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3D-Virtualization of a Conveyor Machine

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Thesis abstract

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The purpose of this thesis was to create a virtually working 3D-model of a conveyor machine. The topic and the machine were provided by Siemens. Siemens will use this virtual model to ease their education, as it is not necessary to have the real equipment nearby. The first model was made in Solid Edge, and then transported to Siemens NX and MCD –software. The PLC-program was made in Siemens TIA portal. The connection between TIA portal and MCD was made with an OPC-server. The theory part of this thesis contains information about the software used in this project. Also theory about virtual commissioning and digital –twin concept is studied.

Keywords: Virtual Commissioning, PLC, OPC, Virtual model

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Tämän opinnäytetyön aiheena oli tehdä virtuaalisesti toimiva 3D-malli kuljetinlaitteesta. Aiheen sekä kuljetinlaitteen, josta malli tehtiin, antoi Siemens. Siemens käyttää laitetta opetukseen, ja virtuaalisen mallin käyttäminen helpottaisi tätä koska tällöin ei välttämättä tarvita oikeaa laitetta viereen. Alkuperäinen malli tehtiin Solid Edge –ohjelmalla. Tämä malli siirrettiin Siemens NX ja MCD –ohjelmiin. PLC-ohjelma tehtiin TIA portaalilla, ja yhteys näiden ohjelmien välille tehtiin OPC-serverin avulla. Teoriaosuudessa käydään tarkemmin läpi käytettyjä ohjelmia, sekä teoriaa virtuaalisesta testausympäristöstä ja digital twin -käsitteestä.

Avainsanat: Virtuaalinen käyttöönotto, OPC, PLC, Virtuaalinen malli

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Abbreviations

HMI Human Machine Interface. Part of the machine that handles the interaction between Humans and Machines.

HIL Hardware-in-the-Loop. Real PLC hardware is connected to a virtual plant.

I/O I means Input and O means Output.

MCD Mechatronics Concept Designer. An application in Siemens NX –software, which allows you to simulate physics in your 3D-model.

OPC Open Platform Communication / OLE for Process Control. Series of specifications for the exchange of data in industrial automation.

OPC UA OPC Unified Architecture. Industrial communication protocol.

PLC Programmable Logic Controller. A device used in automation industry. Used for controlling automated machines.

PROFIBUS Communication standard in automation technology.

PROFINET Industrial Ethernet standard.

Siemens NX Software for modeling and simulating machines.

SIL Software-in-the-Loop. PLC Program and plant are both virtual in SIL.

Tag Name for memory location. For example I1.0 could be named or tagged as PushButton_Start.

VC Virtual Commissioning

1 INTRODUCTION

Introduction consists of background, objective and the structure of the work. The topic of this thesis was to make a working virtual model of a conveyor machine provided by Siemens. The conveyor machine is used for teaching PLC programming at the Siemens headquarters in Espoo. The 3D-model of the conveyor machine is going to be helpful as the students do not have to have the real machine with them.

There was a meeting about this possible thesis topic, and we made an agreement that one student would make the 3D-model for his project course, and another student would do the rest including putting up an OPC-server, creating the signals in Mechatronics Concept Designer and linking them to the PLC-program. Also any possible problems with the 3D-model need to be fixed.

1.1 Objective of the project

The reason for making a virtual model of a machine is to see how it works and to minimize the risk of problems before making the real machine. This reduces the costs of production because if you can find the problems at this stage, the fixing does not cost that much. It also makes teaching easier because you do not necessarily need the real machine near you, as you can use the virtual 3D-model of the machine and see how it operates.

Another goal was to get a deeper understanding of the programs used in this project and to learn to use them better. TIA Portal and Siemens NX programs, for example, were studied more thoroughly because they are used in many automation companies.

1.2 The structure of the project

The first part of this thesis is introduction that focuses on the background of the work, the goal of the work and gives some information about Siemens as a company.

In the theory part there is first information about Virtual Commissioning to help the reader understand what it means and why it is used. The programs and protocols like TIA portal and Siemens NX used in this project are also introduced in the theory part as well as the OPC protocol. The project part of the thesis consists of the planning of the project, how the project succeeded eventually, and about the problems in the project.

1.3 Siemens

The company of Siemens is focusing on the areas of electrification, automation and digitalization. It is one of the world's biggest producers of energy-efficient and resource-saving automation technologies. Siemens has been in automation business for more than 50 years. They have around 343 000 employees in more than 200 countries all around the world. Their revenue is almost €72 billion. (About Siemens, 2015.)

Siemens provides the SIMATIC product family. Simatic is a unique, integrated system designed to be deployed with all sorts of manufacturing systems in many different industries. The family contains for example programmable controllers, distributed I/Os, programming devices, software, machine vision and micro automation sets.

2 VIRTUAL COMMISSIONING ENVIRONMENT

Most modern manufacturing industries consist of many different automated robots. The advantages of being as highly automated as possible include a lot higher production rates, better safety, improved product quality and decreased need for labor. Making changes to these automated workstations may be problematic if they are being used at the same time. The complexity and diversity of the different components, in terms of communication channels and control system, requires so much time for on-site setup and testing. This means there will be production system downtime and costs that will follow from the downtime. Therefore simulation of the workstations is important.

Virtual commissioning introduces validation capabilities by means of considering the mechatronic behavior of the resources. Virtual Commissioning provides a solution to the verification of mechanical behavior of an assembly line and a cell. The application of such a solution may lead to reducing the errors detected during the ramp-up phase that necessitate reworks in upstream processes, since it enables the verification of real PLC engineering with virtual line and cell in the early production design phases. (S. Makris, G. Michalos, and G. Chryssolouris, 2012.)

Optimization of an automation system can now be accomplished under the use of digital products, control data and resource data. 3D-models involving kinematics, geometric and electrical aspects are capable of a 1:1 representation of an automated system. (S. Makris, G. Michalos, and G. Chryssolouris, 2012.)

Simulation enables the measuring the production output and also the validation of the physical system without damaging any real equipment. However, to get as accurate results as possible, the simulated model must be made in great precision. If the model is not made accurately, there might appear some unexpected problems in the later stages of the project. The connection between a real plant and a virtual plant is well presented in figure 1. It is possible to switch between virtual and real plants. For example, if the user wants to make modifications in the real plant but is not sure how it will work, it is possible to make the modification in the virtual plant first to see how it works. If it works in the virtual plant, it is easier to show the idea for others and take it in action if it is accepted.

The safety of teaching with a virtual plant is a lot higher than teaching with a real machine, as nothing is really at risk when driving a virtual model. When driving a real machine there is a risk of breaking the machine or in the worst case scenario an injury to a person could happen if driving recklessly.

