

An interactive control using 3D models

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Abstract—It presents the 3D model design of a real prototype system with movement simulations using SOLIDWORKS and the development of the interactive GUI button controls using OMRON PLC. The SOLIDWORKS 3D modeling and simulation software is utilized to construct a 3D model representation of the real prototype hardware with actuators. The actuator movement simulation of the 3D model has also been developed and controlled with the LabVIEW interface software. The actuators of the real prototype are wired to the PLC and are also controlled with LabVIEW by connecting the PC to the PLC through a serial USB to RS-232 communication adapter. The HostLink protocol is automatically used by the PLC when communicating with the LabVIEW “VISA serial communication” features block. The developed LabVIEW program and GUI will send C-mode commands to the PLC to trigger an output at the click of a button. Lastly, both the program or system of the 3D model simulation and PLC control are integrated to allow both the actuators to move simultaneously.

Keywords— *Interactive control, 3D models, PLC control, actuators, Solidworks.*

I. INTRODUCTION

This work consists of 3D Computer-Aided Designs (CAD), Programmable Logic Controller (PLC), and a prototype that utilizes sensors and actuators. Computer-Aided Design can be defined as a design method using computers to create any three-dimensional models of products while also generating a schematic document of the design. It is developed to ease the process of producing the specified product by notifying the information of the product's ingredients, procedures, and dimensions (Anon, n.d.). The term for the producing process is called Computer-Aided Manufacturing. Furthermore, PLCs are durable and simplified computer devices that automate industrial processes. It uses the Ladder Logic programming language to create functions to run manufacturing automation. A PLC will collect data from input devices such as sensors, evaluates the data, and manipulate the outputs which are actuators [1]. Moreover, Sensors and Actuators are the primary components and vital elements of an embedded system such as microcontrollers. A sensor functions to keep track of the changes of environmental or physical factors such as temperature while using mathematical measurands. On the other hand, an actuator plays a role in applying the change of the said factors to achieve a desired condition or result while getting data from the sensors [1].

In this globalization era, graphical user interfaces (GUI) such as Human-Machine Interface (HMI) and Supervisory Control and Data Acquisition (SCADA) are very crucial in the

industry. However, they are mostly two-dimensional schematic designs that require knowledge of the simplified symbols of the components in a system. The schematic designs must be accurate and represent the hardware, which is not too easy to achieve. Poor designs or lack of standardization may cause human errors when evaluating the hardware system [3]. Fortunately, 3-D interfaces exist and are more user-friendly and can be comprehended easily.

Furthermore, one of the most common issues in the industry is software and hardware communications [4]. For example, there are difficulties to connect old systems with modern ones or systems that have different protocols. The usage of one standard communication method is highly recommended to prevent the need for different software interfaces in the industry. Without a common communication standard, it would be time-consuming to fix the problems faced, many unnecessary communication methods will be invented, and the data transmission speed of different protocols may be reduced [5].

A simulation of the conveyor control system using virtual communication and virtual reality has been done for the ability to simulate industrial automation and machines. The Siemens PLC S7-300 was utilized to control the conveyor itself and the sensors through ProfiNet communication protocol. The OPC Server was utilized to connect the PLC with the Process Simulate software. The testing methodology of the researchers was by creating a control program to the actual PLC control system on the real conveyor station [6]. The researchers [7] have worked on the project with the title of “Integration of Sensor and Actuator Networks and the SCADA System to Promote the Migration of the Legacy Flexible Manufacturing System towards the Industry 4.0 Concept”. The project consists of multiple manufacturing stations with sensors and actuators that need to connect with the SCADA (Supervisory Control and Data Acquisition) system through ethernet and PROFIBUS (Process Field Bus) communication protocols.

Another work proposed is the automation of a soap windscreens washer filling machine with PLC and LabVIEW. The researcher intends to solve the limitations of Pico PLC in old windscreens systems and the communication problem between PLC and PC software in the industry. The proposed system utilizes the Allen Bradley PLC, SCADA system using LabVIEW and OPC server as the interface. The OPC server works with the Ethernet communication protocol to communicate with the PLC and LabVIEW [8]. The web-based work on educational programming logic controller training set based on vocational high school students was presented. The purpose of the project was to design and develop a PLC

training set as an education need for high school students. The project utilizes the Siemens SIMATIC S7-200 and the VB.NET programming language as the communication medium through the internet (TCP/IP) [9].

