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Computer-Based Control for Chemical Systems Using LabVIEW® in Conjunction with MATLAB®

Syamsul Rizal Abd Shukor, Reza Barzin and Abdul Latif Ahmad
*University Sains Malaysia,
 Malaysia*

1. Introduction

Current trend and characteristics in chemical industries has become more complex, hybrid and intensified in nature thus requiring faster and more powerful control systems to perform adequate control action for optimal performances (Charpentier, 2005). The time would not be more suitable to accommodate this advancement in the chemical industries with the existence of more powerful computer technologies either hardware or software. This development of more advanced and powerful computer architecture provides a better alternative to address the problems of performing optimally for the state-of-the-art chemical industries. Thus, computer-based control systems become the inevitable platform for fast, precision and close control of chemical processes. The advanced, powerful and user-friendly programming environment enables the process control engineers to easily design appropriate controller with minimal time and at lower cost, eventually implementing the designed controller directly on the actual systems via these tools. MATLAB® and LabVIEW® are amongst the most powerful and useful software that can be extremely helpful in this regard. MATLAB® is a very powerful mathematical tool, which enables us to use its powerful controller design toolboxes and also perform simulation in SIMULINK® environment with ease. Nonetheless, interfacing the control equipments such as measurement devices and control valves via MATLAB® is not an easy task. In contrast, LabVIEW® is among the best available software for communicating with the hardware in PC based systems. Utilising LabVIEW® facilitates easy data acquisition from the hardware and sending the corresponding signal to the final control element.

The idea of incorporating the two software for the computer-based control system would enable us to have an easy data acquisition (getting signal from all measurement devices and processing the signal to the desirable form) using LabVIEW® and then the signal is transferred to MATLAB® which conventionally acts as the controller to perform control calculation. Finally, the output signal from the controller is transferred back to LabVIEW® software to be applied to the final control element to perform adequate corrective action. In order to connect these two software, there are number of toolboxes in LabVIEW® which can help the user to easily connect them based on the needed environments. For example, using SIMULINK Interface Toolkit (SIT), LabVIEW® can easily communicate with SIMULINK environment in a continuous mode.

The proposed combination of these two powerful software not only can help researchers to design and implement their designed controller in various forms in a very short time but

also in some cases it facilitates operation under conditions that might not be possible using conventional systems. For example, controlling of miniaturized intensified systems is a very challenging issue (Abd Shukor and Tham, 2004, Etchells, 2005) where traditional control approaches were found to be very difficult in achieving sufficiently fast control (Luyben and Hendershot, 2004, Bleris et al., 2006) which is due to the sampling speed limitation of the industrial controllers and slowness of the mentioned systems. However, using the proposed combination software in tandem, we have the opportunity to choose a wider range measurement of the analytical devices and additionally the controller is not restricted to specific sampling range and even more important, the same controller can be used for both simulation studies and actual controller (because the developed controller in MATLAB® is used for both parts)(Barzin et al., 2010).

This chapter will provide some insights of the proposed utilization of the two software (MATLAB® and LabVIEW®) for proper control of a microreactor-based miniaturized intensified system. An overview of the designed miniaturized intensified systems will be described and followed by the description of traditional control method limitations on the control of the described system. Then, the structure of the proposed system is described in order to show the data flow on the system. This is followed by interfacing the control components with LabVIEW® and the required low level programming steps. Then, controller design in MATLAB® and SIMULINK as well as the data flow between LabVIEW® and SIMULINK® are discussed in detail and finally, the controller performance of the system using the proposed system is presented which shows the successful implementation of the proposed system.

2. Overview of the microreactor-based system

The designed system as presented in Fig. 1 consists of a single slit interdigital micro mixer (SSIMM) with volume of 0.23 ml as the reaction chamber (A) which is capable of performing very fast reactions. Having very small holdup, residence time can vary from fraction of a second to 3 seconds which can be extremely useful for fast reactions or reactions that need precise residence time in order to achieve high selectivity. In this study, a simple weak acid (phosphoric acid, 0.1 Molar) and strong base (sodium hydroxide, 0.1 Molar) reaction will be taken as the case study.