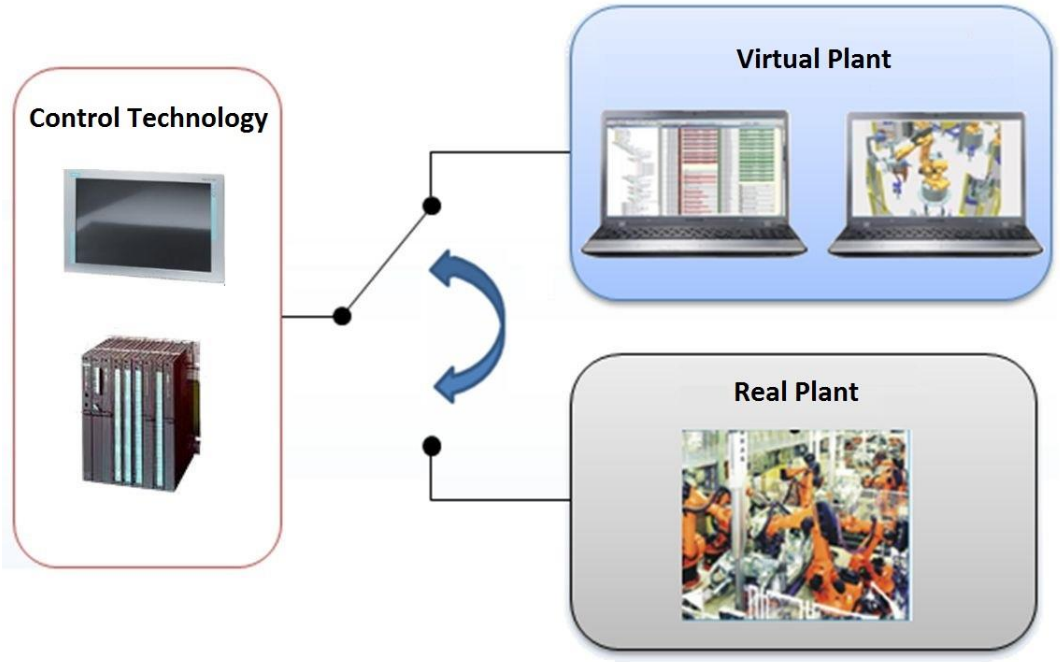

Figure 1. Virtual commissioning example with real hardware and virtual plant. (EngRoTec 2015.)

The two most important simulation types are Software-in-the-Loop and Hardware-in-the-Loop. SIL, which is also called offline-programming, means that both Plant and PLC program are simulated with a PC. By doing this, the complete project can be simulated without any hardware requirements except PC. In figure 2 the Software-in-the-Loop is presented visually. (Dzinic, Yao [Ref. 10.7.2015].)

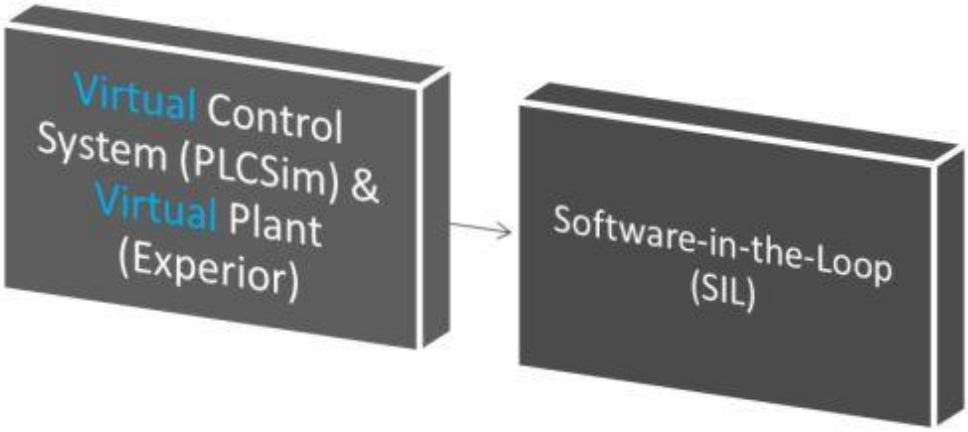

Figure 2. Software-in-the-Loop (Dzinic, J. Yao, C. [Ref. 10.7.2015].)

HIL, which is also called soft-commissioning, is a method where a real PLC hardware is connected with a virtual plant or workstation. In figure 3 the Hardware-in-the-Loop is presented visually. The difference between these two systems is that SIL uses a virtual control system and HIL uses a real control system. (Dzinic, J. Yao, C. [Ref. 10.7.2015].)

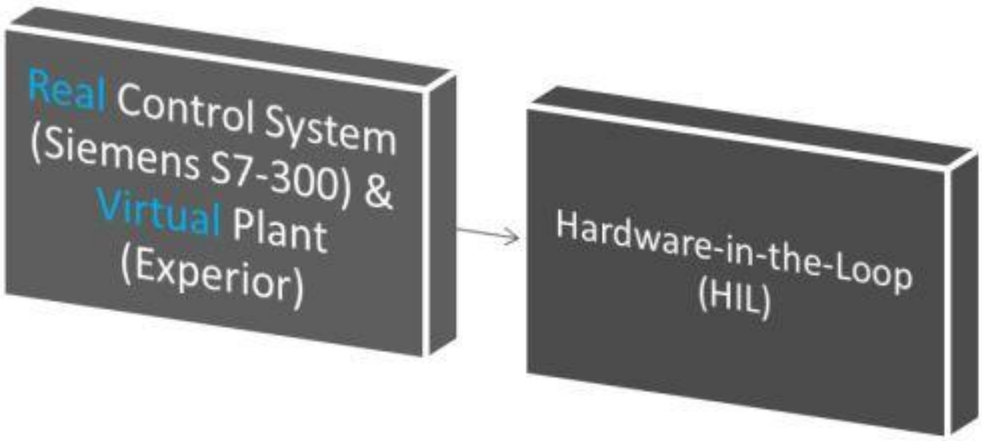

Figure 3. Hardware-in-the-Loop (Dzinic, J. Yao, C. [Ref. 10.7.2015].)

In this project a real PLC was used and connected with a virtual 3D-model, so this means that this project was Hardware-in-the-Loop. Under the Software-in-the-Loop method, the control programs for the resource controllers, which usually means PLC, are located in virtual controllers and the TCP/IP connection is established between the mechanical object and the software-emulating controllers.

The main advantage of the SIL approach is that no PLC hardware is required during the designing and validation of a control software and standard desktop PCs can be used for its implementation. On the downside, there has been identified a low availability of up-to-date control simulation packages for a particular control version and therefore, the control software cannot provide an exact reproduction of the control behavior. (S. Makris, G. Michalos, and G. Chryssolouris, 2012.)

The second method, known as hardware in the loop (HIL), involves the simulation of production equipment in real time, connected to the real control hardware via fieldbus protocol. Under this setup, the commissioning and testing of complex control and automation scenarios, under laboratory conditions, can be carried out for different plant levels for example field, line, or plant testing. Hybrid commissioning combines the HIL-commissioning and real-commissioning phases, which interact with each other thus achieving a lower cost and more efficient real commissioning. (S. Makris, G. Michalos, and G. Chryssolouris, 2012.)

