INTEGRATION OF SIMULATION TECHNOLOGIES WITH PHYSICAL SYSTEM OF RECONFIGURABLE MATERIAL HANDLING

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ABSTRACT: The rapid-changing manufacturing environment requires a manufacturing system that is easily upgradeable to match new technologies and new functions such as Reconfigurable Manufacturing System (RMS). RMS is distinctive from the conventional manufacturing system, where the RMS can be accomplished by using reconfigurable hardware and software, such that its capability and functionality are changeable over time. The reconfigurable components of a RMS include mechanisms, material handling system, sensors control algorithms, machines and modules for the whole production system. The objective of this project is to verify the integration between a simulation with a physical system of a reconfigurable material handling, in order to allow the simulation software controls the physical system directly. The methodology of this project starts with modelling of the physical system. Then, the control logic of the physical system model is constructed in simulation software in line with the behavior of the real physical system. Next, PLC as the controller of reconfigurable material handling connects a computer through OPC server. The PLC communication tags are extracted from OPC server. These tags are used to build the communication between simulation and OPC server. As a result, the integration capabilities are verified by using data comparison over time between simulation and reconfigurable conveyor system.

KEYWORDS: *Integration; Simulation; Reconfigurable Conveyor System; OPC*

1.0 INTRODUCTION

In the fourth industrial revolution, the competition of manufacturing environment was very dynamic, whereby many worldwide companies tried to produce a wide range of products and adapted quickly to the demanding market variations [1]. The rapid-changing manufacturing environment requires a manufacturing system that is easily upgradeable to match new technologies and new functions. According to [2], reconfigurable manufacturing system (RMS) is an agile and responsive system. RMS is completely different from the traditional manufacturing system, which is the dedicated manufacturing line (DML) and flexible manufacturing system (FMS). RMS can be accomplished by using reconfigurable hardware and software, such that its capability and functionality can be changed over time [3]. The reconfigurable components include mechanisms, material handling system, sensors control algorithms, machines and modules for the whole production system. Every tool is needed to estimate well for both the reconfigurable aspects and strategic benefits of having good manufacturing system because the startup capital for RMS is high [4].

According to [5], establishing simulation models, training and testing are becoming an essential part of the manufacturing system for the reduction of time and costs. Besides, simulation reduces the inherent risks and enormous costs from any material handling project [6]. There are several types of simulation which can be found in manufacturing systems. Types of the simulation are classified into dynamic or static, deterministic or stochastic, and discrete event simulation [7]. Discrete event simulation depicts the changes at precise points in simulated time by utilizing the logical model of a physical system [8]. The design and operational rules of RMS enable improvement through discrete event simulation. Meanwhile, simulation system is starting to replace the new standards and techniques to take over old simulation standards since 2000 [9].

From the research, some manufacturing industries have tried to implement the Cyber-Physical System (CPS) [10], where they use the new generation of systems with integrated physical capabilities and computational system [11]. Since CPS is in the initial stage of development, it is essential to clearly define the structure and methodology of CPS as guidelines for its implementation in industry [12]. Usually, in CPS, the process control is referred to the embedded system. The system can be developed through simulation and integrated with a physical system which will be highlighted in this paper. So, by integrating simulation technology and reconfigurable material handling, the interactions between them can reflect the virtual models which are similar to the real system, and thereby the results are produced from the simulation [13].

Lately, the sudden change of the market requirements has been more common than before. The manufacturing industry requires a new system to overcome the demands of the market [14]. The new system requires a physical system and software where it can quickly adjust production capacity and respond to the sudden changes in market quantity demand. Thus, the combination of automation system and simulation is essential to cope with unpredicted events and situations [15]. The research of integration between a simulation with the physical system is still new. Therefore, the relevance of simulation integration with hardware of the system needs to be clarified.

The objective of this paper is to propose a novel architecture and approach used in establishing the communication between simulation software with the physical system of the reconfigurable material handling. The proposed architecture has been verified with two experiments in order to prove that the architecture is capable to control the reconfigurable material handling system.