This work is intended to benefit engineers in industries and even in institutions. The three-dimensional feature is a huge advantage, users can comprehend the system quickly and effectively. Users may inspect the design and structure of the hardware thoroughly in the display. It is also convenient as the users can see hardware details in the display. Simulations of the system can also be implemented to allow efficient understanding, especially for the beginners and trainees. Furthermore, this project utilizes a common communication standard to connect the computer with PLC. The communication method used will not be complex or unnecessary to the users. Additionally, this work can be applied with the Internet of Things (IoT) or web-based training which allows users to access the system from other locations. Finally, the interactive controls can be very user-friendly when operated with the 3D virtual representation of the hardware. The interactive controls will be like a user interface of daily machines such as vending machines.

II. BLOCK DIAGRAM AND OPERATION OF THE PROPOSED SYSTEM

The overall proposed system will consist of a 3D virtual system design, an interface software to connect the virtual system with a real system, and a prototype of the real PLC system. The virtual 3D system design will be a 3D model of the real PLC system including a simulation of the real PLC system. The 3D design and interface software will be researched on its level of functionality and reliability for this project. The virtual system will include tag numbers for the sensors and actuators used in the PLC including their hardware details to provide the user convenience instead of using a user manual. The model and prototype of the real PLC system will be an industrial-like production system that includes components such as sensors, motors, and even pneumatic cylinders. Lastly, the interface software will allow interaction of the 3D virtual system with interactive buttons to control the real PLC system.

A. General Block Diagram

The block diagram of the overall framework of the system is demonstrated as shown in Fig. 1. According to the block diagram above, the OMRON PLC will communicate with LabVIEW and SOLIDWORKS by employing a Modbus RTU adapter to the PC and OPC server in the PC. The Modbus RTU adapter will be a serial RS-232 converter from the OMRON PLC to the PC running OPC server, LabVIEW, and SOLIDWORKS. The LabVIEW software comes with an OPC server module and SOLIDWORKS toolkit. Thus, LabVIEW can be the medium for the PLC and SOLIDWORKS while also developing the interactive controls similarly to an HMI (Human-Machine Interface).



Fig. 1. General block diagram

The utilized serial communications protocol is Modbus RTU involving the RS-232 or RS-485 serial interface to connect the PLC with a PC. Modbus RTU can be referred to as an open serial protocol which comes from the developed Master/Slave architecture (Anon, n.d.). This communication protocol is commonly used as it is simple, reliable, and easy to use. The RAM processor code usage of Modbus is generally low which is crucial in the early days. Modbus also allows the connection of multiple devices through networks or buses.

The OPC (Open Platform Communications) server is operated in LabVIEW as the most important interface feature for the project. OPC is known as a standard for software interface which allows communication between other PC software and industrial devices. It alters the PLC communication protocol to OPC protocol that can be used for programming and control. By using OPC, manufacturers can reduce cost because it is an open standard and compatible with many types of hardware devices. The OPC UA (OPC Unified Architecture) can also be used in the case of the chosen PLC is not supported by OPC. The OPC UA does not depend on OLE or DCOM technology from Microsoft, therefore it can be implemented on any platform other than Windows. Moreover, the OPC and OPC UA servers are features and modules categorized as "I/O Servers" and provided by the LabVIEW software. There is another module that is required for the research methodology which is the "Softmotion module". This feature allows control of the motion simulation of the 3D virtual CAD model designed in SOLIDWORKS.

B. System Flow Chart:

Fig. 2 shows the complete system flow chart. The flowchart below shows the process to set up the software and hardware for this project. The SOLIDWORKS software will be set up before the LabVIEW software to focus on the 3D model. The 3D model simulation requires the feature "SOLIDWORKS Motion" to be installed. When the 3D model and its simulation is completed, the LabVIEW software and the "Softmotion module" add-in will be installed in evaluation mode. The "Softmotion module" add-in allows LabVIEW to send a signal to the motor axis created on the actuators in SOLIDWORKS. Next, the system is planned to run in 2 different modes which are running in the automatic and manual modes. The automatic mode flowchart is obtained from the datasheet of the prototype which included a ladder diagram program for the PLC. The ladder diagram program will be uploaded to the PLC before running the system. The planned system will be able to switch between the 2 modes freely. The flowchart below shows the execution steps where it starts with the first pneumatic cylinder pushing n blocks out from the container of the prototype. Then, the conveyor belt motor will be turned on while the second pneumatic cylinder will push the blocks onto the conveyor belt to move it to a sorting contraption. The program ends when every actuator is turned off with a specific elapsed time.