2.1 Digital Twin

Virtual model of a factory or just one part of a factory is also called a Digital Twin. The Digital Twin -concept was introduced in 2003 by Michael W. Grieves on a course on Product Lifecycle Management. At 2003 this concept was relatively new, and the information collection of the physical product was slow and mostly paper-based. The amount and quality of information about the physical and virtual products have progressed a lot since 2003.

The issue is, that the connection between the real product and virtual product has been lacking. Most of the global manufacturers today work with either the virtual product or the physical product, not both. We have not developed a connection between these products so we could work with both of them at the same time. Typically in developing a product a 3D-model is created, but it is not used in the later stages of the project. In some cases, it is even watered down to a 2D-blueprint for the factory floor. There are some manufacturers who are bringing the 3D-models to the factory floor, however there isn't any integration between the virtual and physical product. The 3D-model just acts as a reference and the human has to make up the connection between the two products. The connection should be made so the information of the physical product would overlay the virtual one, and highlight any differences that need to be addressed.

Grieves in his article says that in order to deliver these benefits to be gained from this connection between the two products, one solution is to have a Unified Repository (UR) that would link the products together. Here, both the virtual and physical tools would populate the UR.

On the virtual tool side, design and engineering would identify dimensions, torque requirements, tolerances and such things and put a unique product tag in the virtual model that would serve as a data placeholder for the physical product. When the design will be released for manufacturing, these tags would be collected from the virtual product model and used to create the UR.

Then on the physical side, these unique tags would be incorporated into the Manufacturing Execution System (MES) in the Bill of Process creation at the process step where they will be captured. As the processes are completed in the floor of the factory, the MES will output the captured characteristics to the UR.

The last step would be to incorporate this back to the factory simulation. This means instead of simulating what should be happening in the factory, the model would be replicating the exact thing what was actually happening at each step of the manufacturing process in the factory for each unique product. This replica of the factory would constantly communicate with the UR, getting updated data from the actual production and displaying it in the digital factory in the computers screen.

The digital twins' three most important capabilities are conceptualization, comparison and collaboration. Conceptualization with Humans means that they conceptualize the situation by looking at different reports, numbers and other information sources. In the process of looking visually like this, humans lose a big deal of information and inefficiencies happen. Digital twin sees the situation directly and eliminates all inefficiencies and counterproductive mental steps. Instead of a human looking at a report of performance, we can look at the products in the virtual factory and see the actual trend lines that can indicate if a problem is happening or is going to happen.

Humans use comparison unconsciously and continuously in search for the wanted result and actual result for determining the difference between. Then it is decided how to get rid of this difference. Problem here is that human vision is not always so accurate. With the digital twin, we can look at the wanted characteristics, measurements and the trend line to determine whether our production is where it needs to be. Depending on the digital twin implementation, we could see differences for example in different colors from green, “Everything is okay.” to yellow, “We are near the tolerance.” to red, “We are beyond tolerance and this needs to be fixed.” Machine vision is more accurate than human vision.

Problem with collaboration without digital twin is that it occurs only with the individuals looking at it. With digital twin, we can look at the physical product on the factory and overlay it with the virtual product. This helps other individuals look at the performance and problems in the factory and it means that there will be more people to solve the problem.

In conclusion, digital twin frees us from the physical limits where humans operate inefficiently. Virtually, we can have a common visualization, identify the problems and collaborate together to fix it. (Michael W. Grieves, 2014.)

2.2 Siemens NX

Siemens NX software offers a way to design, engineer and simulate different industrial models. It enables smarter decisions in an integrated product development environment. (NX Software, 2015.)

The version used in this project was Siemens NX 9.0, although there is a newer version 10.0 available. Siemens NX has many different purposes of use. It has integrated modeling, design and manufacturing software. Usually these are all different programs, but in NX they are together. In addition NX enables you to simulate your model in the add-on Mechatronics Concept Designer.

2.3 Mechatronics Concept Designer

Mechatronics Concept Designer allows you to make kinematic simulation for your machine design. It also combines mechanical design with automation design. The reason for this is to save time in the design process by figuring out the best mechatronic configuration.

MCD is integrated in the Siemens NX software, and you can just switch to it in few clicks. MCD uses NVIDIA PhysX to realistically simulate physics where forces act on different parts of the machine. PLC controller is connected to MCD usually via Profinet or Profibus. (ISILOG, 2015.)

MCD is often used to test the machine virtually, before making a prototype, to get fewer problems in later stages of the project. This cuts a lot of expenses, because it is cheaper to fix problems earlier than later in machine development projects.

2.4 TIA Portal

Siemens TIA Portal is the newest software for PLC-programming from Siemens. TIA is an abbreviation of Totally Integrated Automation. It integrates controllers, HMI, drives, motion control and motor management into a single engineering environment as seen in the figure 4. It is best to use it with Siemens hardware, so all the interaction becomes flawless. The new interface makes TIA Portal easier to use for programmers all over the world. (TIA Portal, 2015.)

