

Remote Control of the FESTO MPS PA Compact Workstation for the Development of a Remotely Accessible Process Control Laboratory

<https://doi.org/10.3991/ijoe.v16i05.12809>

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Abstract—The technical education sector of the UAE adopts hands-on dominated curricula with the aim of meeting the industrial needs of highly qualified technical personnel with significant practical experience in their field. The utilization of remotely accessible laboratories is one of the technologies that is expected to have a significant role in improving the attainment of hands-on skills. This paper presents the design and implementation of a LabVIEW software interface to remotely control the FESTO MPS PA compact workstations. This workstation is commonly used as laboratory equipment and for training in the process-control field. To showcase the developed remotely accessible process control laboratory, Proportional-Integral-Derivative (PID) and ON/OFF controllers were designed and implemented on the system. The proposed remotely accessible process control laboratory offers practical and industrial training over the Internet. This feature could open doors for sharing the laboratory's resources between higher educational institutes of the UAE. Which is expected to result in the optimal utilization of the available resources. The proposed remotely accessible process control laboratory is expected to have a major cost reduction of the usually high education system cost through the efficient utilization of the available laboratory equipment.

Keywords—Remotely Accessible Laboratory, Process Control, Education and Training, PID Control, ON/OFF Controller

1 Introduction

In today's modern world of rapidly evolving technology, it is difficult to assemble and maintain a high-performance well-educated workforce without proper education and training. One of the challenges that hinder educational organizations' abilities to provide proper practical education and training is the cost of training equipment. Educational institutes within a country or a region could overcome this problem with the

use of remotely accessible laboratories. The sharing of laboratory resources through remote operations could result in the optimal use of equipment. This, in turn, will result in significant cost reduction. In the past years, various remote experiments and remote laboratories have been developed [1-13]. The vast majority of these studies gave training based on experimental setups in the Mechatronics field. The quantity of studies offering online training opportunities in the process control area is very limited. An internet-based remote-controlled robot was presented in [14]. This work was a crossover project through an international cooperative program situated in Japan, China, Thailand, and Taiwan. Williams et al developed a platform that allows remote access to photovoltaic laboratory equipment. Their proposed method enables users to access and remotely control experimental equipment located at Loughborough University [15]. The work in [16] described several advanced solutions for performing laboratory experiments over the Internet. These include the use of LabVIEW software and solutions based on the functionalities of modern web browsers. Berntzen et al programmed a PLC to control the operation of the laboratory system and used SCADA to monitor the process. The web interface was designed using Visual Studio, which allows users to access the lab and collect information about the experiment [17]. An analytical chemistry experiment is developed by using a headspace gas-chromatograph (GC) is presented in [20]. Virtual laboratory experimentation has been presented in [21]. A modular Internet-based undergraduate laboratory facility using commercially available hardware and software has been presented in [22]. This work features a built password control and user tracking, and simultaneously accessibility to multiple clients.

In this paper, LabVIEW software is used to develop a software interface that supports remote access to the process control laboratory at Abu Dhabi Polytechnic; specifically, the MPS PA Compact Workstation. The MPS PA Compact Workstation (MPS PA CWS) developed by FESTO Didactic is an educational system that is specially designed to meet a number of different industry-oriented training and vocational requirements. The system represents laboratory-scale equipment that resembles real industrial systems found in different fields including chemical industries, oil refineries, paper, and pulp factories. Furthermore, the MPS PA CWS can be used for training in topics such as programmable logic controllers, closed-loop control design, and fault finding and/or troubleshooting. The MPS PA CWS is shown in Figure 1. This workstation consists of several mechanical components, electrical components, sensors, and actuators. Please refer to the user manual for more information about the CWS [18].

The rest of the paper is organized as follows. Section 2 provides a brief description of the MPS PA CWS; Section 3 describes the LabVIEW programming of the software platform; system identification and control design are presented in Section 4; experimental results are demonstrated in Section 5; while the concluding remarks are presented in Section 6.

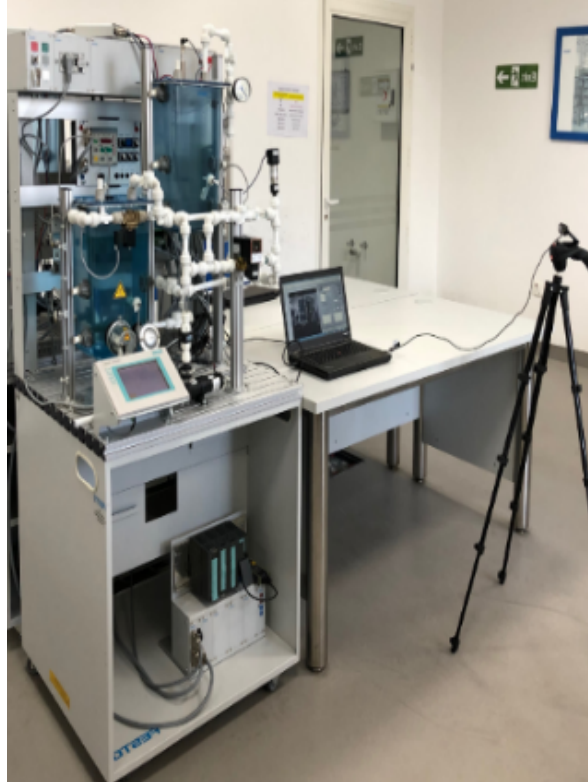


Fig. 1. FESTO MPS PA Compact Workstation.

2 MPS PA CWS System Description

2.1 System components

The MPS PA CWS combines four control loops which are level, pressure, temperature, and flow rate control loop. The actuators that are used in the system are centrifugal pump, proportional valve, and heating element. The sensors included in the MPS PA CWS are an ultrasonic sensor, flow rate sensor, temperature sensor, and a pressure sensor. These sensors are used for measuring the level, flow rate, temperature, and pressure, respectively. The MPS PA CWS also has multiple proximity sensors and float switches. The MPS PA CWS has a terminal connection with 24 pins. This connection allows communication between the MPS PA CWS and a personal computer by using the EasyPort USB interface card. The Components of the MPS PA CWS is shown in the P&ID given in Figure 2. A short description of the aforementioned components is given in Table 1.