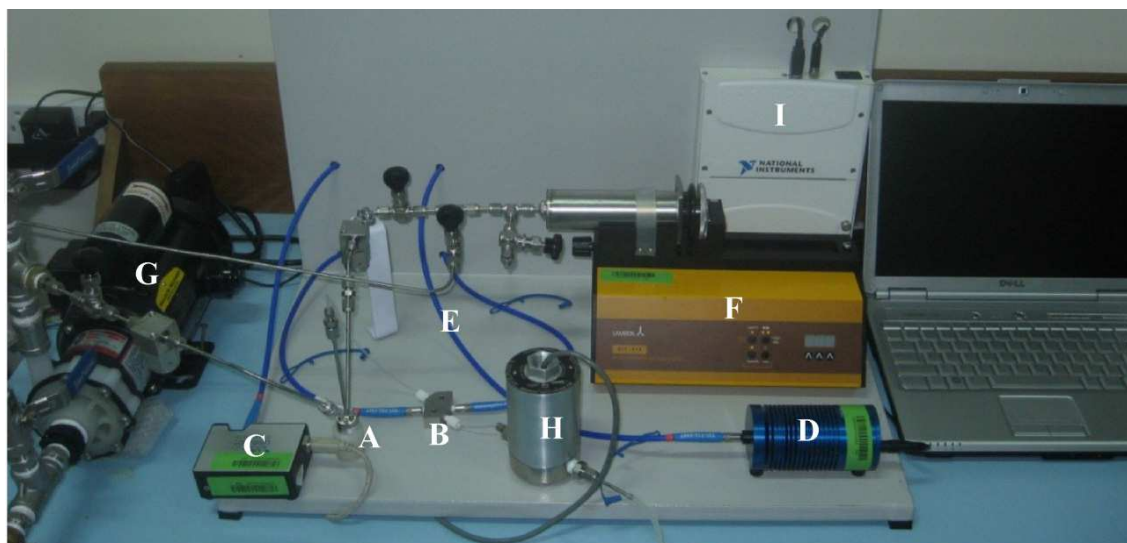


Fig. 1. Experimental rig and components

In order to perform measurement of the reactor outlet, the reaction part is connected to the Z-flow through cell (B) which is connected to a USB 2000+ (Ocean Optics, USA) spectrometer (C) and a HL-2000 (Ocean Optics, USA) tungsten halogen light source (D) via optical fibers (E). The spectrophotometric setup is used to perform online pH measurement from the reaction product every few milliseconds (Barzin et al., 2010). A 100 ml stainless steel LAMBDA VIT-FIT syringe pump (Lambda Laboratory instruments, Switzerland) (F) is used as the final control element in order to manipulate the flow rate of the injected strong base into the SSIMM microreactor. A centrifugal pump (G) is used to provide continuous and pulsation free flow of the weak acid into the micro reactor. In order to measure the total flow rate which passes through the micro reactor, a FMTD4 nutating micro flow meter (DEA Engineering Company, USA) (I) is used. A NI DAQ-Pad 6015 (J) is also used in order to carry out data acquisition from the micro flow meter and to send the controller output signal from the controller to the final control element (syringe pump).

3. Limitations of traditional control systems

Traditional chemical industries usually operate in a high residence time (in the range of few minutes to few hours), hence, conventional measurement system which having much lower residence time than the process able to provide adequate measurement for optimal control of the process. This is not the case for miniaturized intensified system as the conventional measurement system would definitely have higher residence time than the intensified process (Jones and Tham, 2006). This would then hamper the control system to work efficiently as the measurement is very slow in response to the fast reaction in the micro system. Thus, such system necessitates a much faster measurement systems and controllers to provide sufficiently fast measurement. Having a controller with a sampling time of 10 seconds for industrial systems would be considered fast enough whereas for miniaturized intensified systems, it is considered very slow and makes the system difficult to control.