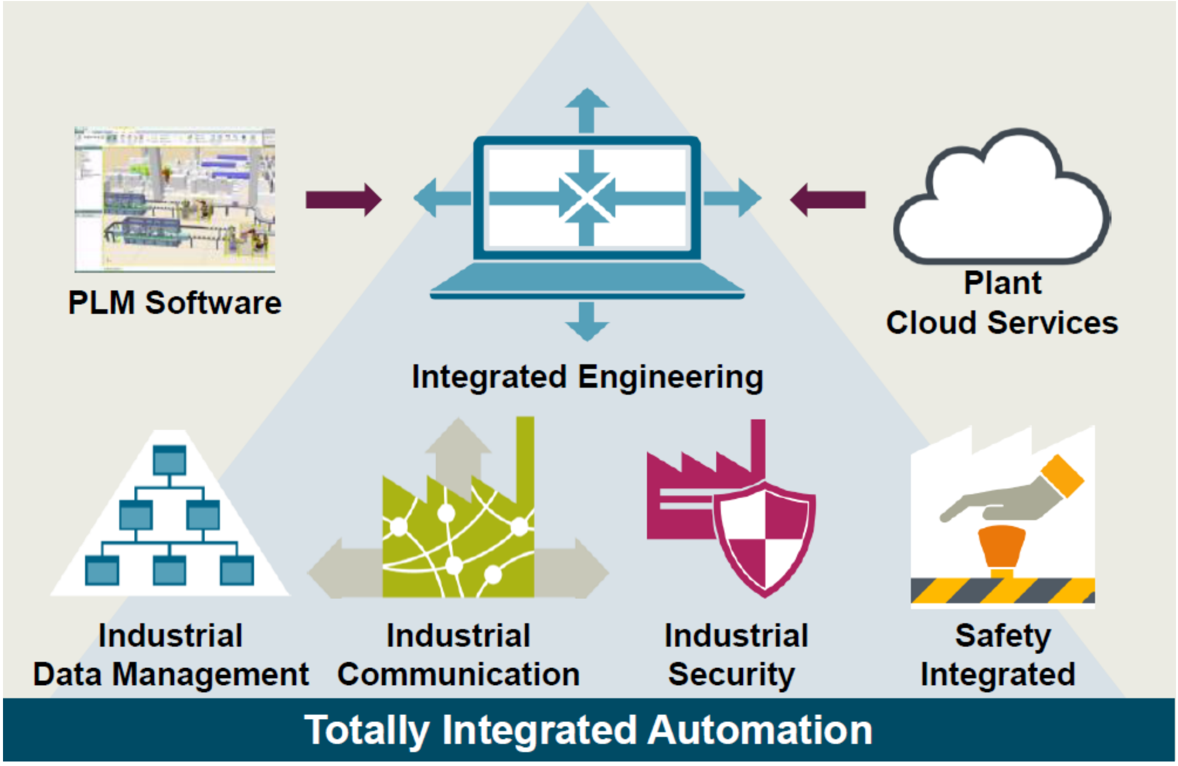

Figure 4. TIA Portal has many different functions. (Ralf-Mikael Franke [Ref 3.9.2015].)

The interface of TIA Portal is shown on figure 5. The design of it makes it more comfortable to use at least for the author of this project than the previous PLC-programs made by Siemens. Many things can be done in drag & drop style, for example adding tag into a function block. The author has not used TIA Portal before this project, so there was a lot of learning involved in this project. The difference between the old step7 programming software and the new TIA Portal is quite big.

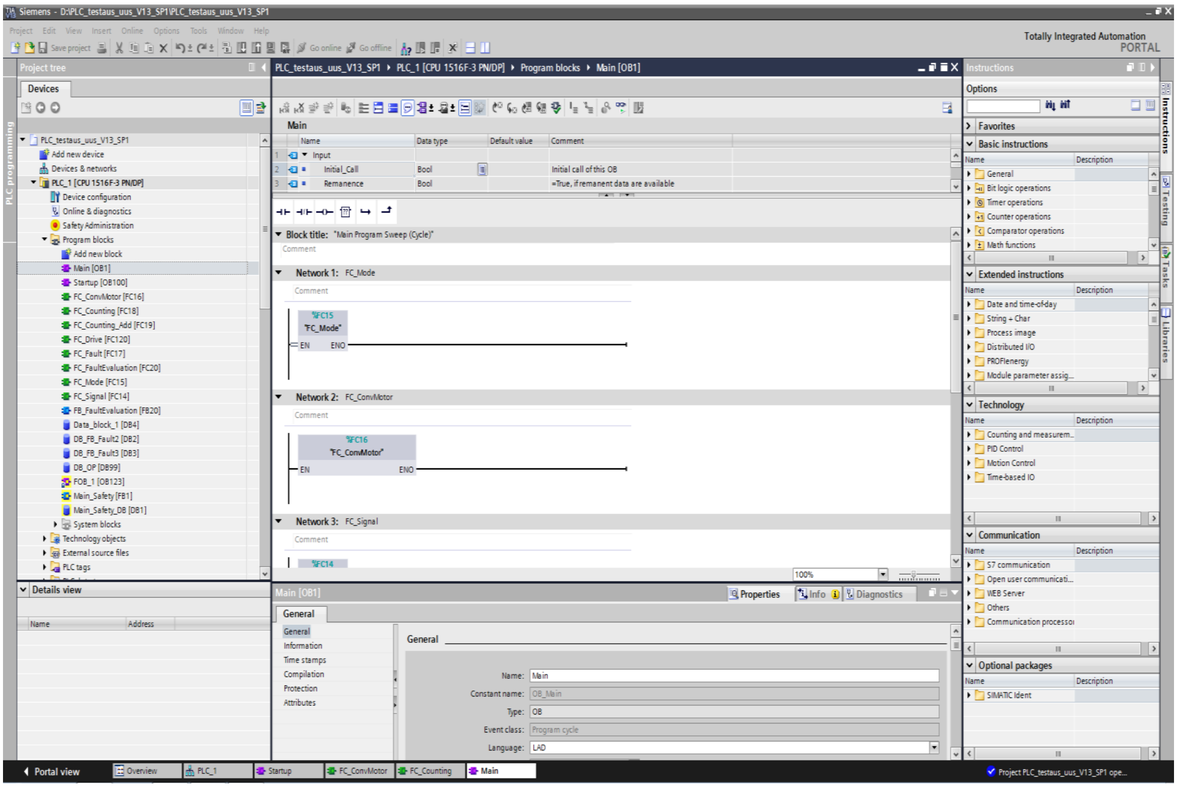

Figure 5. TIA Portal Interface

2.5 OPC-connection

OPC is a software interface standard that allows communication between Windows programs and different kind of industrial hardware devices. OPC server is a program that converts the hardware communication protocol used by a PLC into the OPC protocol. There also needs to be OPC client, which is a program that connects to the hardware such as PLC or HMI. The client uses the server to interact with the hardware.

OPC is an open standard, so it creates more possibilities for users and lower costs not having to buy some expensive software for this. Manufacturers need just a single OPC server for all of their devices with OPC client to communicate between stations. Software vendors just have to include OPC client possibility in their program, and it will be compatible with many hardware devices using the standard. (OPC DataHub, 2015.)

There are different types of OPC connections. Such as:

- typical server-client connection with just a single PC.
- OPC client to many different OPC servers.
- OPC client to an OPC server over a network.
- OPC server with another OPC server if they need to share data with each other.

OPC UA is the new generation of OPC. It is the successor of the normal OPC with some new features:

- It makes it possible to use OPC in any operating system
- Its security management has been improved
- It replaces DCOM communication with TCP/IP, HTTPS and SOAP
- It enables OPC in embedded software (Prosys OPC, 2015.)

The connection between OPC client and the server is demonstrated in figure 6.