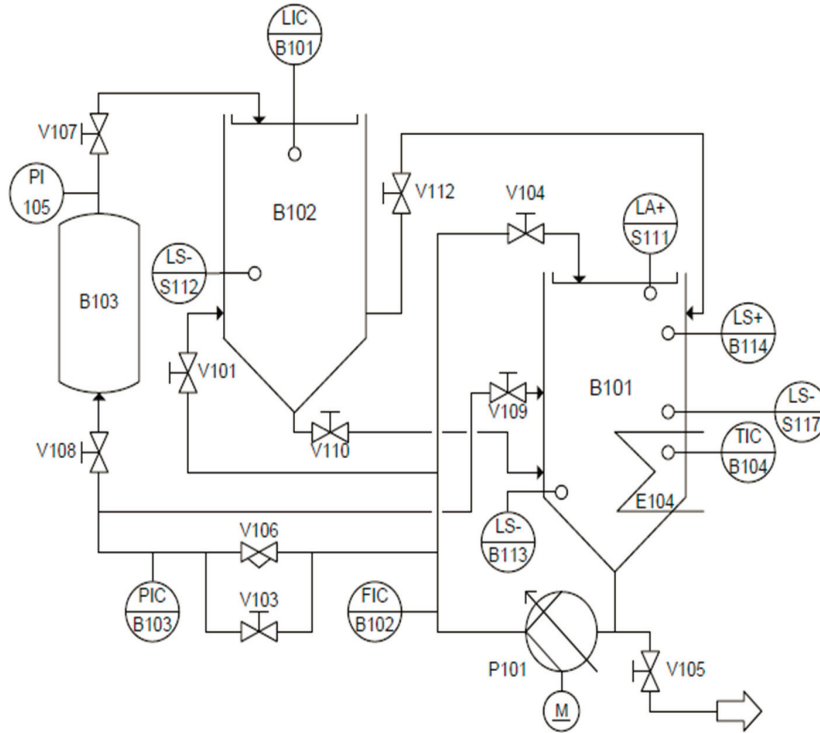


Fig. 2. P &ID for the FESTO MPS compact workstation.

Table 1. MPS PA CWS components description

Labels	Description
B101 and B102	B101 and B102 refer to the upper and lower tanks which are storing the liquid. Both tanks have a measurement scale to observe the liquid level
B103	Pressurized air tank
P101	Centrifugal pump
E104	Heating element that is used to increase the liquid temperature in the tank B101
V101, V103, V104, V105, V107, V108, V109, V110, and V112	Manual valves that control the flow rate through the pipes of the MPS PA CWS
V106	2/2 proportional valve for flow control
FIC/B102	Flow indicator controller
PIC/B103	Pressure indicator controller
TIC/B104	Temperature indicator controller
LIC/B101	Liquid-level indicator controller
PI/105	Pressure indicator
LS- B113 and S117	Switches for low liquid level
LS+ S111 and B114	Switches for high liquid level

2.2 Easyport USB data acquisition card

The EasyPort card, developed by Festo, allows bidirectional transmission of signals from sensors and to actuators. The EasyPort is supported by several software packages that are dedicated to the simulation and development of control applications such as Easy Veep, Fluid Lab-PA, and Fluid SIM [19]. The aforementioned software packages do not allow operators to create their own control algorithms. In this work, the communication interface between the PC and the USB EasyPort will be developed based on the ActiveX elements within the LabVIEW programming environment. The EasyPort communicates with the MPS compact workstation by connecting panels dedicated to handling digital and analog signals. Eight digital inputs and outputs of the card are connected to the MPS panel by two plug sockets with 24 contacts Syslink according to IEEE 488 standard. While the four analog inputs from sensors and two analog outputs to control the pump and the proportional valve of the MPS compact workstation communicate to EasyPort by a plug socket with 15-pin Sub D connector. Analog/digital conversion of these signals is performed with a resolution of 12 bits at a sampling frequency of 5 kHz [19]. The development of applications with EasyPort can be performed with three different methods as shown in Figure 3. ActiveX controls are used to interface with the EasyPort card because they offer accessible methods and events for communication with EasyPort modules when LabVIEW is used as a development platform. ActiveX controls are software blocks based on invoke nodes shown in Figure 4. These software blocks can be used by different components of a program to communicate with each other and reuse their code. ActiveX controls are built in COM (Component Model Object) which allows them to be used in other programming languages other than the one in which they were created, among these languages stand out C++, Java, and Visual Basic.

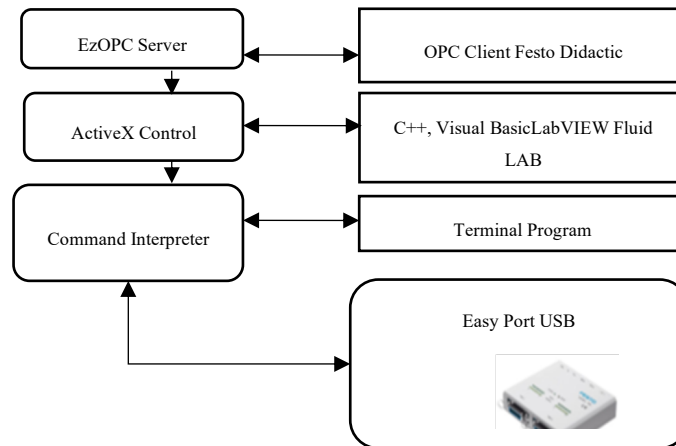


Fig. 3. Easy port software interfaces.

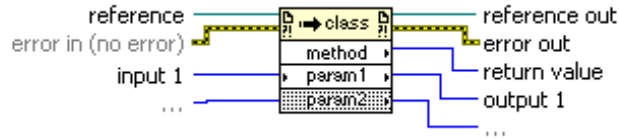


Fig. 4. Invoke Node.

3 LabVIEW Programming

This section describes the developed Virtual Instrumentations (VIs) used for operating the MPS PA CWS remotely over the Internet. Several LabVIEW VIs were created to manipulate the actuators and obtain information from the sensors of the MPS PA CWS as well as video streaming for the real-time monitoring of the stations.