2.0 DESIGN AND DEVELOPMENT

In the design and development of the architecture, Tecnomatix Plant Simulation has been used as the simulation software meanwhile, the physical material handling system was a reconfigurable conveyor system. The approach used to integrate between simulation and physical system is divided into four stages as follow:

i. Design the physical system modeling of conveyor system
ii. Construct the logic control of the modeling
iii. Constructed the ladder diagram for PLC of conveyor system
iv. Build the connection between simulation and conveyor system

2.1 Modelling of the Reconfigurable Conveyor System

The modelling of the physical system is based on the actual reconfigurable conveyor system design. In order to ensure the reliability of the simulation outcomes, the system model was built as close as possible to the real physical system. The system model is constructed in Tecnomatix Plant Simulation. Figure 1 shows the system model of the reconfigurable conveyor system. The total length of the conveyor is 160 meter (m). Sensor 1 (DS1), sensor 2 (DS2), sensor 3 (DS3) and sensor 4 (DS4) are located 46m, 79m, 110m and 148m away from the edge respectively. The stopper 1 (PU1) is located between DS1 and DS2, 58m away from the edge and the stopper 2 (PU2) is located between DS3 and DS4, 121m away from the edge.

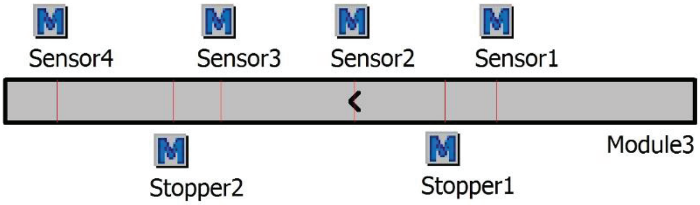


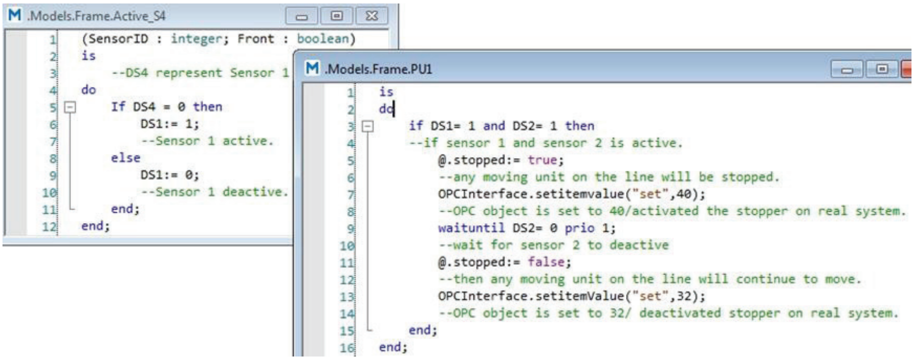
Figure 1: The design of physical modeling in simulation

2.2 Construction of the Logic Control of the System Model

After the system model is developed, the control logic of the system model is constructed in the simulation software. Tecnomatix Plant Simulation programming language, SIMTALK is used to program all the required methods (Active_S4, Active_S1, PU1, PU2 etc.). Figure 2 shows some of the programming codes for the methods.

2.3 Modification of the Ladder Logic Diagram for the PLC

Next, the communication between simulation (system model) and physical system of the reconfigurable conveyor system is focused at this stage. First, Omron PLC CP1L is connected to simulation computer using Ethernet communication protocol. The existing ladder logic diagram for the reconfigurable conveyor system is shown in Figure 3. To establish the communication between simulation and physical system of the conveyor system, the existing ladder logic diagram should be modified by adding several new addresses in the input part. These new addresses are normally in the format of internal memory.



```
(SensorID : integer; Front : boolean)
is
    --DS4 represent Sensor 1
do
    If DS4 = 0 then
        DS1:= 1;
        --Sensor 1 active.
    else
        DS1:= 0;
        --Sensor 1 deactive.
    end;
end;
```

```
is
do
    if DS1= 1 and DS2= 1 then
    --if sensor 1 and sensor 2 is active.
        @.stopped:= true;
        --any moving unit on the line will be stopped.
        OPCInterface.setitemvalue("set",40);
        --OPC object is set to 40/activated the stopper on real system.
        waituntil DS2= 0 prio 1;
        --wait for sensor 2 to deactive
        @.stopped:= false;
        --then any moving unit on the line will continue to move.
        OPCInterface.setitemValue("set",32);
        --OPC object is set to 32/ deactivated stopper on real system.
    end;
end;
```