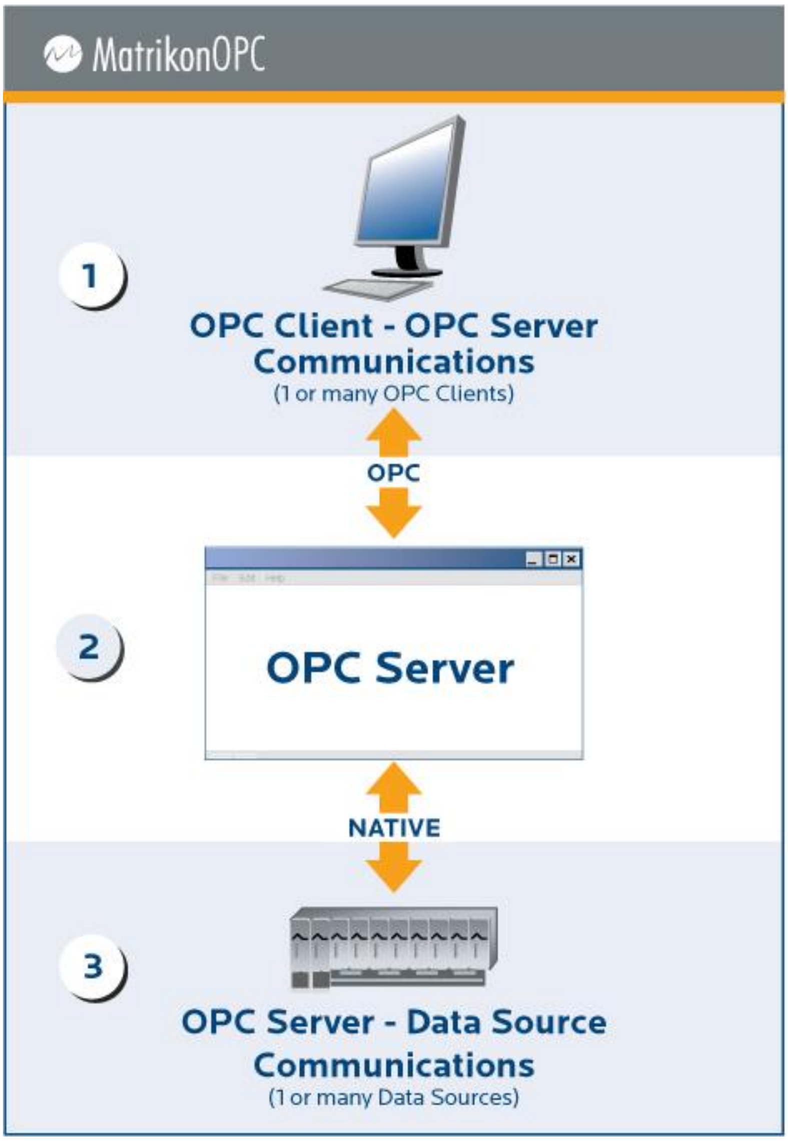

Figure 6. The connection between OPC client, server and hardware.

Here it can be seen how OPC clients are connected with the OPC server and OPC Server is natively connected to different data sources such as a PLC.

2.6 OPC Scout

A program called OPC Scout was also used in this project. This program is also made by Siemens and it is in the Simatic NET software family. With this program the user can test and monitor the OPC connections made. The program can write values for different objects directly, so it made testing the OPC connection pretty handy. Different functions of this program include:

- Browsing and displaying the OPC servers available on your PG/PC interface.
- Testing connections and objects
- Monitoring items
- Reading and writing items
- Displaying alarms
- Diagnosing S7-connections.

3 PROJECT

The progression of the project, problems and such will be presented in this part. Includes different parts of the project such as planning of the project, modeling the conveyor and creating the OPC-server.

3.1 Planning

The project started in the summer of 2015. The equipment that was used in this project was all located in the laboratories of Seinäjoki University of Applied Sciences.

First thing was learning how to use the new TIA Portal and Siemens NX as the author had never used them before. After learning the programs for a while, there were some meetings with the guiding teacher and the author received some tips what to do next. The teacher also taught the basics of Siemens NX for the author. Also the basics of OPC servers and clients had to be learned, as they haven’t been taught in any classes.

3.2 Equipment

The conveyor has the conveyor belt, three inductive sensors and six pushbuttons. It also has a horn, which indicates specific cases happening in the conveyor.

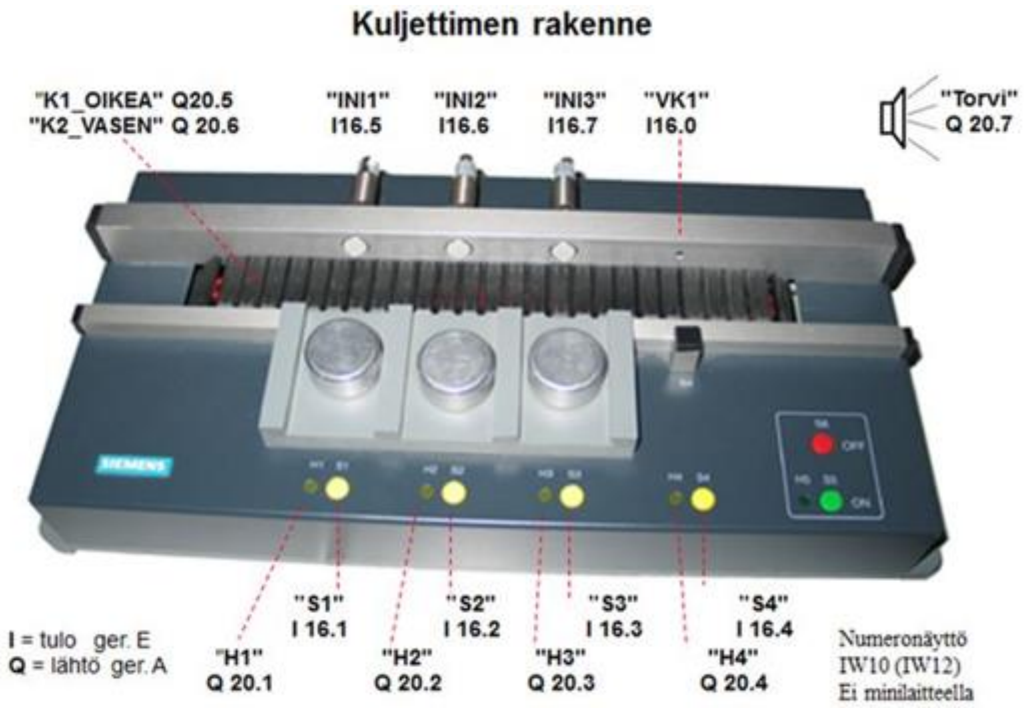

Figure 7. The conveyor machine

The first 3D-model of the conveyor was made with Solid Edge. Solid Edge doesn't have the possibilities for controlling the model, so it had to be done in some different program. The program used in this project was Siemens NX with the additional application Mechatronics Concept Designer. The PLC-program was made with Siemens TIA portal software. There also had to be a connection between Siemens MCD and TIA portal. This connection was made by OPC-server created in TIA portal.