This can be concluded that miniaturized intensified systems need some requirements in order to be able to be controlled properly. For instance, the controller should have a very high sampling rate, the measurement also should be capable of performing measurement every few milliseconds and eventually the obtained results from the measurement need to be transferred to the controller in a very high transfer rate. The proposed spectrophotometric measurement system can provide a very fast measurement. However, not having a suitable control system and also a mean to transfer the collected measurement data to the controller and back to the final control element would hamper a successful control performance to be achieved. To overcome this problem, LabVIEW® provides an excellent solution as it is amongst the powerful software for interfacing and communicating with instruments.

4. Software design

The feedback control loop was built in SIMULINK®, MATLAB® 2006a software. A number of simulations were carried out to study the performance of the designed controller at different controller settings. To better evaluate the controller performance on real system, it is essential to use exactly the same controller on the experimental setup. On the other word, it is preferable to use MATLAB as our controller. However, as mentioned earlier MATLAB has a very limited functionality for interfacing with the hardware. For instance, PC based

data acquisition with MATLAB® is limited to the hardware supported by the MATLAB® DAQ toolbox. Moreover, a number of complicated steps have to be taken to communicate with the hardware.

Thus, in order to use MATLAB® as the controller and also easily communicate with the components of the rig, the current study uses MATLAB® software to build the feedback control loop and LabVIEW® software to communicate with the hardware. A low level programming using SIT were used to provide communication between MATLAB® and LabVIEW®. The following sections show the needed for both to interface the hardware and communicate with the designed controller in MATLAB® environment using LabVIEW® software.

5. Interfacing rig components with computer using LabVIEW®

In the case study, syringe pump, spectrophotometer, flow meter and NI-DAQ, are interfaced with the embedded controller in the computer. This can be clearly seen in Fig. 2 depicting the interfacing of the experimental rig with the supervisory control system.