Figure 2: Example of the programming code for the simulation method

After the modification is done, the ladder logic diagram is uploaded to the PLC. Before uploading, internet protocol (IP) address of the PLC must be configured by using the CX-programmer software. The same IP address for the PLC is used to connect the OPC server with the PLC.

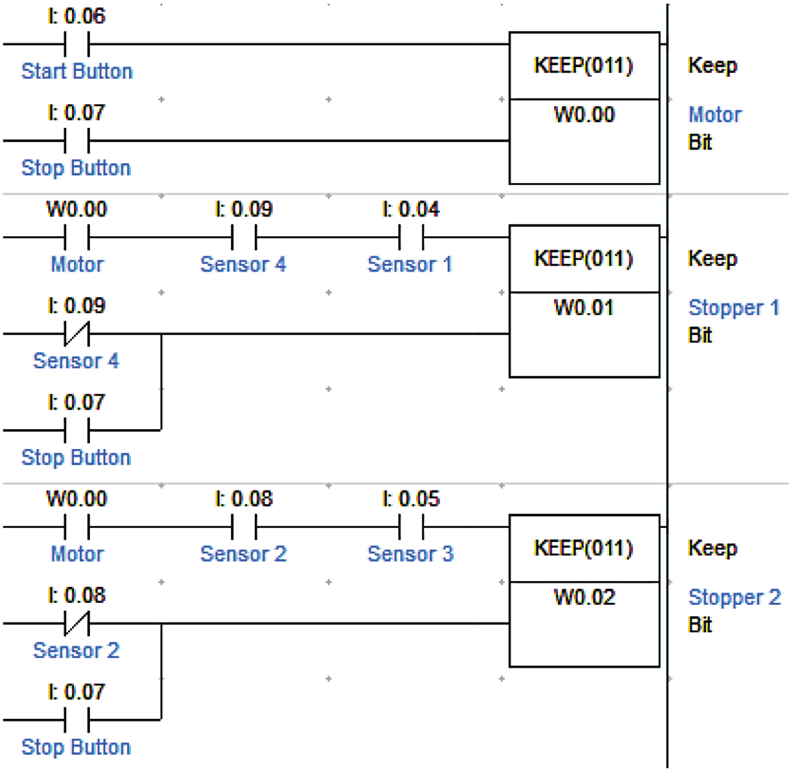


Figure 3: Input section of PLC ladder logic diagram

2.4 Establishing the communication between system model and physical system

Figure 4 shows the communication structure between the system models in Tecnomatix Plant Simulation with the physical system. An OPC protocol is used to build the linkage between PLC and simulation software. In order to build the communication between two different clients, common tags must be created in the OPC server to allow both of the clients to communicate with each other. The tags are created from PLC and the tags that are related to the simulation is extracted out. Some tags can be extracted from PLC but the value inside the tags cannot be changed manually. This is because some tags are already synchronized with the command which is already build in the PLC through the ladder logic diagram. The tags that cannot be changed are the inputs and outputs of PLC. To overcome this issue, new addresses should be added to the existing ladder logic diagram by using CX-programmer.

The new addresses only act as an internal memory in the PLC but not as inputs or outputs. So, these addresses will be extracted from the PLC and used to build the communication with the simulation software through the OPC server. As an internal memory, the new addresses can be read and written. So, when the values change during the simulation, the OPC server writes the new value to the PLC tags and PLC will then energize the output.