The simulation can be accomplished with the "SOLIDWORKS Motion" feature and the "softmotion module" add-in of LabVIEW. The actuator action of the simulation can be done by adding motor axes on the actuators. With the "Softmotion module" add-in, the user can add the assembly file of the SOLIDWORKS and its axes. Lastly, the SOLIDWORKS assembly can be deployed in the project section of the LabVIEW software and initiate the simulation.

The SOLIDWORKS software will automatically run in “Motion Analysis” mode and the LabVIEW program can be executed to control the movements of the actuators.

The actuator simulation for the 3D model is completed initially and then the speed of extension and retraction of the actuators can be adjusted in SOLIDWORKS itself when creating the motor axes. Users may also adjust the position of the extension or movement distance of the actuators. By just click the Boolean switch for the “Softmotion module” add-in block, the actuators in the simulation will act accordingly.

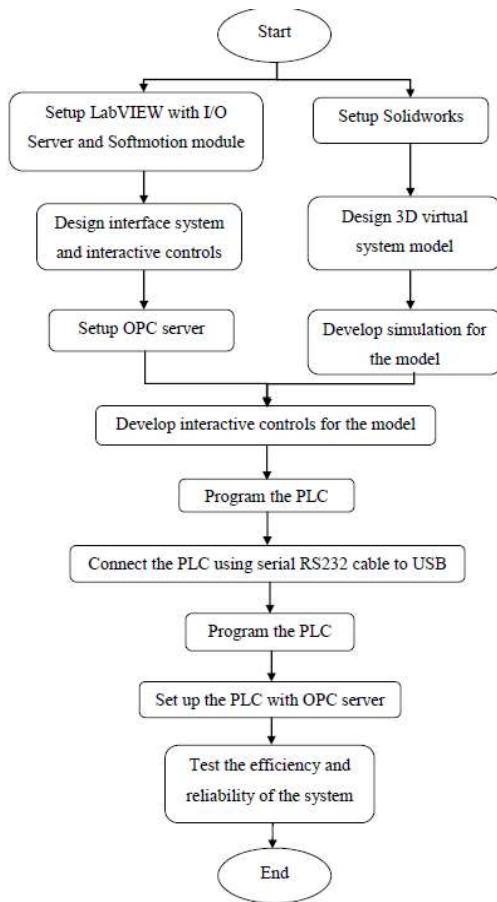


Fig. 2. System flow chart

C. Constructional Diagram

Fig. 3 shows the wiring diagram for the hardware part of the project. The PC used is connected to the Modbus RTU socket of the OMRON PLC with a serial USB to RS-232 communication adapter and an OMRON RS-232 cable. The blue wires indicate air pressure tubes, red wires indicate VCC and V while the black wires are grounds. Next, the tubes connect the outlet of the pressure pump to the inlet of each of the solenoids. From the outlets of the solenoids, the tubes then connect to the double-acting pneumatic cylinders. Moreover, the output 100.00 of the PLC is connected to the solenoid of pneumatic cylinder 1. The output 100.01 on the other hand is connected to the solenoid of pneumatic cylinder 2. For output 100.02, it connects the signal pin of the 5V relay. The solenoids and relay are connected to the main power source of the PLC. Lastly, the grounds of each output are connected to the main ground socket of the PLC.

The programming software used is the National Instruments LabVIEW, it is used to control the movements of the actuators in the 3D model simulation and the real prototype actuators through a PLC. Based on Fig 3, the LabVIEW program consists of features from the “Softmotion module” add-in which controls the motor axis created in the 3D model of SOLIDWORKS. This part of the program is enclosed in a while loop to ensure the 3D model simulation receives signal continuously. The blocks from the “Softmotion module” add-in which are titled “Straight-line move” requires 2 duplicate blocks for each actuator, to extend the simulation’s actuator and retract. The resource inputs receive the file address of the created motor axis from SOLIDWORKS. The blocks for pneumatic cylinder extension will activate when the switch in the GUI is pressed or when the output of the PLC is turned on. On the other hand, the retraction blocks will activate when the switch and output are turned off. The position values only apply to the cylinder actuators in the 3D model simulation. The “set scan engine” block on the right sets the operating mode of the NI Scan Engine on the motor axes to actively scan for changes.