3.1 Front panel and block diagram design

Front panel: The front panel of the designed LabVIEW interface is showing in Figure 5. The user can select the desired control loop from the “Control loop selection” panel with the level being the default option. The controller design is described in Section 3. The designed panel also allows the user to choose between PID and ON/OFF controllers. The controller selection is achieved by typing-in the number of the desired controller in the “Choose a Controller” panel. The user can also adjust the parameters of the selected controller such as the differential gain, proportional gain, integral gain, derivative gain, and sampling time. As can be seen in Figure 5, the front panel as accessed over the remotely using the Windows Internet Explorer browser. The front panel shows the experimental results on the graphs at the bottom left of Figure 5.

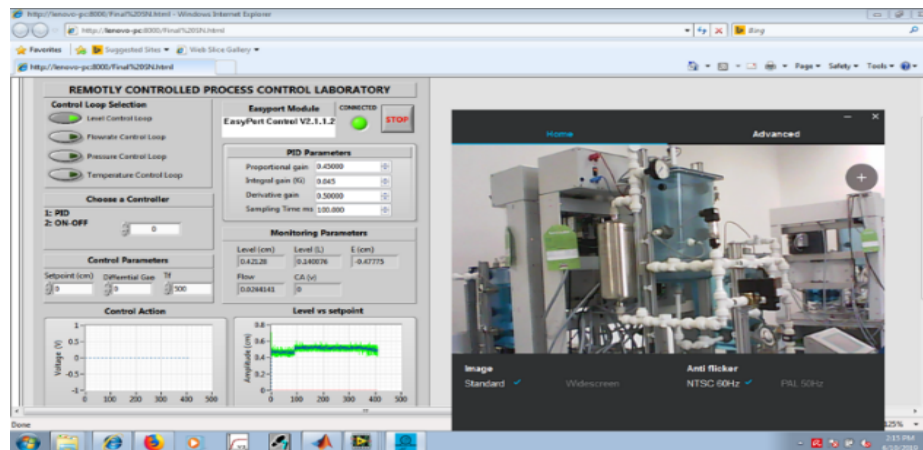


Fig. 5. Front panel of the remotely accessible MPS PA CWS LabVIEW interface.

Connect/disconnect to/from EasyPort: The invoke node “Connect” method of the FESTO ActiveX control is used in order to initiate the login phase. This method checks all serial ports found within the system for EasyPort modules as shown in Figure 6.

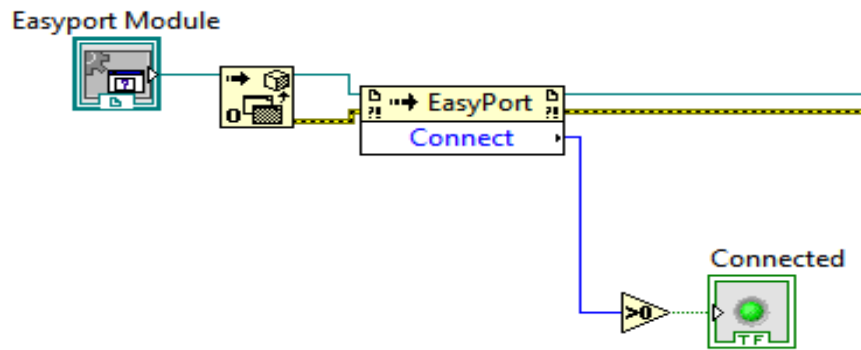


Fig. 6. Login to EasyPort.

Figure 7 shows the “Disconnect” invoke node method used to accomplish disconnection from the EasyPort module.

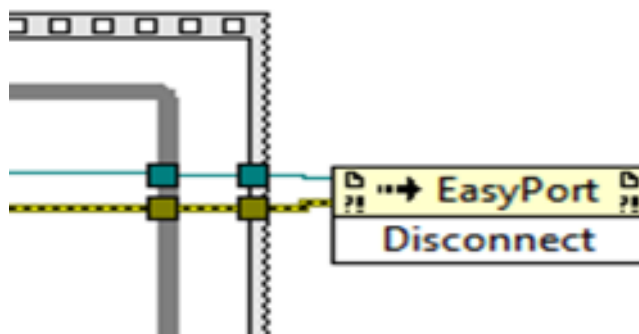


Fig. 7. Disconnect from EasyPort.

Analogue sensor reading: The mapping of the output voltage of the level sensor located in tank B102 is shown in Figure 8. The reading of the level sensor is obtained using the Invoke Node method with GetAnalogOutput0 action. The output of the four analog sensors is an integer between the values 0 to 32767 due to the 12-bit resolution analog/digital conversion. In order to map the output voltage to a value between 0 and 10 V, the sensors’ output is divided by 3276.7. Finally, some mathematical operations were used in order to convert the reading to the desired unit which is cm in the case of the level sensor.

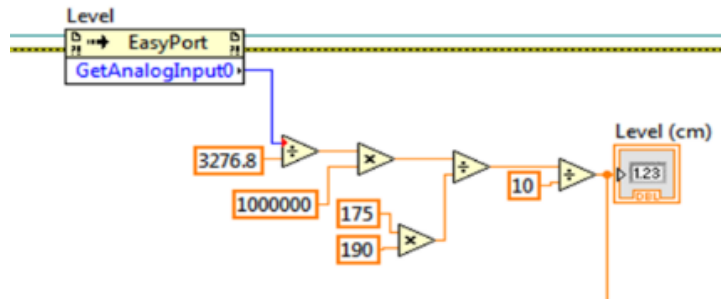


Fig. 8. Reading the signal of the level sensor.

The same invoke node method is used for reading the flow rate, pressure, and temperature sensors, by changing the action to GetAnalogInput1, GetAnalogInput2 and GetAnalogInput3 respectively. Figures 9, 10, and 11 shows the LabVIEW diagrams that are used for reading the flow, pressure, and temperature sensors, respectively.