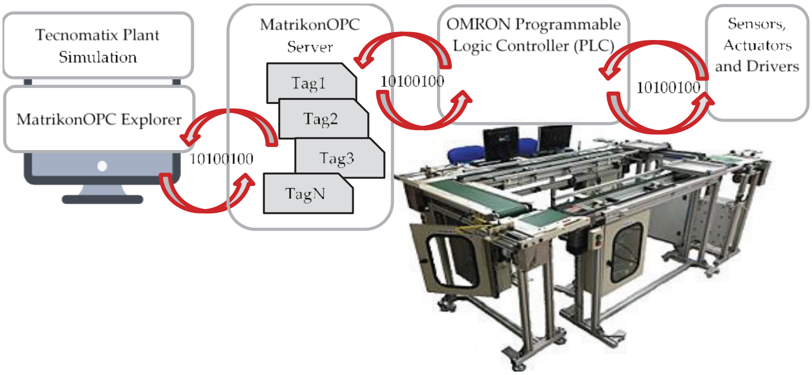
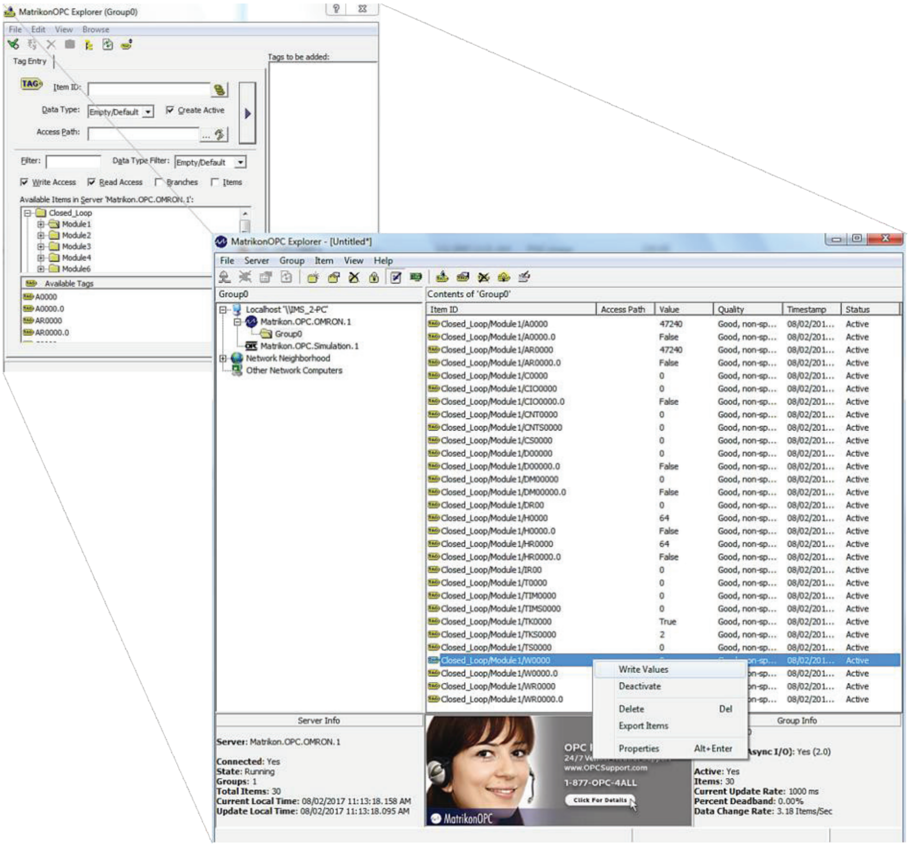


Figure 4: A communication structure between the system model and physical model

Besides, these tags are going to be used in the OPC Explorer, a module of the OPC Server to observe the changes happen in the system model simulation and the PLC (Figure 5). The function of OPC

Explorer in this project is used to verify the communication between simulation and conveyor system. This is because the value change in the simulation will not display in OPC server or simulation software. To verify the communication, the changes between simulation, physical system of the reconfigurable conveyor system and OPC Explorer should be observed. When the value of stopper changed during the simulation, OPC Explorer will display the value and the PLC will energize the stopper. After the PLC tags are linked with the control logic of the system model, communication between system model and physical system is established. Then, the simulation of the system model and commissioning of the physical system can be executed.