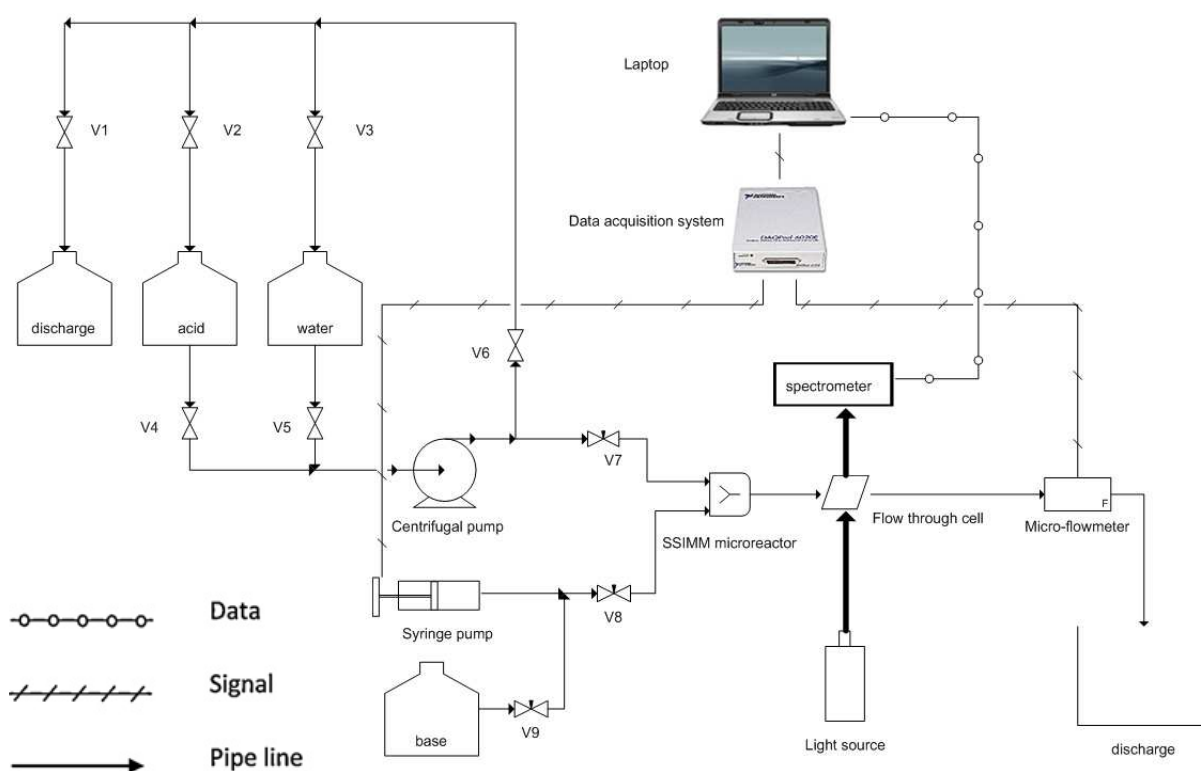


Fig. 2. Schematic diagram of the designed and developed rig

As can be observed from the figure, syringe pump and micro-flow meter are using analog signals to communicate whereas the spectrophotometer uses digital signals to send measurement results to the computer. NI USB-6009 (National Instruments, USA) data acquisition system has been chosen which is amongst the basic products of National Instrument. It can be seen from Fig.3, NI USB-6009 offers analog input with positive and negative polarity suitable for communicating with the flow meter and it also provides two analog out which can be used for the syringe pump.

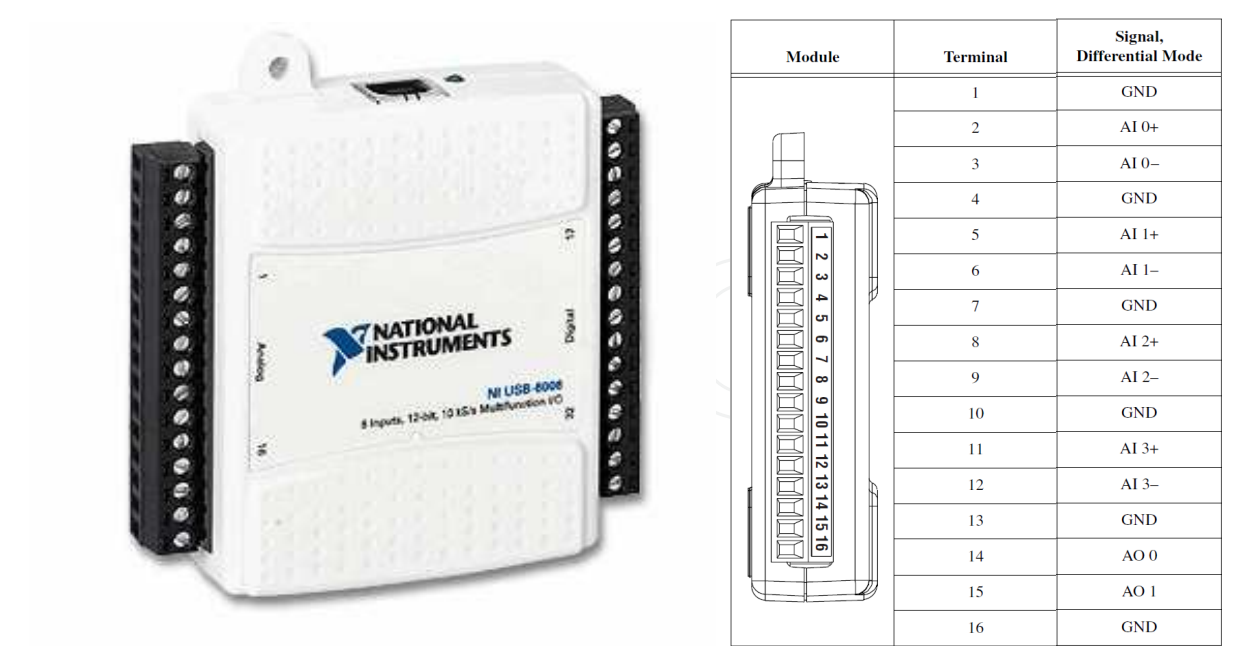


Fig. 3. USB-6009 with corresponding terminals (NI, 2008)