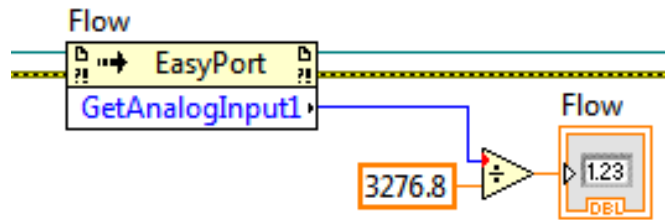


Fig. 9. Block diagram for reading the signal of the flow rate sensor.

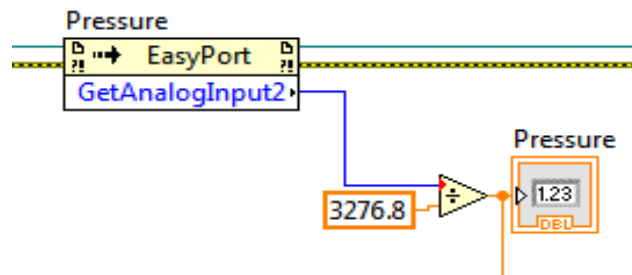


Fig. 10. Block diagram for reading the signal of the pressure sensor.

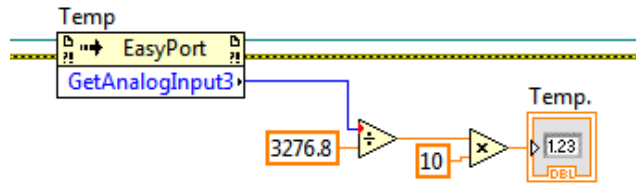


Fig. 11. Block diagram for reading the signal of the temperature sensor.

Sending signals to the actuators of the MPS PS CWS: The Invoke Node method with SetAlanogOutput0 illustrated in Figure 12 is used to set the desired supply voltage for operating the pump. The proportional valve voltage is set in a similar way by changing the method in the Invoke Node to SetAlanogOutput1, see Figure 13.

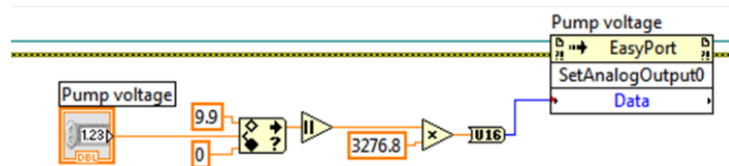


Fig. 12. Set the Centrifugal Pump Voltage.

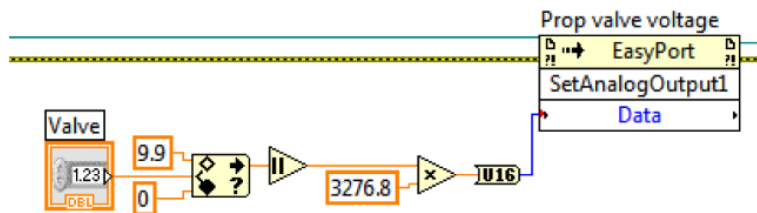


Fig. 13. Set the Proportional Valve Voltage.

3.2 Remote operation

The remote control is accomplished through the web server tool of LabVIEW which allow guests to log in to a local host and remotely operate the MPS PA CWS. The system user can monitor the operations in real time through a camera that is mounted on the system, as shown in Figure 1.

Web publishing: This subsection addresses the implementation of a web server on LabVIEW software. The web server is needed for the remote access to the MPS PA CWS. Figure 14 is an explanatory diagram of the process instrumentation and remote monitoring to be carried out on the MPS CWS. The remote monitoring is realized by the IP camera that is used by the operator to observe the state of the MPS PA CWS. Therefore, it is necessary to explain the configurations and concepts of certain related elements of hardware and software as follows.

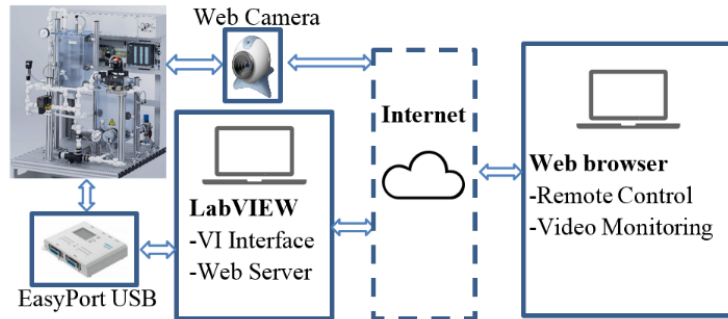


Fig. 14. Explanatory Diagram for the Remote Control and Monitoring of the MPS PA CWS.

Implementation of Web server: The main requirement for the configuration of the web server within LabVIEW VI is to have a functioning online version of the front panel used to control the MPS PA CWS. First, the "Tools" option in the LabVIEW toolbar is selected. Then one has to choose "Options" and finally select "Web Options"; a window opens as displayed in Figure 15. In this window, we proceed to enable the "Enable Remote Panel Server" option and then configure the server communication port. After configuring the server port, "Web Publishing Tool" option is selected, a window will open as shown in Figure 16, where the target VI to be published on the web server is selected.

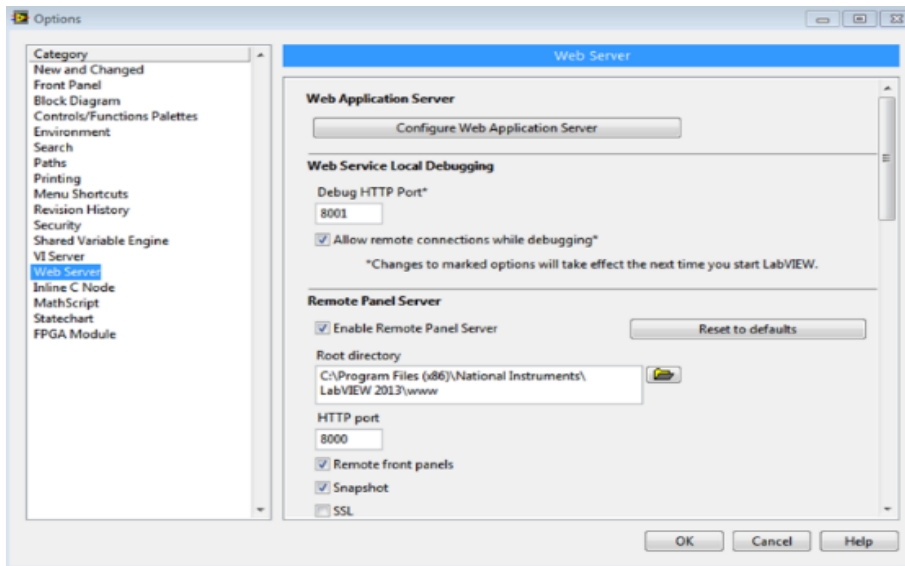


Fig. 15. Window Options Web Server in LabVIEW.