Contents of 'Group0'

Item ID	Access Path	Value	Quality	Timestamp	Status
Closed_Loop/Module1/A0000		47240	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/A0000.0		False	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/AR0000		47240	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/AR0000.0		False	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/C0000		0	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/CIO0000		0	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/CIO0000.0		False	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/CNT0000		0	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/CNTS0000		0	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/CS0000		0	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/D00000		0	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/D00000.0		False	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/DM00000		0	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/DM00000.0		False	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/DR00		0	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/H0000		64	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/H0000.0		False	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/HR0000		64	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/HR0000.0		False	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/IR00		0	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/T0000		0	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/TIM0000		0	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/TIMS0000		0	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/TK0000		True	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/TKS0000		2	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/TS0000		0	Good, non-sp...	08/02/201...	Active
Closed_Loop/Module1/W0000		[illegible]	[illegible]	08/02/201...	Active
Closed_Loop/Module1/W0000.0		[illegible]	[illegible]	08/02/201...	Active
Closed_Loop/Module1/WR0000		[illegible]	[illegible]	08/02/201...	Active
Closed_Loop/Module1/WR0000.0		[illegible]	[illegible]	08/02/201...	Active

Server Info

Server: Matrikon.OPC.OMRON.1

Connected: Yes
State: Running
Groups: 1
Total Items: 30
Current Local Time: 08/02/2017 11:13:18.158 AM
Update Local Time: 08/02/2017 11:13:18.095 AM

Group Info

Async I/O): Yes (2.0)

Active: Yes
Items: 30
Current Update Rate: 1000 ms
Percent Deadband: 0.00%
Data Change Rate: 3.18 Items/Sec

Figure 5: The MatrikonOPC Explorer and the actives tags for communication

3.0 RESULT AND DISCUSSION

The data and information exchange between Tecnomatix Plant Simulation software and components such as sensor, actuator, and driver can be done through the established communication. The cyber part of the system is the system model in the Tecnomatix Pant Simulation software while sensors, actuators, and drivers are the physical part of the system. Figure 6 shows the architecture of the integration which will enable virtual commissioning to be performed for the Reconfigurable Conveyor System.

The integration between this two system is established by showing the verification results in two different sections:

i. The change of the values in the OPC client
ii. Data collected from simulation and conveyor system

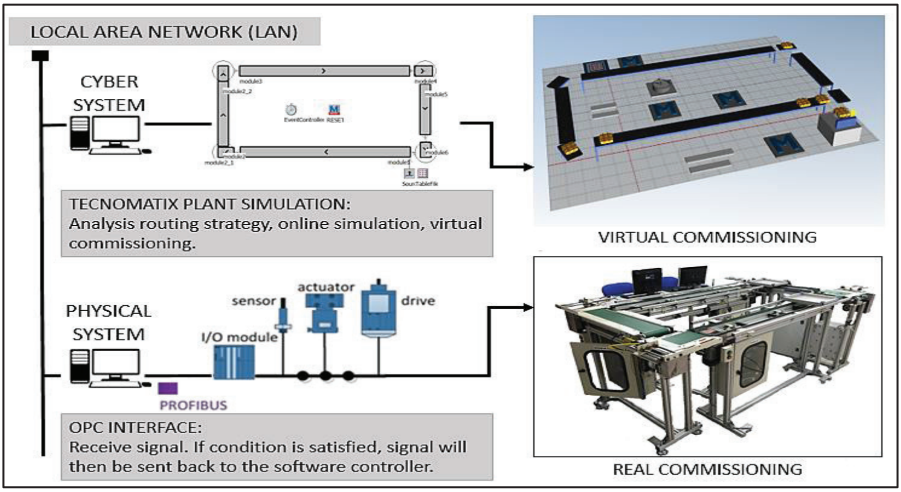


Figure 6: Architecture of the integration between simulation with physical system

Since the communication between simulation and physical system of the reconfigurable conveyor system has been established, the value of the physical system actuators is changed by the changing of the actuator model value in the simulation. When the physical system responds to the input data in system model simulation and vice versa, the integration between the two systems is proved to be working.

