA Portal by using variables. It is downloaded to PLC SIM advanced and then commissioned using watch table. It is then tested by connecting it with VC using OPC UA.

8.4 Direction for future research.

- This design can be further modified by adding another process at the end of the third conveyor. It can be fed to a machine.

- The lift can be used in this process if the production process is carried in two different floors.

- If two products are used and these products need to be attached then a human robot can be used to fit these products.

- Mobile robots can be used as well for the transportation of products from one place to another.

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Appendix

A1. List of all input and output variables defined in tag table.

Tag table_1

	Name	Data type	Address	Retain	Acces...	Writa...	Visibl...	Supervision	Comment
1	Startwp1	Bool	%I0.0	☐	☑	☑	☑		
2	powerOnConv1	Bool	%I0.1	☐	☑	☑	☑		
3	Senswp2	Bool	%I0.2	☐	☑	☑	☑		
4	Roboin	Bool	%I0.3	☐	☑	☑	☑		
5	gripOpen2	Bool	%I0.4	☐	☑	☑	☑		
6	gripClose	Bool	%I0.5	☐	☑	☑	☑		
7	Startwp3	Bool	%I0.6	☐	☑	☑	☑		
8	powerOnConv2	Bool	%I0.7	☐	☑	☑	☑		
9	Senswp4	Bool	%I1.0	☐	☑	☑	☑		
10	Robotin2	Bool	%I1.1	☐	☑	☑	☑		
11	Senswp5	Bool	%Q3.5	☐	☑	☑	☑		
12	Startwp5	Bool	%I1.3	☐	☑	☑	☑		
13	ConvTrans1	Bool	%Q0.0	☐	☑	☑	☑		
14	Robturn1	Bool	%Q0.1	☐	☑	☑	☑		
15	Robturn2	Bool	%Q0.2	☐	☑	☑	☑		
16	ConvTrans2	Bool	%Q0.3	☐	☑	☑	☑		
17	Robout	Bool	%Q0.4	☐	☑	☑	☑		
18	ConvTrans3	Bool	%Q0.5	☐	☑	☑	☑		
19	powerOnConv3	Bool	%I1.4	☐	☑	☑	☑		
20	downtopick1	Bool	%Q0.6	☐	☑	☑	☑		
21	performopen	Bool	%Q0.7	☐	☑	☑	☑		
22	CylinCreation	Bool	%Q1.0	☐	☑	☑	☑		
23	Senswp1	Bool	%I1.5	☐	☑	☑	☑		
24	StopCylin	Bool	%Q1.1	☐	☑	☑	☑		
25	Readytopick	Bool	%I1.7	☐	☑	☑	☑		
26	PalletCreation	Bool	%Q1.2	☐	☑	☑	☑		
27	Opengrip2	Bool	%Q1.3	☐	☑	☑	☑		
28	Placeprod	Bool	%M20.0	☐	☑	☑	☑		
29	Tag_3(1)	Word	%MW60	☐	☑	☑	☑		