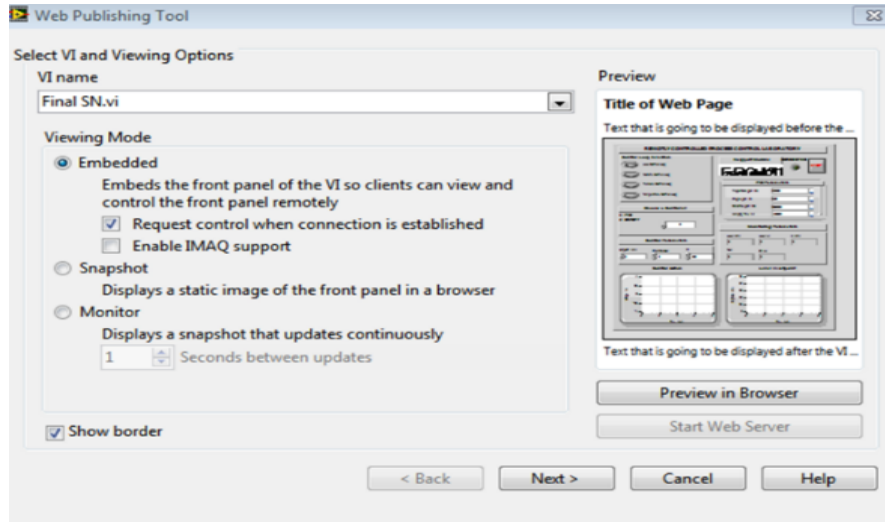


Fig. 16. Web Publishing Tool Setup.

One can also configure the type of interaction between the server and client, enabling or disabling the "Request Control when the connection is established" option. If this option is enabled, the customer must request control of the VI after the connection, otherwise the user takes control of the VI immediately once connected to the server has been established. Finally, the window shown in Figure 17 will appear, this window specifies the address where the file will be saved on the computer that will serve as a server and also the route used to enter the control panel of the plant via the web.

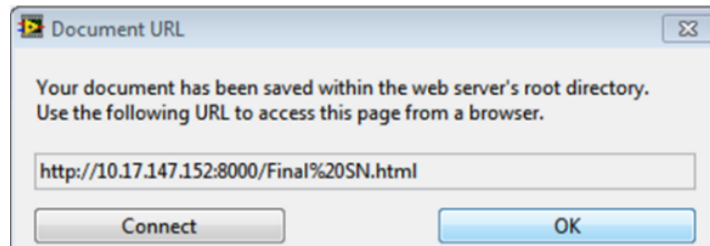


Fig. 17. Web Publishing Tool in LabVIEW URL.

4 System Identification and Control Design

4.1 System identification

It is well known that the plant mathematical model should resemble the dynamics of the system as close as possible. This is desired in order to achieve a good controller response as the controller is designed based on the obtained model. The system in hand

is a laboratory scale; therefore, there will be no significant change in the system's dynamics. Thus, the system can be approximated by a single transfer function. The MATLAB system identification (Ident) tool is used to estimate the system transfer function from open-loop experimental data. The following process was used to obtain the mathematical model for the level, flow rate, pressure, and temperature control loops. However, only the level control loop system identification is presented here. The centrifugal pump was operated on open-loop mode with Pseudorandom Binary Sequence (PRBS) input. The PRBS was chosen because it persistently stimulates the system; i.e. the signal PRBS provide sufficient energy to the process to overcome the noise and disturbances. In addition, the PRBS signal operates between two random fixed limits, and when injected into the process it excites the fast and slow process dynamics. The PRBS is shown in Figure 18.

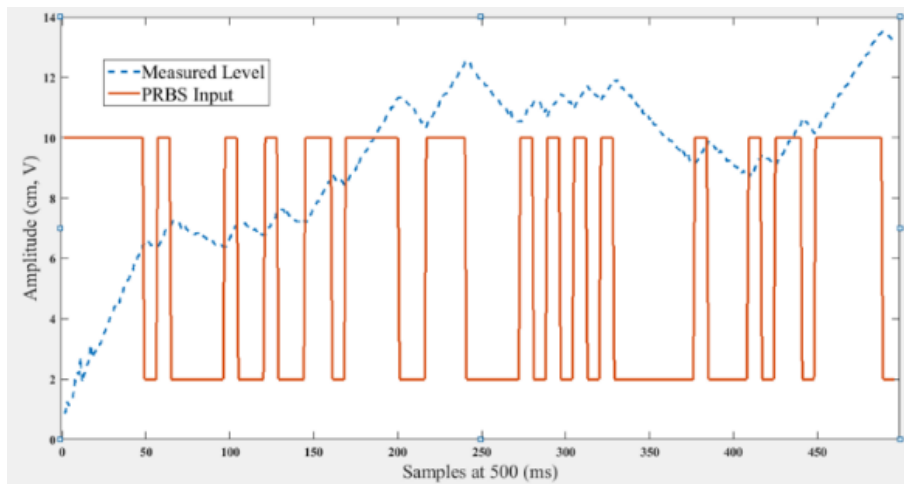


Fig. 18. PRBS input and the measured level.

The liquid level on the upper tank is sensed with the ultrasonic level sensor. The PRBS input and the sensor output are logged in an excel file that is used with the Ident tool for obtaining the system transfer function. The system identification window is shown in Figure 19, after importing the time-domain data for the experiments which are the PRBS input and the measured level.