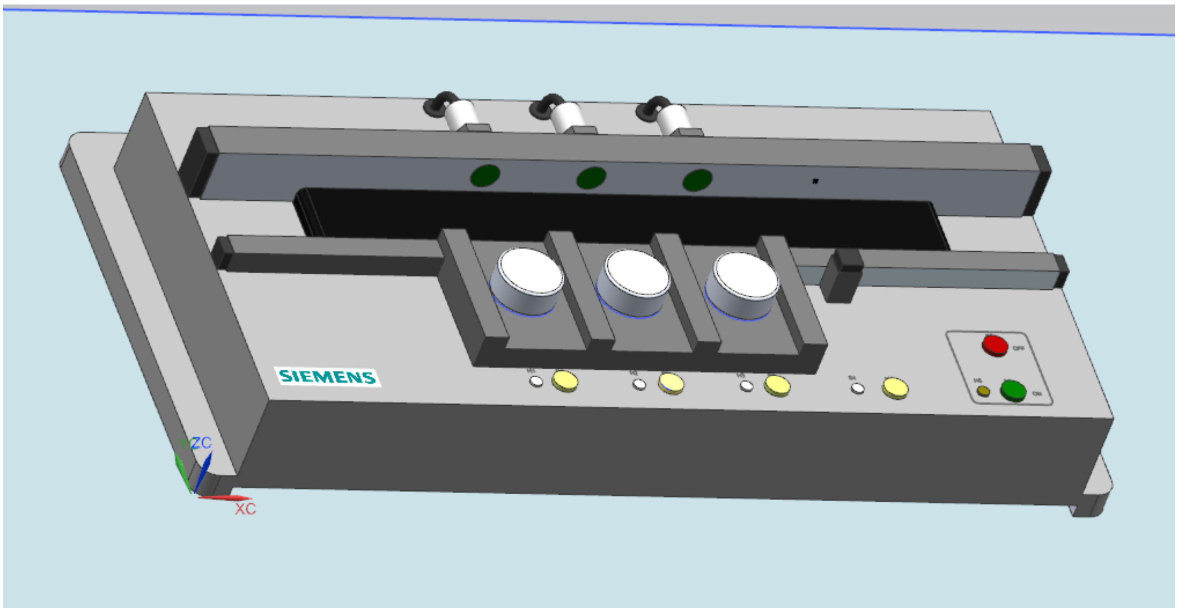

Figure 8. The 3D-model

The final model can be seen above in figure 8. The colors of the model and real conveyor are not matching, but it does not really matter in the simulation. The PLC used in this project was Simatic S7-1500, was provided by the school.

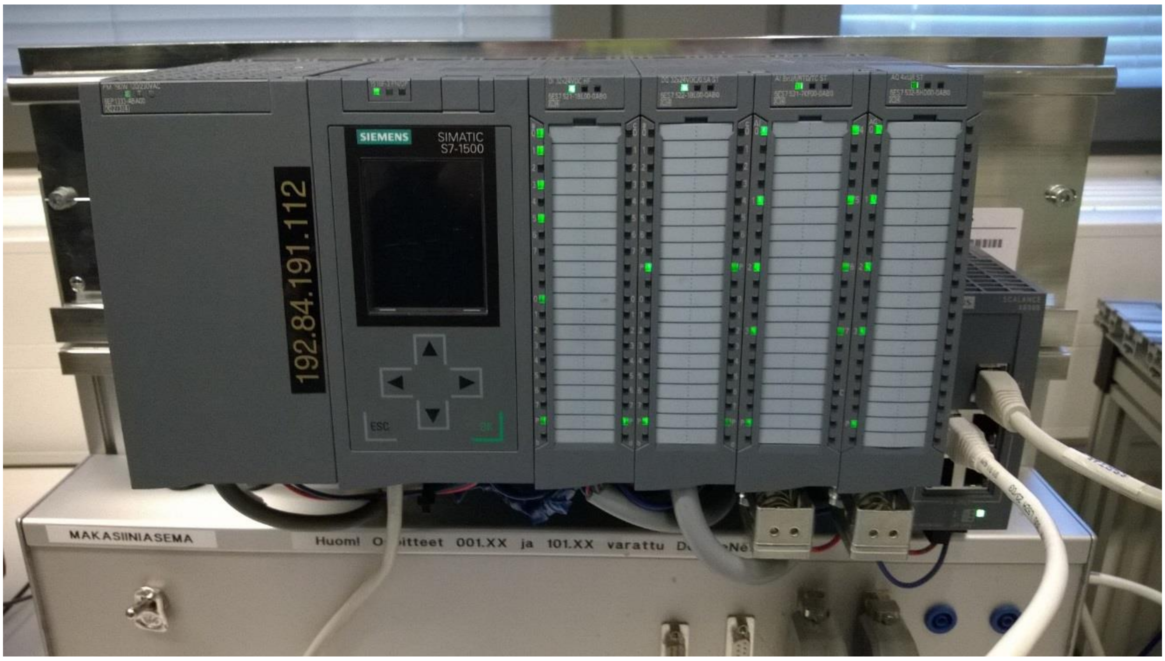

Figure 9. Simatic S7-1500 PLC

3.3 Creating the physics and sensors for the 3D-model

For every part of the model there needed to be a collision body for it. Collision body makes the part have physics, so it doesn't just drop off the model when you simulate it. This was done in Siemens NX by choosing the part and using the create collision body –tool. This was done for the objects sliding in the conveyor, all the pushbuttons, sensors and also the conveyor itself.

For the conveyor belt there had to be made a joint, which moves the object on top of the belt horizontally, depending which way the user wants to move it. A transport surface was created for the belt in order to do this. If the belt needs to move right, the numerical value of the transport surface is positive and if it needs to move left the value will be negative. The transport surface is highlighted in figure 10. Different settings can be changed in the tool, for example changing the parallel velocity in order to make the belt faster or slower.

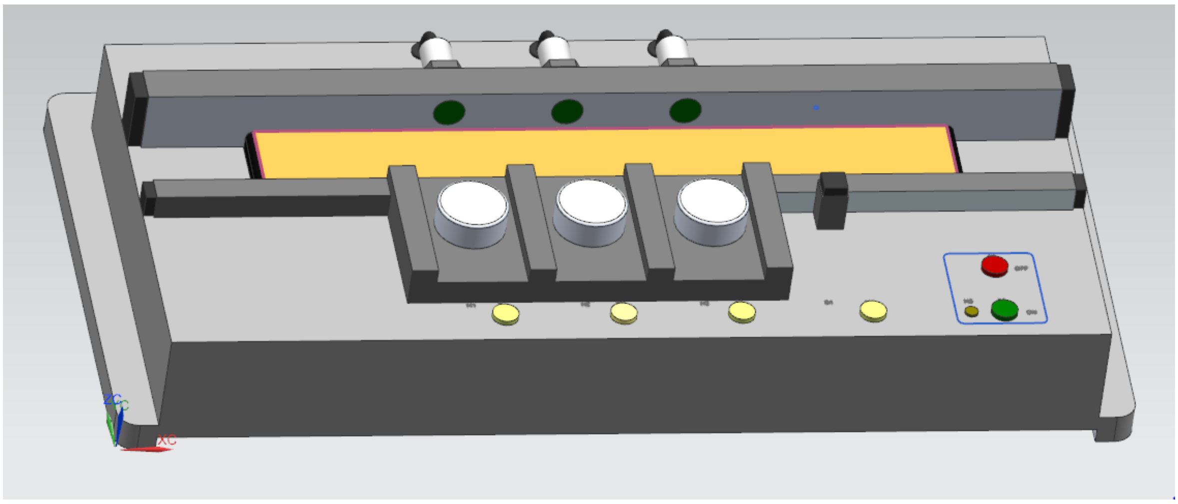

Figure 10. Transport surface

There had to be something for the three sensors for them to recognize if there is an item sliding in front of them. This was done by creating a collision sensor for each one of them. There are two different states for the collision sensor, True and False. The sensor is on True-state when something is in front of it and False-state when nothing obstructs the sensor.