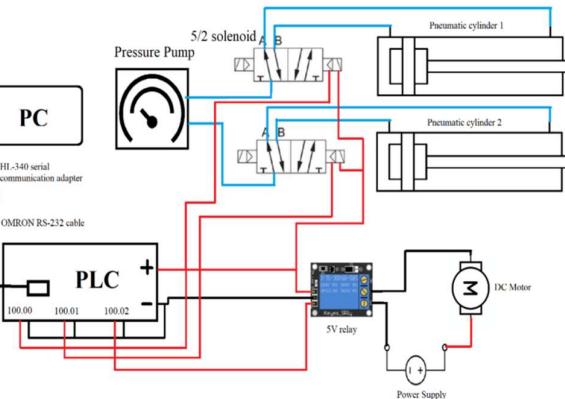


Fig. 3. Constructional diagram

Fig. 4 shows the LabVIEW program module to communicate with PLC through serial communication. The first white block on the left is the “VISA Configure Serial Port VI” which is a built-in LabVIEW SubVI for serial communications. The block will receive information of the connection to PLC such as the COM port number, baud rate, data bits, parity, byte count and so on. This information can be adjusted with the settings of the CX-Programmer software for OMRON PLCs. Next the block will be wired to the “VISA Write”, “VISA Read” and “VISA Close” function blocks to send signals and commands. The working principle of this methodology is to send specific OMRON PLC C-mode commands in hexadecimal strings. The PLC will recognize the commands because the commands are a built-in feature in the PLC.

The section labeled “FCS Configuration” checks the last 8 bits of hexadecimal data from the input command and compares it to 0. The 8 bits of data are then converting into 2 bits of data and will be concatenated with the initial input command with a terminator at the end. The full length of string data is required to communicate with the OMRON PLC. For example, the command to write output 100.00 is

“@00WR01000001” will be modified to “@00WR0100000141*” which the PLC will understand. Next, the modified command will go through the “VISA Write” function and into the PLC. The “VISA Read” function will always receive any response from the connected PLC when the C-mode read command is sent into this section of the overall program.

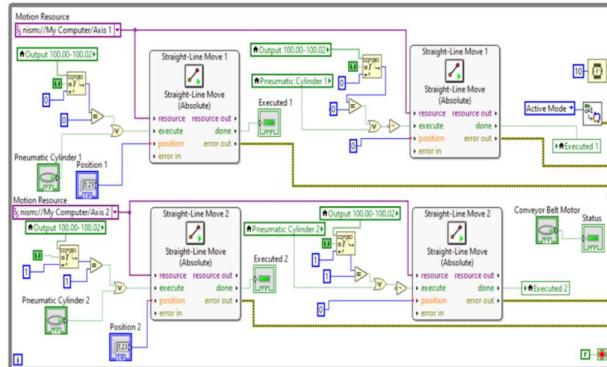


Fig. 4. The LabVIEW program to control the SOLIDWORKS 3D model

Lastly, Fig. 5 embodies the ladder diagram program for OMRON PLC using CX-Programmer. The ladder program code runs automatically with an interval between each actuator. The automatic mode could not be achieved in the LabVIEW program of this project; therefore, a mode switch is developed to separate both the manual and automatic modes. This CX-Programmer ladder code also prevents each of the actuators from activating at the same time by turning each of them off after their execution.

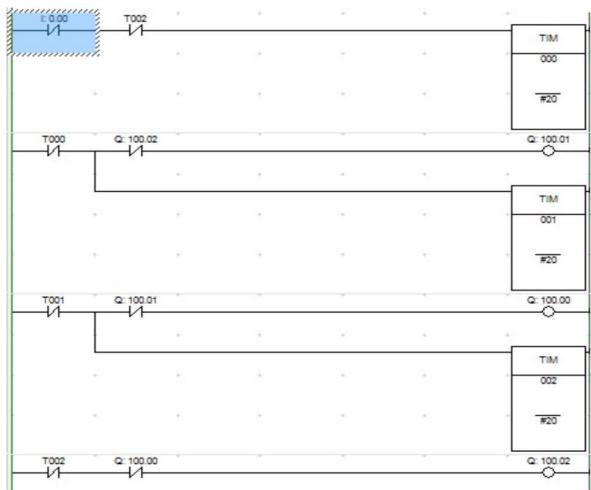


Fig. 5. Simple CX-Programmer ladder code for automatic mode

D. Working Principle

The overall system runs on either 2 modes, run mode and monitor mode for the PLC and LabVIEW GUI. When in run mode (automatic mode), the PLC will run its downloaded ladder diagram program. The interactive control buttons will not work on manipulating the output of the PLC. On the other hand, during monitor mode (manual mode), the ladder diagram program in the PLC will not run while the interactive