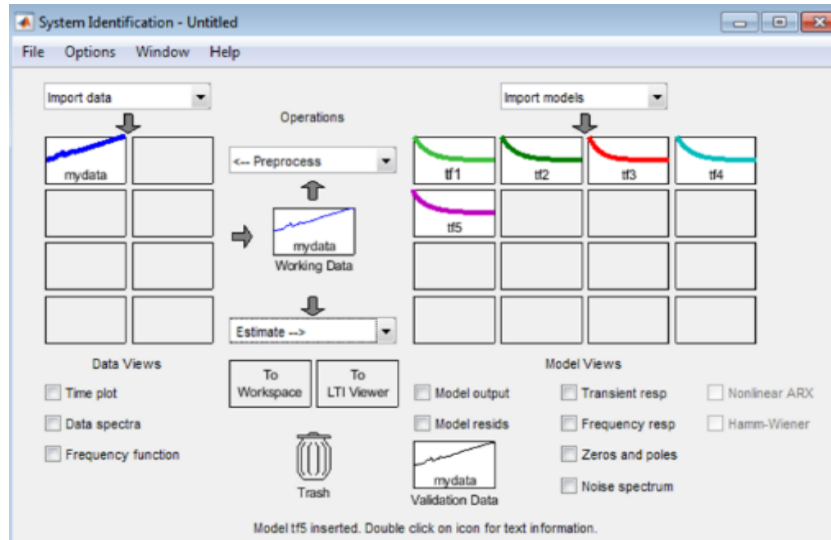


Fig. 19. System transfer functions estimation with MATLAB System Identification Tool.

The obtained system model is validated as follows; the validation process starts by dragging the input signal to the box "Validation Data" on the main screen of the system identification tool. Then by selecting "Model Output" which will open the window shown in Figure 20. Figure 21 shows the transfer function estimation report for the best fit and Figure 22 shows the output of the transfer function with the highest confidence level along with the experimental data.

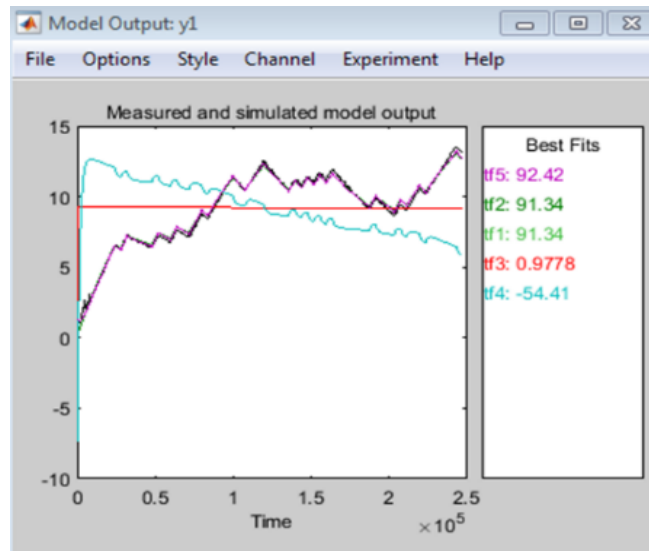


Fig. 20. Validation of the obtained transfer functions.

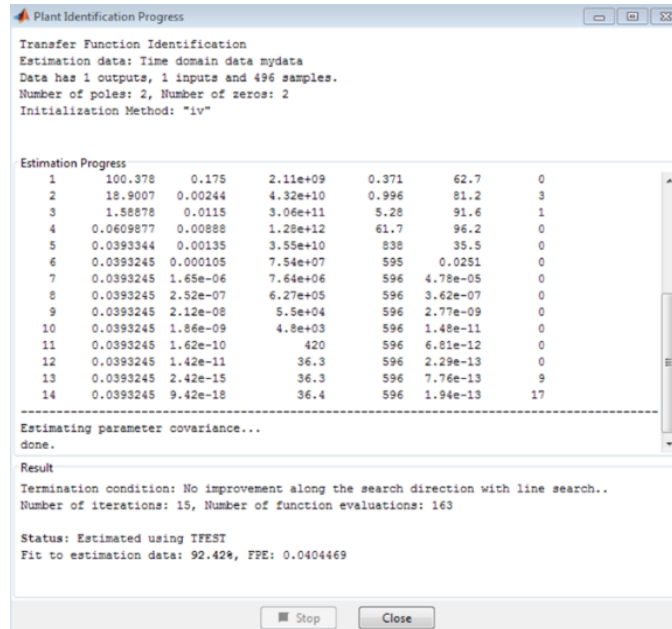


Fig. 21. Transfer function estimation report.

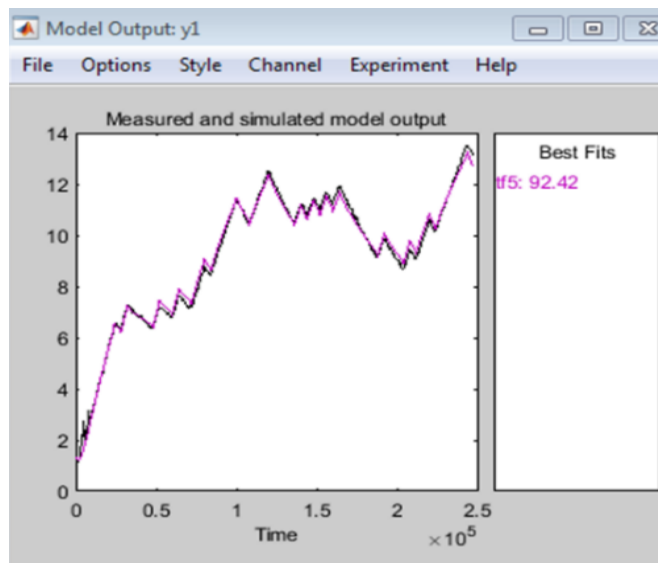


Fig. 22. Real system output vs. the output of the system model with the best fit.

The maximum rate of 92.42% overlap is a transfer function of 2 poles and 2 zeros. The transfer function exported to MATLAB Workspace is given in equation 1. The system identification results are summarized in Table 2.