The NI-DAQ can be connected easily to the computer using USB cable which is automatically detectable and do not require installing. In order to setup the connected NI-DAQ, *Measurement and Automation Explorer* (MAX) is required. Launching the MAX provides access to all National Instruments devices as shown below:

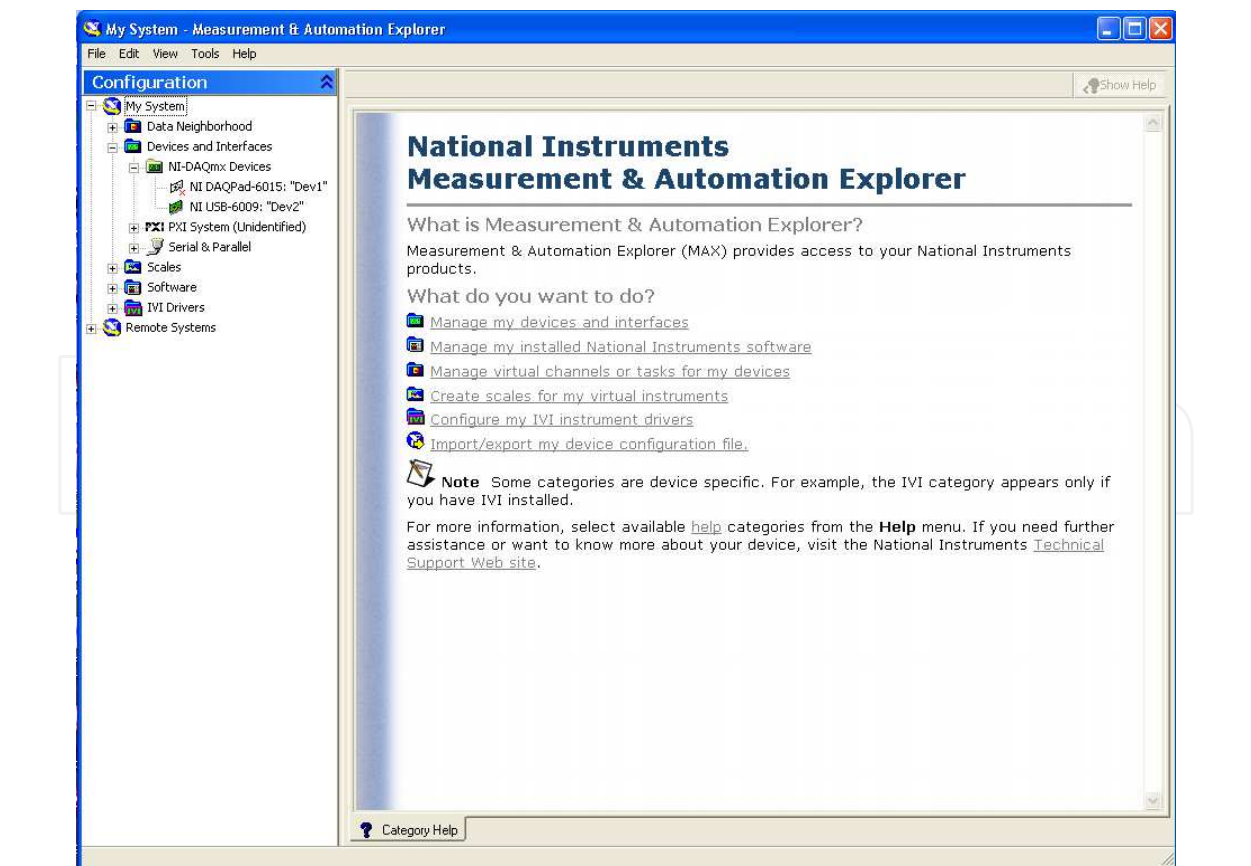


Fig. 4. Measurement and automation explorer showing the connected DAQ.