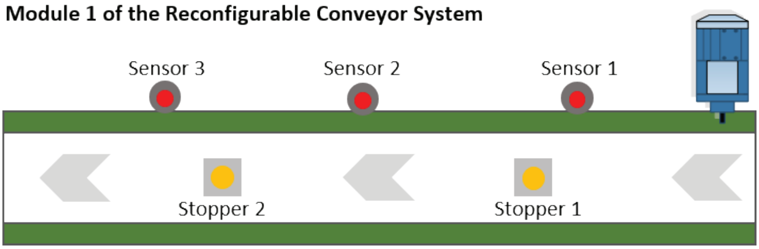
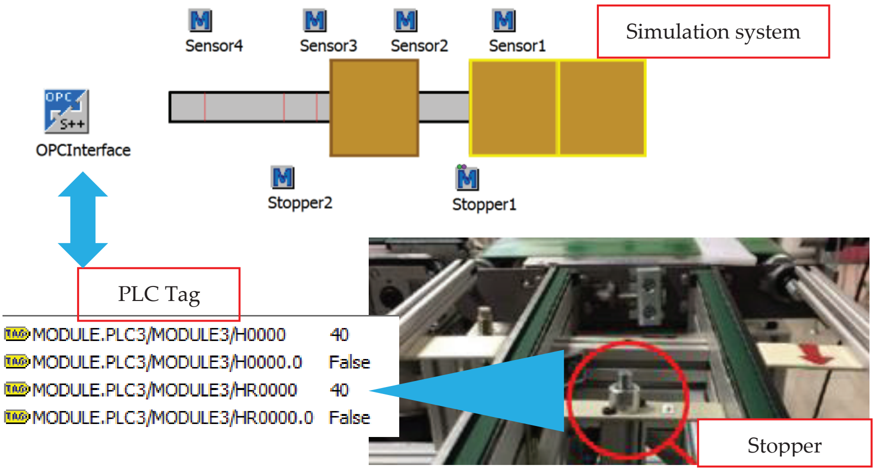


Figure 7: A schematic diagram of the selected module of reconfigurable conveyor system

An experiment is conducted as a proof of concept. In the experiment, only one module is selected and modelled (Figure 7). After the architecture has been developed and configured, the system model simulation is executed. When the simulation start button in EventController (simulation object) is pressed, pallets will be produced from the source and moves on the conveyor belt module. A pallet will then trigger the Sensor 1 (DS1 value will change from 0 to 1) and Sensor 2 (DS2 value will change from 0 to 1), which will result in energizing the Stopper 1 (PU1). Figure 8 shows that Stopper 1 in the simulation is energized which makes the next pallet stopped (pallets with dark yellow border). When the virtual Stopper 1 energized, the OPC server will receive a new value (40) from the simulation and writes it to PLC and OPC Explorer. So, the Stopper 1 at the physical conveyor module will be energized as well.



MODULE.PLC3/MODULE3/H0000 40
MODULE.PLC3/MODULE3/H0000.0 False
MODULE.PLC3/MODULE3/HR0000 40
MODULE.PLC3/MODULE3/HR0000.0 False