Table 2. Confidence Values Obtained with MATLAB Ident Tool

Step input parameters		Percentage				
Amplitude (v)	Sampling Time (ms)	1 Pole	1 pol, 1 zero	2 poles	2 poles, 1 zero	2 poles, 2 zeros
2-10	500	91.34%	91.34%	0.9778%	-54.41%	92.42%

$$G_p = \frac{-0.014s^2 + 3.436e - 5s + 1.214e - 8}{s^2 + 0.0004s + 5.834e - 9} \quad (1)$$

4.2 Control design

ON/OFF controller: The ON/OFF controller is a digital controller, which is the simplest form of control. The ON/OFF control action turns the pump ON or OFF based on the level setpoint. The output frequently changes according to actual level readings. To prevent rapid switching of the control action from happening, a level band called hysteresis is created between the ON and OFF operations. The implemented ON/OFF controller is shown in Figure 23.

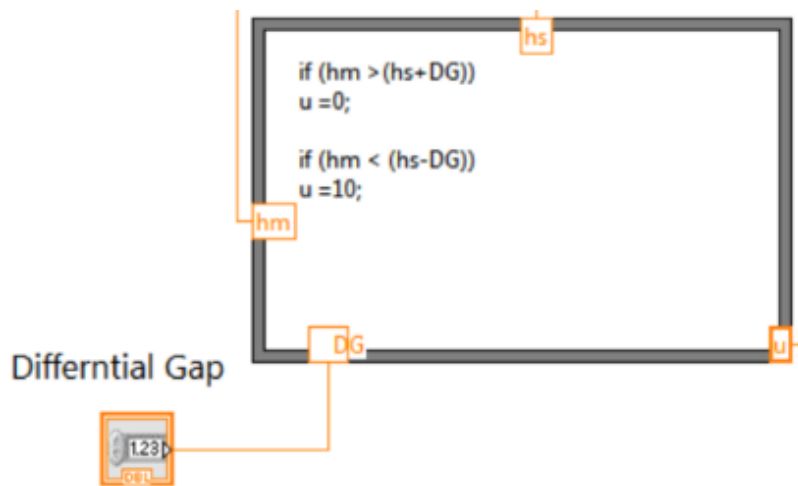


Fig. 23. ON/OFF controller implementation.

PID controller: The MATLAB Control System Designer Toolbox provides multiple options for the automatic tuning of PID controllers. For example, controllers can be tuned using classical tuning methods, graphically by varying the root locus, or the frequency responds. Figure 24 shows the main screen of the Control System Designer Toolbox. The system transfer function obtained in the previous section is imported to the Control System Designer Toolbox and the automatic PID tuning with robust response time is used to obtain the PID compensator transfer function as shown in Figure 25.

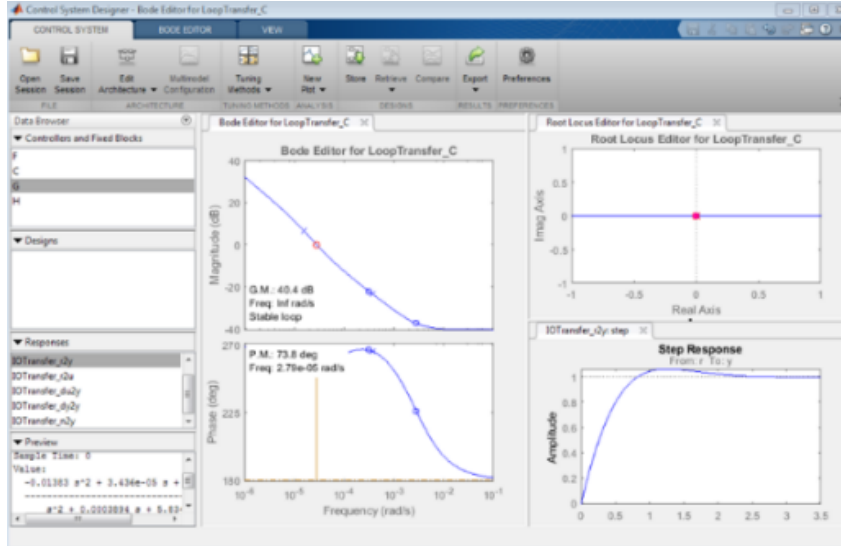


Fig. 24. Control system designer toolbox main window.

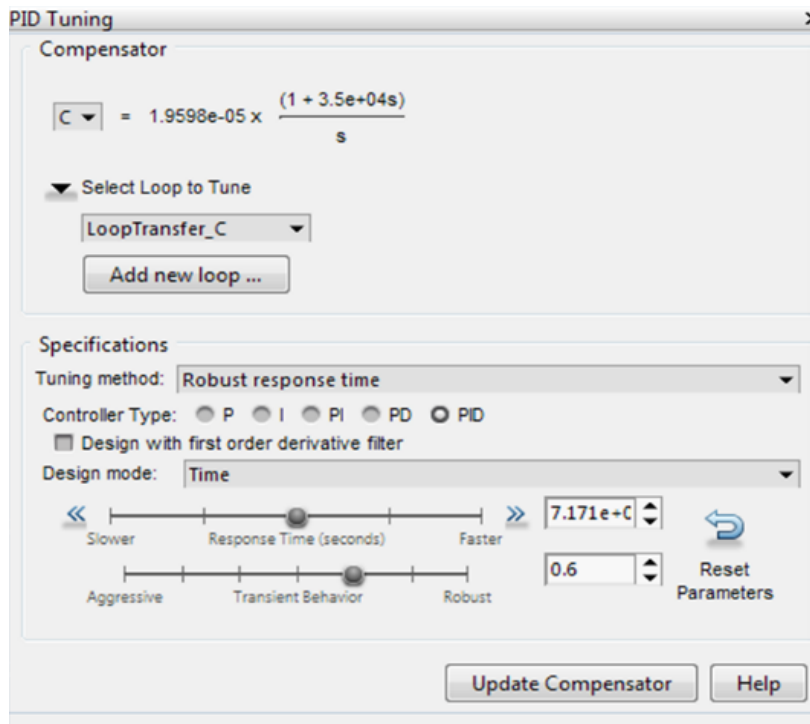


Fig. 25. Control system designer PID tuning window.