control buttons will overwrite the outputs. Fortunately, the developed LabVIEW program can trigger the actuators on the 3D model simulation in both modes.

Based on the flowchart in the Fig 6., the developed system using LabVIEW will always send read I/O C-mode commands to the PLC. Then, the response received will be analyzed and the I/O LEDs in the LabVIEW GUI will be turned on accordingly. The PLC downloaded ladder program will run automatically when run mode is selected. The actuators of the prototype and the 3D model simulation will act according to the downloaded ladder program which is to run continuously with an interval between each other in this project. On the other hand, the ladder program will stop once the monitor mode is selected. The actuators will only act when manipulated by the interactive control buttons of the LabVIEW GUI as shown in Fig. 6.

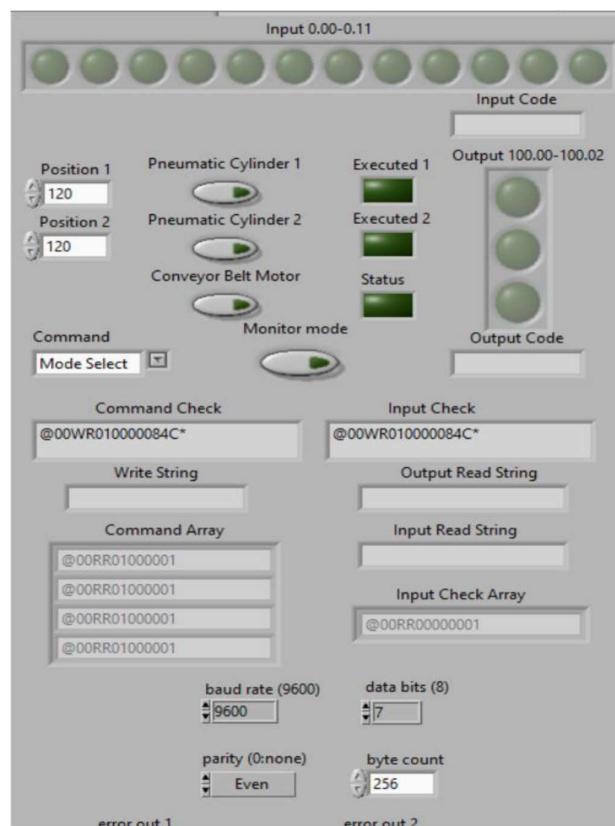


Fig. 6. GUI for the overall system

The developed LabVIEW GUI can be observed from the Fig. 6. First and foremost, the PLC modes can be selected with the drop-down list titled “Command” in the GUI. It will be run mode when the “Monitor mode” button is not activated, and the PLC will run its internal downloaded program. By pressing monitor mode, the PLC will stop running and the outputs can only be activated by the buttons in the GUI. The square LEDs will light up when the execution of the actuators in the 3D model simulation is completed successfully. The arrays of LEDs will behave the same as the LEDs from the OMRON CP1E PLC Training Kit. This is achieved by sending read commands to the PLC and examining the response feedback as mentioned before. The arrays and/or string indicators below will display the mode change, read and

write commands that went through the main section of the program. The settings to connect to the PLC and the error report for the VISA serial communication function blocks are placed below. Additionally, the position control on the left can only be used to control the length of extension of the 3D model actuators. However, the speed of execution of the 3D model actuators can only be adjusted in the SOLIDWORKS software.

III. PERFORMANCE TESTING AND SIMULATION RESULTS

The overall performance of the developed system has been evaluated by conducting various simulations of response time, execution time, and efficiency of different parts of the system. The tests will be applied to the input, output, 3D simulation, and the real PLC prototype.