The connected NI device can be observed in MAX as NI-USB 6009 is shown in green color which means that it is connected properly. Further DAQ setting can be done later at the programming stage which will be discussed in the following.

5.1 Interfacing the syringe pump

The pump offers multiple control options such as RS232 and RS485 or through analog signals (0-10 V or as an option: 0-20 mA or 4-20 mA) which is one of its big advantages over similar products. Based on the available connectors on the DAQ system, voltage signals are selected to manipulate the flow rate of the syringe pump.

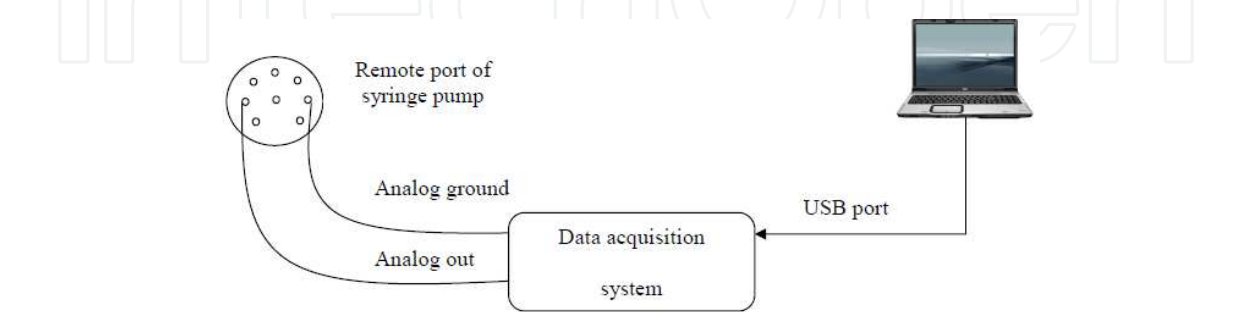


Fig. 5. Electrical connections from computer based controller to the data acquisition system and to the syringe pump

In order to connect the syringe pump to the DAQ, we need to identify the signal type and also the corresponding connector. This can be done easily using DAQ assistant and selecting the proper output type and also the range of applicable voltage for the pump as can be observed in Fig.6.