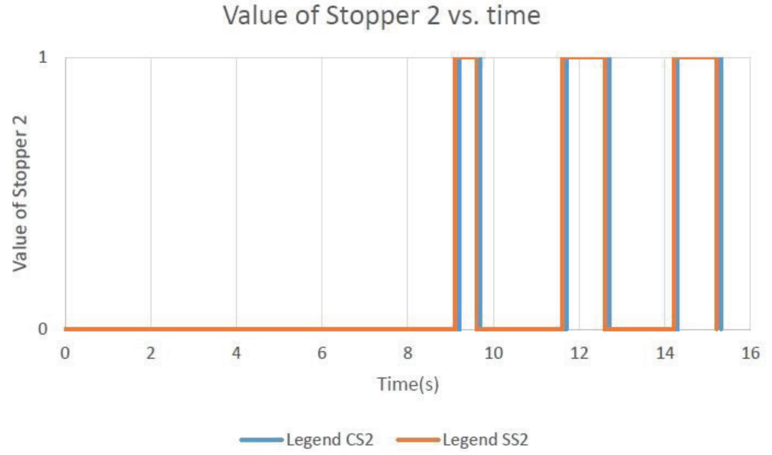
Figure 8: The next pallets are stopped when the virtual Stopper 1 is energized in the simulation

As the pallet moves forward and triggered Sensor 3 (DS3 value will change from 0 to 1) and Sensor 4 (DS4 value will change from 0 to 1), Stopper 2 is energized in the simulation. Then, a value (36) is written to the OPC server and sent to the PLC and the OPC Explorer. When PLC reads the value that is written by the OPC server, physical Stopper 2 at the conveyor module will be triggered.

As the simulation run, Stoppers 1 and 2 will be triggered and generated the value of 40 and 36 respectively. Besides these two values, the stopper will remain at rest and OPC Explorer will show the value of 32. So, changing the value in OPC Explorer is one way to verify the communication between simulation and physical system of the conveyor system. From these two results, we can validate that the integration is established because whenever there is value change in simulation, changes would occur in the physical conveyor module.

The integration between simulation and physical system of the conveyor module is also verified through another experiment that monitors and records the value of the actuators. The experiment is carried out for both systems. The data value generated by the actuators is classified into true (1) or false (0) only. When the stopper is energized during the simulation, the data value of the stopper is 1, otherwise 0. The experiment is conducted in 16 seconds and the value is recorded and the graph is plotted to verify the integration.

(a)



(b)

Figure 9: Value of the virtual and physical (a) Stopper 1 and (b) Stopper 2 over time

In Figure 9, CS1 is represented the physical Stopper 1, CS2 is represented the physical Stopper 2, SS1 is represented the virtual Stopper 1 and SS2 is represented the virtual Stopper 2. The value of Stopper 1 is starting to change after 4 seconds as Sensor 1 and Sensor 2 are triggered. When the virtual Stopper 1 is triggered, Stopper 1 at the physical system is energized with values of 1 and vice versa. By comparing the data value in the graph, it shows that the communication between both systems is established. This is because both stoppers (CS1 and SS1) are operated in the same manner as shown in the graph. The communication which is established allows both CS1 and SS1 to write and read values to each other. During the experiment, the value of Stopper 2 is recorded as well. The value of Stopper 2 starts to change after 8 seconds because the pallet is transferred to touch and triggered Sensor 3 and Sensor 4. The data value of the stopper will be read or written by both OPC clients.

By observing the two graphs, there is a similarity between them such that the path of value change is same. This means the integration happens between the simulation and physical system. Whenever the changes happen in simulation, the physical conveyor system will execute the same results and vice versa. However, the time delay appears between the energization of virtual stoppers and physical stoppers. The value changed in the simulation is faster than physical system due to some delay time in data transfer and synchronization frequency of the OPC server.

4.0 CONCLUSION

In conclusion, the objectives of this project are accomplished by the integration of simulation with the physical system of reconfigurable material handling. The communication between OPC client and OPC server is established. The OPC is the main protocol to build the communication between the physical reconfigurable conveyor system and simulation. The concept of software in the loop (SiL) is applied in the simulation part meanwhile the technique of hardware in the loop (HiL) is applied in the communication between simulation and physical system of the reconfigurable conveyor system. The architecture of the integration between the two systems has been proposed. The proposed architecture has been verified by comparing the data generated from simulation of the system model and the physical reconfigurable conveyor system. The data analysis is proven the communication exists between simulation and physical reconfigurable conveyor system. Through that, the reconfigurable conveyor system is capable to be reconfigured physically and logically.

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