Tag table_1

	Name	Data type	Address	Retain	Acces...	Writa...	Visibl...	Supervision	Comment
30	Tag_10(1)	Bool	%M10.0	☐	☑	☑	☑		
31	Tag_11	Bool	%M30.0	☐	☑	☑	☑		
32	Releasepart	Bool	%Q1.4	☐	☑	☑	☑		
33	SensPallet	Word	%MW70	☐	☑	☑	☑		
34	StopthePallet	Bool	%Q1.5	☐	☑	☑	☑		
35	Robot2ready	Bool	%I2.0	☐	☑	☑	☑		
36	downtopick2	Bool	%Q1.7	☐	☑	☑	☑		
37	Palletispicked	Bool	%Q2.0	☐	☑	☑	☑		
38	Robturn3	Bool	%Q2.1	☐	☑	☑	☑		
39	Moveotrack	Bool	%Q2.2	☐	☑	☑	☑		
40	Robturn4	Bool	%Q2.3	☐	☑	☑	☑		
41	movedown	Bool	%Q2.4	☐	☑	☑	☑		
42	Placeonsens5	Bool	%Q2.5	☐	☑	☑	☑		
43	Readytopick2	Bool	%I2.1	☐	☑	☑	☑		
44	PickthePallet	Bool	%I2.2	☐	☑	☑	☑		
45	Readytomove	Bool	%I2.3	☐	☑	☑	☑		
46	movetosens5	Bool	%I2.4	☐	☑	☑	☑		
47	RobPlacePallet	Bool	%I2.5	☐	☑	☑	☑		
48	Placeonwp5	Bool	%I2.6	☐	☑	☑	☑		
49	wp5Ready	Bool	%I2.7	☐	☑	☑	☑		
50	gripopen1	Bool	%Q2.7	☐	☑	☑	☑		
51	downtoplace	Bool	%Q2.6	☐	☑	☑	☑		
52	pickCylin	Bool	%I3.0	☐	☑	☑	☑		
53	pickingtheCylin	Bool	%Q3.0	☐	☑	☑	☑		
54	Readytoplace	Bool	%I3.1	☐	☑	☑	☑		
55	homePosOfRob	Bool	%I3.2	☐	☑	☑	☑		
56	moveToHomePos	Bool	%Q3.1	☐	☑	☑	☑		
57	picknext	Bool	%I3.3	☐	☑	☑	☑		
58	Robotfullturn	Bool	%Q3.2	☐	☑	☑	☑		

A2. List of all inputs used for commissioning in watch table.

	i	Name	Address	Display format	Monitor value	Modify value		Comment
3		"Startwp1"	%I0.0	Bool	TRUE	TRUE		
4		"powerOnConv1"	%I0.1	Bool	TRUE	TRUE		
5		"Senswp2"	%I0.2	Bool	TRUE	TRUE		
6		"Roboin"	%I0.3	Bool	TRUE	TRUE		
7		"gripOpen2"	%I0.4	Bool	TRUE	TRUE		
8		"gripClose"	%I0.5	Bool	TRUE	TRUE		
9		"powerOnConv2"	%I0.7	Bool	TRUE	TRUE		
10		"Startwp3"	%I0.6	Bool	TRUE	TRUE		
11		"Senswp4"	%I1.0	Bool	TRUE	TRUE		
12		"Robotin2"	%I1.1	Bool	TRUE	TRUE		
13		"Startwp5"	%I1.3	Bool	TRUE	TRUE		
14		"powerOnConv3"	%I1.4	Bool	TRUE	TRUE		
15		"Readytopick"	%I1.7	Bool	TRUE	TRUE		
16		"Placeprod"	%M20.0	Bool	TRUE	TRUE		
17		"Tag_3(1)"	%MW60	Hex	16#000F			
18		"Tag_10(1)"	%M10.0	Bool	FALSE	TRUE		
19		"Tag_11"	%M30.0	Bool	TRUE			
20		"SensPallet"	%MW70	Hex	16#0000			
21		"Robot2ready"	%I2.0	Bool	TRUE	TRUE		
22		"Readytopick2"	%I2.1	Bool	TRUE	TRUE		
23		"PickthePallet"	%I2.2	Bool	TRUE	TRUE		
24		"Readytomove"	%I2.3	Bool	TRUE	TRUE		
25		"movetosens5"	%I2.4	Bool	TRUE	TRUE		
26		"RobPlacePallet"	%I2.5	Bool	TRUE	TRUE		
27		"Placeonwp5"	%I2.6	Bool	TRUE	TRUE		
28		"wp5Ready"	%I2.7	Bool	TRUE	TRUE		
29		"pickCylin"	%I3.0	Bool	TRUE	TRUE		
30		"Readytoplace"	%I3.1	Bool	TRUE	TRUE		
31		"homePosOfRob"	%I3.2	Bool	TRUE	TRUE		