The pushbuttons had to be created so they could be pressed in the simulation with computers mouse. Sliding joints seen in figure 11 were made for them in X-axis so the buttons would only move vertically. The buttons have also a numerical value of their position made with Position control -tool. When this value reaches certain point the signal of the button will switch to True. This had to be made adding a code in Formulas section of the signal adapter. The code looks like this:

“buttonTriggered = If (buttonPos >=5) Then (True) Else (False)”

There are also four LEDs for each of the buttons. These LEDs will light up when the user presses the pushbutton. This is also done by adding a formula for the led. The formula is simple and looks like this:

“ledOn = buttonTriggered”

This means that when buttonTriggered is true, also the ledOn is true.

The “Enable upper limit” had to be set at 5mm so the pushbutton wouldn’t go too high. In Position Control –tool the speed constraint was set on 50mm/second.

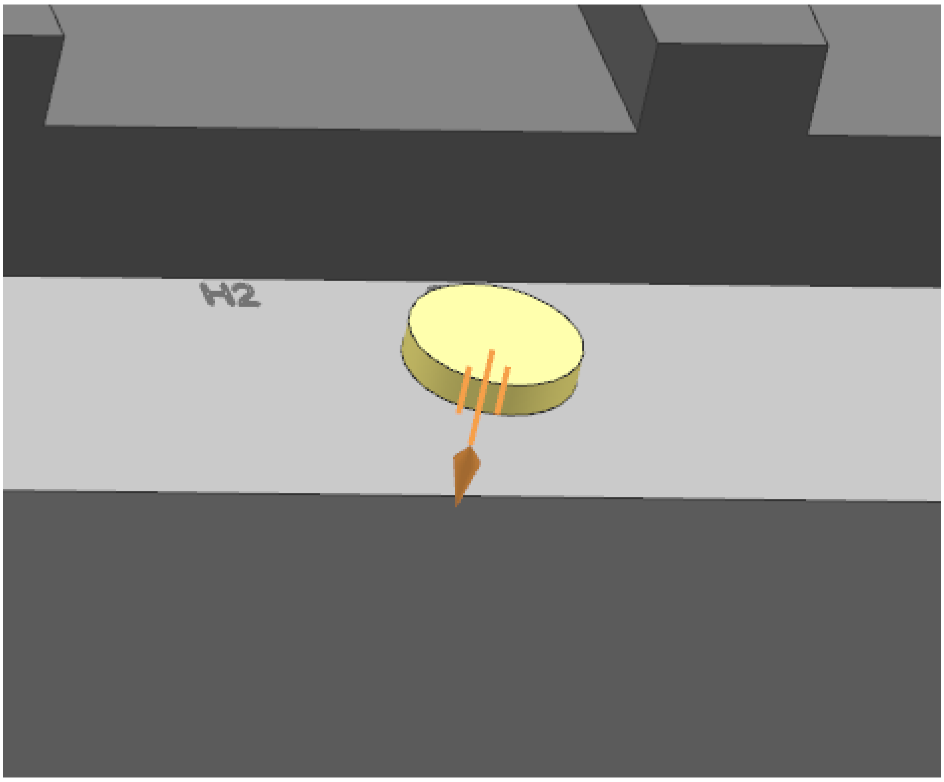

Figure 11. Sliding joint

3.4 Setting up the TIA portal configuration and OPC-server

First the hardware was defined in TIA Portal to match the hardware that was used in the project (Siemens S7-1500). The hardware consisted of:

- power Supply
- CPU
- digital Input and output cards
- analog input and output cards.

After this a PC-station was made in the project. In PC-station there was added a network card and OPC-server. The PLC was connected to the PC station. The topology view of this setup can be seen on figure 12.

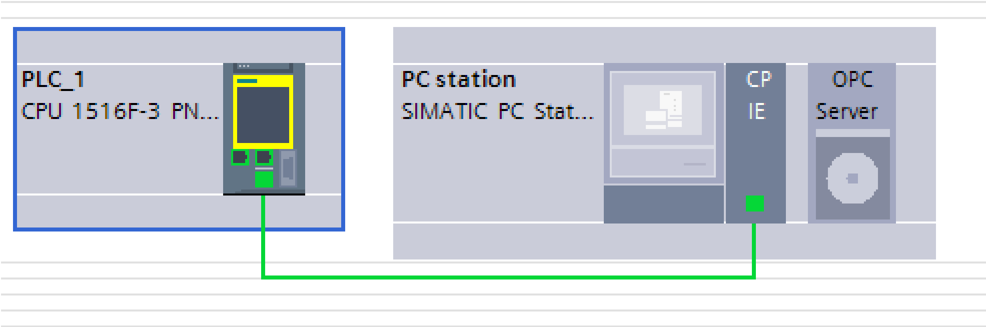

Figure 12. Topology view

The IP-configurations of the computer had to be modified to match with the configurations in TIA Portal. The computers IPv4 IP-address had to be exactly same as the IP-address in the TIA Portal projects network card in order to get the connection between PLC and PC work. The PLC and PC were connected with a Siemens network cable to be sure it works as flawless as possible.

After getting the connection between PLC and PC work, the OPC-server had to be tested. TIA Portal was used as the OPC-server and MCD-software as OPC-client. MCD recognized that there is OPC-server available. The OPC connection was tested by creating a single signal adapter in MCD and connecting it to a Tag in TIA Portal project. For example, when the inductive sensor goes to true-state, the tag made for the sensor in OPC-server should go to true-state also and after this the TIA Portal tag should go to true-state. The test signal worked well so after this all the needed signals in this project were to be made.

3.5 Creating signals in MCD

The following signals had to be created:

- first button from the left, ButtonS1
- second button, ButtonS2
- third button, ButtonS3
- fourth button, ButtonS4
- signal for the LED H1, Led1
- signal for the LED H2, Led2

- signal for the LED H3, Led3
- signal for the LED H4, Led4
- signal for the sensor B_Bay1
- signal for the sensor B_Bay2
- signal for the sensor B_Bay3
- signal for the light barrier, B_LB
- signal for the transport surface, K_Right
- signal for the transport surface, K_Left.