A. Input LED response time test

Firstly, the foremost testing that is conducted will record the response time of the input LED in LabVIEW when the input switches of the PLC is turned on. This response time is the time taken for the designed system to receive a signal from the input of the PLC and to turn on a LED in the GUI. This test is crucial to determine the efficiency of data transfer from the PLC to the PC.

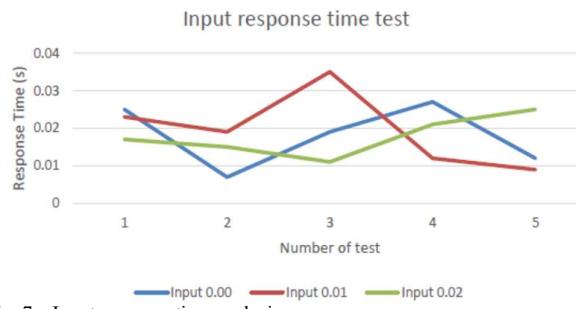


Fig. 7. Input response time analysis

The input test shown in the Fig. 7 test is carried out by starting the timer with a Boolean switch while turning on the input switch of the PLC at the same time. Next, the timer will stop when the system receives a response of the specific input. The elapsed time will be shown in the GUI as a temporary feature to record all the response times for 3 different inputs. According to Fig. 7, the response times for 3 different inputs are tested 5 times and recorded. The obtained values are realistic and almost constant compared to each other. However, the response times are almost instant that the values obtained are "0" most of the time.

B. Output LED response time Test

Fig. 8 shows the response time of the output LED of the PLC will be tested when the interactive buttons in LabVIEW are pressed. This response time is the time taken for the designed system to send a signal or command from the interactive controls on the GUI in the PC to the output LED of the PLC and receive a response. This test is vital to determine the efficiency of data transfer from the PC to PLC. This test is also carried out by starting a timer but with the output interactive control switch in the GUI of LabVIEW.

Next, the timer will stop when the system receives a response of the specific output. The elapsed time is also shown in the GUI to record all the response times for 3 different outputs.

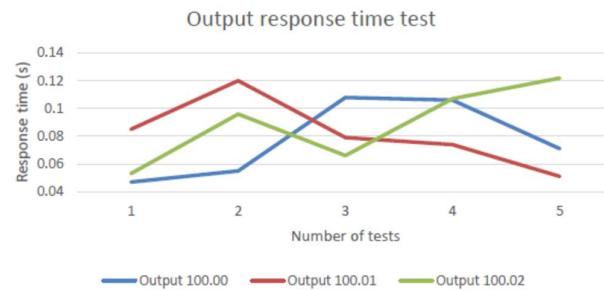


Fig. 8. Output response time analysis

According to the graph in Fig. 8, the response times for 3 different outputs are also tested 5 times and recorded. The response time values obtained are also realistic, but they are inconsistent and fluctuates. The response time of this test is longer than the input response time test due to the additional time required to receive a response from the PLC that the output is turned on.

C. 3D simulation execution time test

Furthermore, the execution time of the 3D model simulation of the system would be tested when the interactive buttons in LabVIEW are pressed. This execution time is the time taken for the pneumatic cylinder of the designed 3D model system in the SOLIDWORKS software to extend fully after pressing the interactive controls on the GUI in the LabVIEW.

For this execution time testing, it also uses a timer embedded in the project block diagram while utilizing the interactive control switch in the GUI of LabVIEW to start and a feature of the "Softmotion module" add-in to stop the timer. Next, the timer will stop when the system receives a response that the "Softmotion module" add-in feature has successfully executed. The elapsed time of execution is also shown in the GUI to record all the response times for the 2 different pneumatic cylinders simulation.

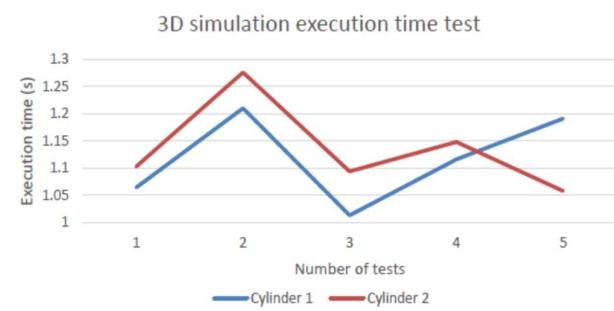


Fig. 9. Simulation execution time analysis

The execution times for 2 different 3D simulation actuators are performed 5 times and documented. The execution time values obtained are also not very consistent. The inconsistency might be due to system lag of the software or the PC hardware itself. Also, the speed of the motor created on the 3D model actuators can be adjusted.