The resulted transfer function is given in Equation 2.

$$G_{PID} = \frac{1.9598e-05 (1+3.5e+04s)}{s} \quad (2)$$

The values of the controller gains are $k_p = 0.45$, $k_I = 0.043$ and $k_D = 0.5$. These values were obtained from fine-tuning after implementing the designed gains on the system. The implemented discrete form of the PID controllers is given in Equation 3.

$$u_k = u_{k-1} + k_p (e_k - e_{k-1}) + k_i T_s e_k + k_d \left(\frac{e_k - 2e_{k-1} + e_{k-2}}{T_s} \right) \quad (3)$$

The implemented PID controller in LabVIEW is shown in Figure 26.

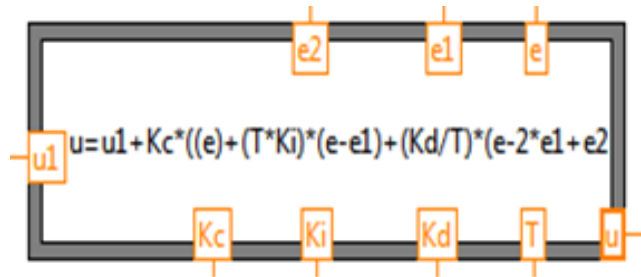


Fig. 26. PID controller implementation.

5 Experimental Results and Discussions

The PID and ON/OFF controllers that were designed in the previous sections were implemented on the developed software interface. The experiential results for the ON/OFF controller and the PID controller are presented in this section. The experimental result for the ON/OFF controller is shown in Figure 27. The setpoint is 8 cm and the differential gap is set to 2 cm. The ON/OFF controller is operated as follows: the ON/OFF controller is selected by typing number '2' in the "choose a controller" panel. Then, the setpoint and differential gap values can be selected.

The PID controller for the level control system is operated as follows: the PID controller is selected by typing number '1' in the "choose a controller" panel. The PID controller parameters are selected and can be tuned online as desired; then, the value of the setpoint is selected. In the provided example, the setpoint was chosen to be 8 cm. The experimental result for the PID controller is depicted in Figure 28. The maximum overshoot is 10% and the settling time is 10 sec.

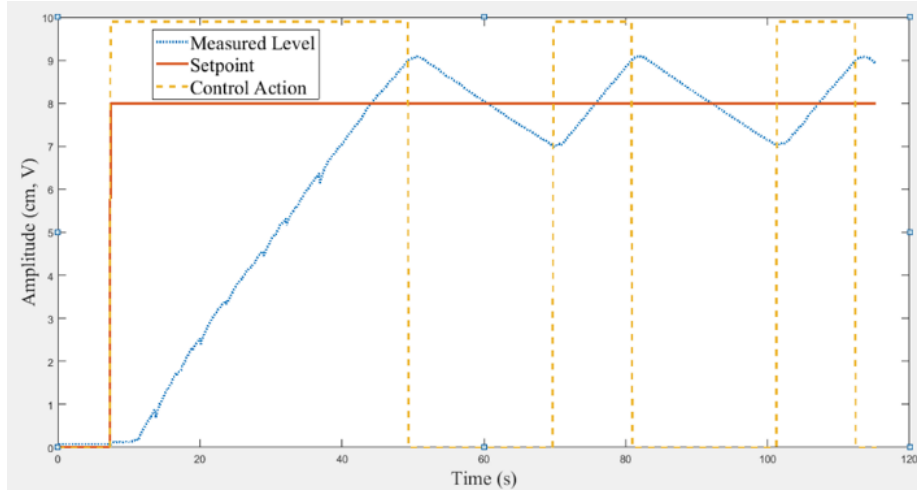


Fig. 27. Experimental results for ON/OFF controller.

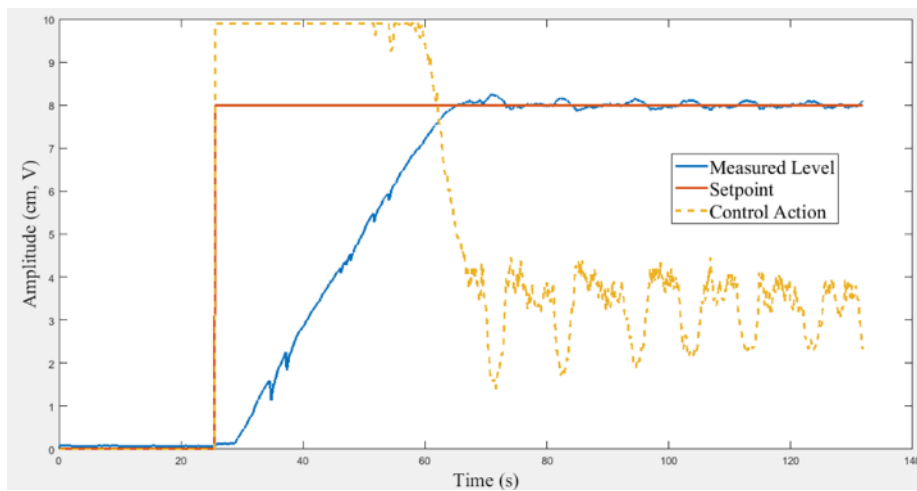


Fig. 28. Experimental results for PID controller.

6 Conclusion

In conclusion, this paper presented a special online experimental platform that allows remote access to the FESTO MPS PA CWS used for education and training in the process control and the mechatronics fields. Custom-built LabVIEW VIs were used to interface with the MPS PA CWS through the EasyPort data actuation board. After designing the components that allow reading the sensors of the MPS PA CWS and sending data to its actuators; PID and ON/OFF controllers were implemented on the system. The designed platform is published using the Web Server tool of LabVIEW to allow

remote access while viewing the system operations in real time through a camera that is mounted on the system. The proposed remotely accessible process control laboratory can be used to conduct online experiments and /or training to students at other universities in the UAE. In addition, this platform is expected to result in a significant cost reduction and efficient utilization of the available laboratory equipment at IAT.

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Article submitted 2019-12-18. Resubmitted 2020-01-15. Final acceptance 2020-01-17. Final version published as submitted by the authors.