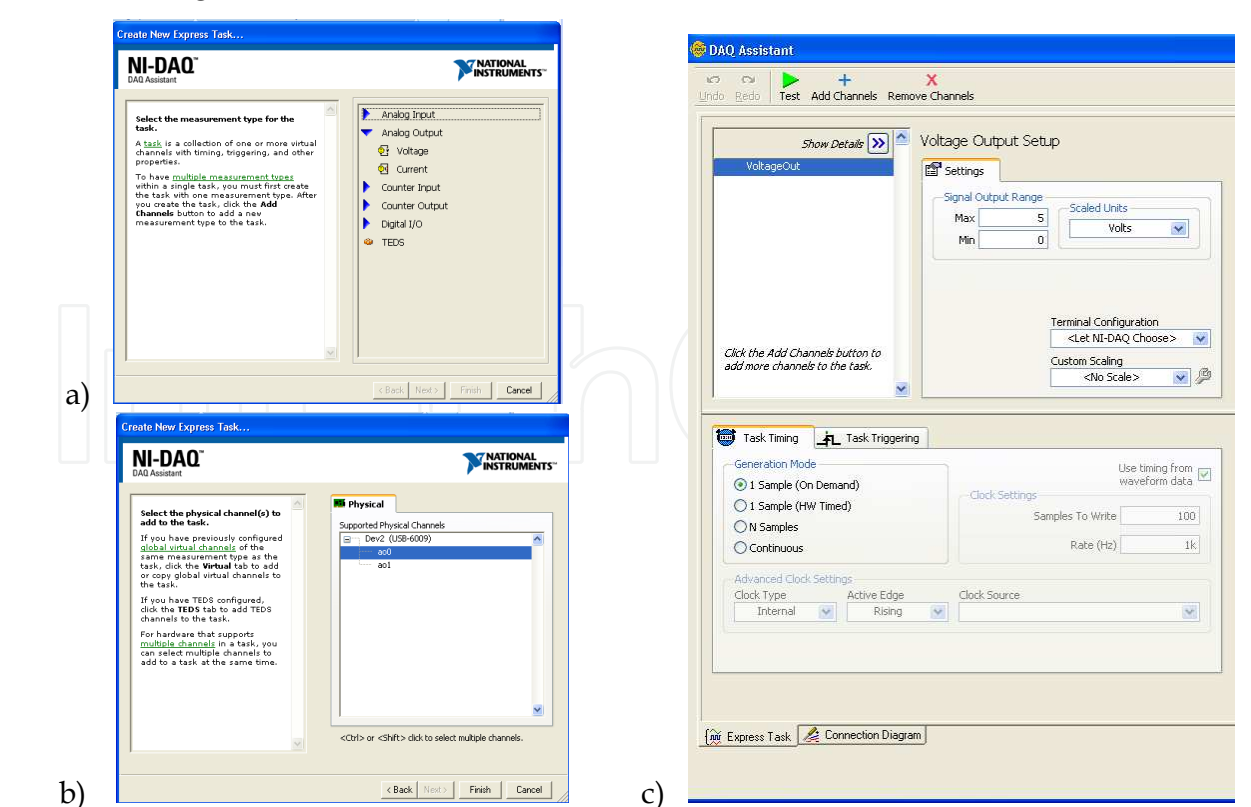


Fig. 6. Syringe pump interfacing steps, a) signal type b) connector selection c) signal settings

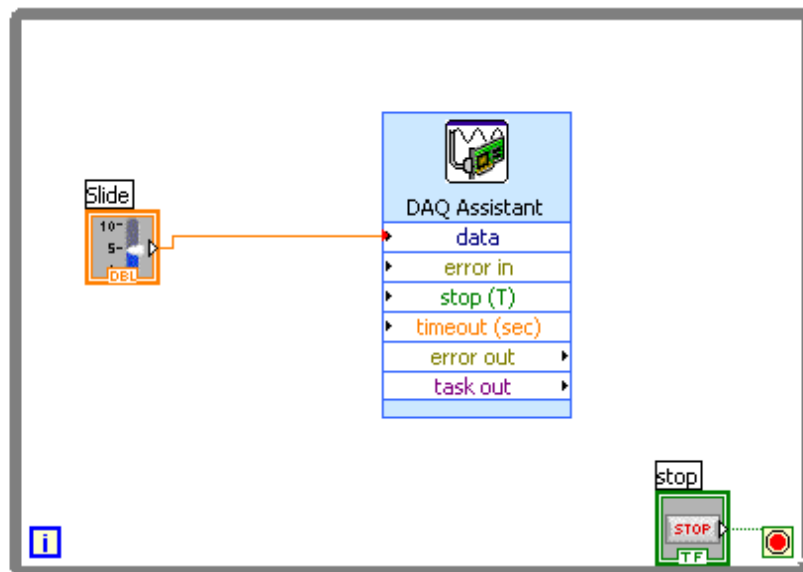


Fig. 7. DAQ connected to a slide bar to test the syringe pump.

Then, using a *while loop* and a slide bar we can actually check if the desired signal is being received by the syringe pump as shown above. This shows that LabVIEW® easily facilitates sending the desired signal to the final control element by just doing 4 simple steps.

5.2 Interfacing the micro-flow meter

In this study, FMTD4 nutating micro flow meter (DEA Engineering Company, USA) was used which has an operation range of 1-250 ml/min in order to measure the flow rate of the system. The flow measurement principle is shown in Fig. 8.