D. Prototype execution time test

Additionally, the execution time of the real prototype of the system would also be tested by pressing the same interactive control buttons. This execution time is the time

taken for the pneumatic cylinder of the real prototype system to extend fully after pressing the interactive controls. The actuators of the prototype are wired to the PLC properly and turned on for this testing while the PLC is connected to the PC.

The execution time of this test will be different as a stopwatch will be used while also using the interactive control switch in the GUI of LabVIEW to activate the solenoid for the pneumatic cylinder. The elapsed time of execution for the 2 different pneumatic cylinders of the prototype which is measured with the stopwatch will be recorded.

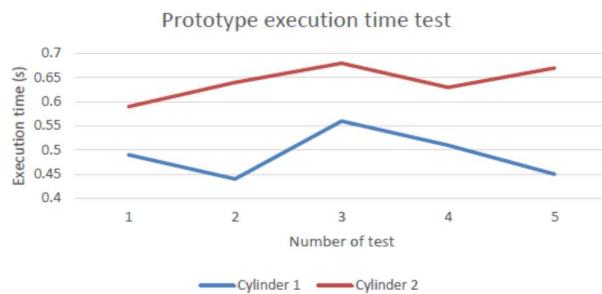


Fig. 10. Prototype execution time analysis

While referring to the graph in Fig. 10, the execution times for 2 different prototype actuators are achieved 5 times and tabulated. The execution time values obtained are considerably consistent. The huge difference between the pneumatic cylinder 1 and 2 is due to the load on cylinder 2. The pneumatic cylinder 2 is attached to a long load to push the block onto the conveyor belt. The load is subjected to friction on the foundation of the prototype. Also, the execution time of the actuators of the prototype is approximately twice as short as the simulation. However, the speed of the actuators in the simulation can be adjusted.

E. Efficiency/Reliability of prototype test

For the final test, the ability to complete 5 cycles of prototype application with a specific number of blocks will be tested. The concept of the prototype is to push blocks from a container to the flat surface part of the foundation, then allow a separate CNC milling machine to cut the block. Next, the block will then be pushed into a contraption that will sort the block and the milled part. Therefore, a complete cycle includes the extension of pneumatic cylinder 1, followed by the extension of pneumatic cylinder 2, and lastly the conveyor belt motor.

For the method of testing, the main GUI of the LabVIEW program will be used to control the actuators of the prototype. The interactive control button of output 100.00 which is connected to the first pneumatic cylinder will be pressed to extend and again to retract. Similarly, the button for output 100.01 will be pressed twice and the button for output 100.02 will also be pressed. When all 3 buttons are pressed, 1 cycle will be completed. The whole process is repeated 5 times for 1 block. The next test will start with 2 and then 3 blocks. When the block(s) has completely passed through the prototype and be sorted at the last contraption, it will be recorded as a success.

TABLE I. EFFICIENCY AND RELIABILITY TEST

Number of blocks, n	Efficiency/Reliability of the prototype to complete 5 cycle with n blocks
1	Completed with 4/5 success rate
2	Incomplete with 1/5 success rate
3	Incomplete with 0/5 success rate

During the testing, it is found out that the blocks are not able to be pushed out of the container when they are stacked in 2 and 3 blocks. The blocks are not too heavy but the friction between the container and blocks is quite high even with a pressure of 100 psi for the first cylinder. However, it is too risky to increase the pressure for the pneumatic cylinder because it broke the blocks partially during continuous testing.

IV. CONCLUSION

The 3D model design of a real prototype system with movement simulations using SOLIDWORKS and the development of the interactive GUI button controls using OMRON PLC are presented. The real prototype hardware with actuators are modeled using SOLIDWORKS. The actuator movement simulation of the 3D model has also been developed and controlled with the LabVIEW interface software. Furthermore, the virtual system with actual PLC and control of the real system are integrated to demonstrate the efficiency and reliability. Moreover, the efficiency of the virtual and real system control is highlighted using five different tests. The response time of the LEDs, the execution time of the actuators, and the efficiency of the prototype are all tested and observed the feasibility of the developed system.

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