After creating the signals in MCD, they all needed to be connected with the TIA Portal project. The OPC Scout program was helpful in this part because with the program the user can monitor all the OPC connections between the client and the server. All the created signals and OPC connections can be seen in figure 13.

The simulation could now be tested in NX by pressing the simulation start -button in NX. Now, for example, the conveyor belt is wanted to drive to the right. In a PLC program there is a function block which sets the K_Right transport surface to a true-state when ButtonS1 is pressed. When K_Right is in a true-state, the user can see in the simulation that the conveyor belt is moving right.

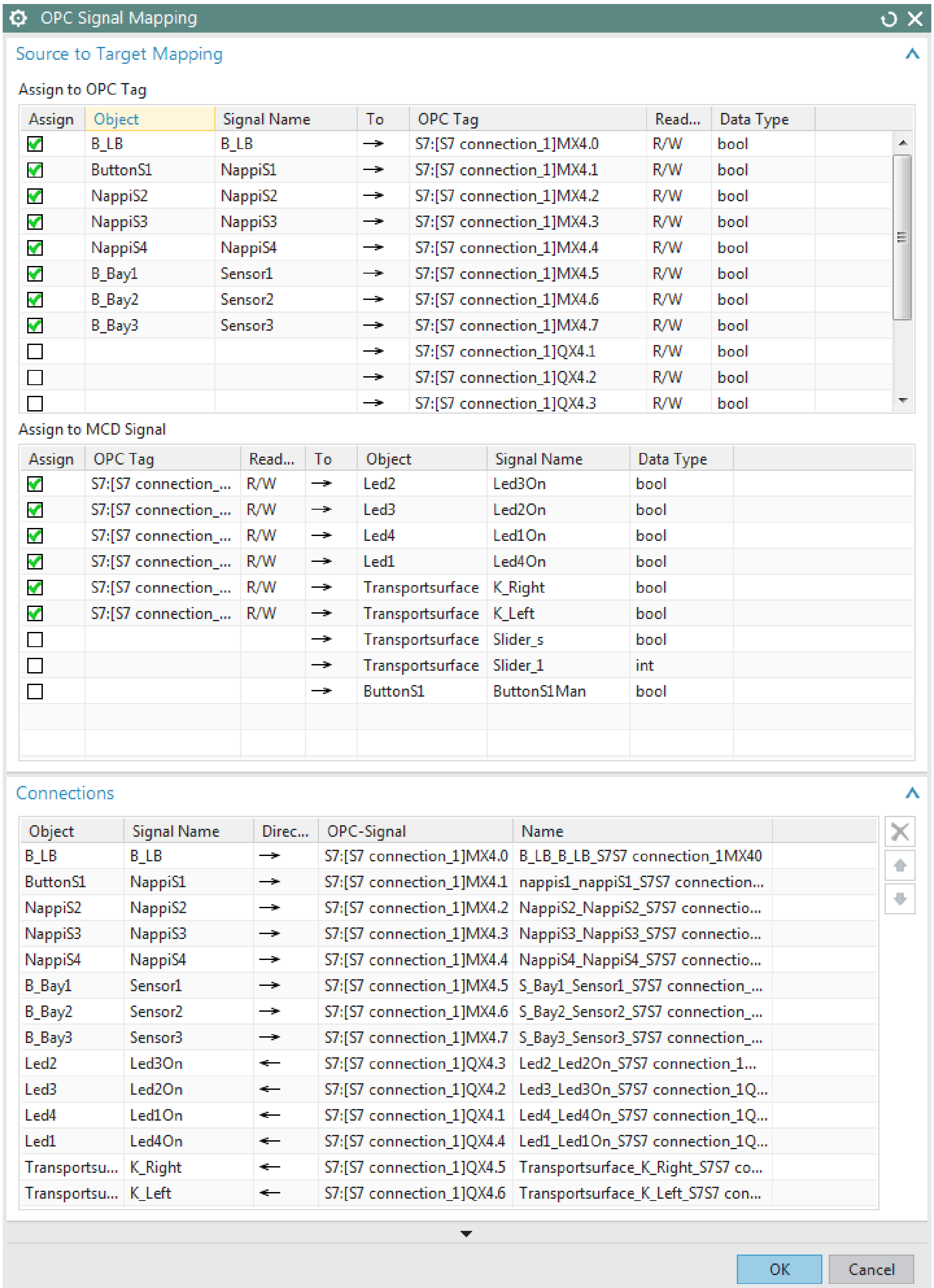

Figure 13. OPC and MCD Signals

3.6 Problems in the project

There was a slight problem with the conveyor belt in the modeling stage of the project. The belt was originally modeled exactly like it is in the real conveyor. This caused some problems with the sliding joint, as Siemens NX wouldn't recognize it as a straight belt because the real belt wasn't flat. After some testing it was decided that it is better to modify the belt so it is just a flat part.

Second problem was that the PLC-program provided by Siemens was made for newer TIA Portal version so it couldn't be opened in the computers in Seinäjoki University of Applied Sciences. After manually finding the update and installing it for the TIA Portal the PLC-program opened and worked well.

There was also a problem with the connection to the PLC. This was because the IP-address was different in PLC and PC, and as a student the author of this project didn't have administration rights to change the IP-address of the PC. Getting the administration rights took a while but after they were gotten the IP-configuration could be modified and the connection was working.

The Siemens NX -software was updated during the summer break in the university. For some reason this update deleted some of the signals made in the project, and these signals had to be created again to make the project work.

The communication between the university and the author of this project happened mostly with email. This was a bit slow, because most of the summer no-one was working at the university. This made the project a bit harder as all help needed had to be asked with email or phonecall. After summer the author of this project went to do his internship so it slowed the project down even more, but after all the project got done.

4 Results and conclusions

The 3D-model and its signals and the OPC connection between the model and the PLC program were made successfully. Most companies probably still use Siemens step7 as their programming software, but in future it will be changed to the TIA Portal so it is good to have some basic knowledge of the new program.

The project opened eyes to a different kind of approach to automation with virtual commissioning. The usage of virtual commissioning is going to grow in the future of teaching as it is easier for universities and businesses to teach with a virtual presentation than a real machine. Also safety is important, as nothing is at risk when the user is driving a virtual plant as opposed to driving a real machine and having a risk of breaking the machine. Virtual plant being cheaper also makes it more affordable for universities which maybe can not afford a real machine for their teaching purposes.

Manufacturers could also benefit from virtual commissioning by providing a 3D-model and simulation of their product to make the product more understandable for the client. This would probably improve the sales of the product as the client could see how and why the machine works before actually ordering it.

The digital twin -concept synchronizes the physical product and the virtual product. By merging these two we can get data that cannot be seen by human eyes, and it helps us to fix problems faster and more efficiently. By conceptualizing visually and then comparing between the physical and virtual models, we can collaborate to have real time information on what is happening on the factory floor. This will improve productivity and product quality.

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