Fig. 8. Flow measurement principle for the flow meter. Pistons movement inside the chamber while the liquid passes through the flow meter (DEA, 2008)

The pistons inside the flow meter chamber rotate in a cycle motion while the flow passes through the flow meter. Each cycle displaces approximately 0.02 ml. Signal detection is accomplished by light interruptions of a photo emitter/detector device. A ferromagnetic wire tracks the magnet in the nutator (through a pressure tight barrier) causing these interruptions. The interruptions are electronically shown as sine waves. The obtained sine waves can be conditioned by conventional electronic means to provide a square wave output as shown in Figure 9. However, the flow meter is not designed to directly measure flow rate and it only gives raw data using 5 volt pulses for each cycle. Therefore, a code need to be developed in LabVIEW® environment to calculate the actual flow rate based on the obtained pulses from the flow meter.

In order to address the problem, NI-DAQ receives the analog voltage in pulse form as can be observed in figure 9 then, these number of pulses are calculated every seconds and consequently, the flow rate passing through the flow meter. The appropriate block diagram in LabVIEW® environment is presented in Fig. 10.

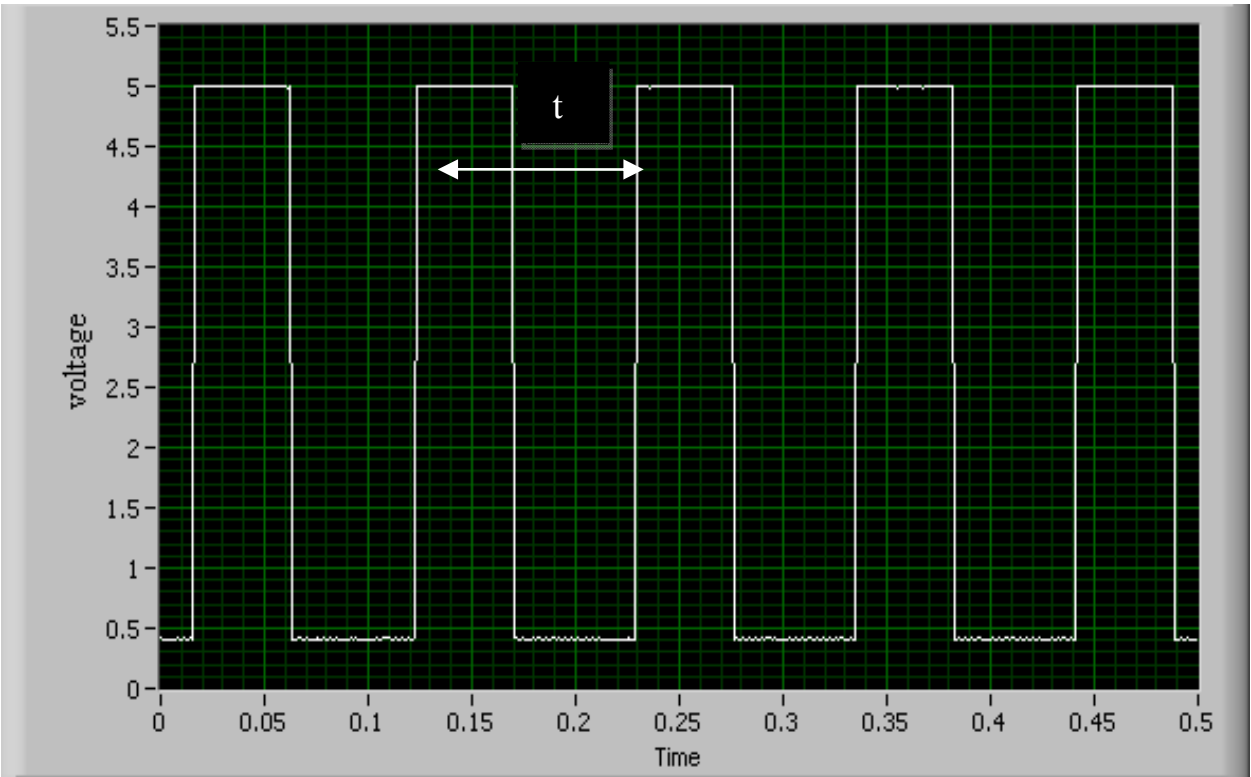


Fig. 9. Obtained pulses from the flow meter while the flow passing through the flow meter

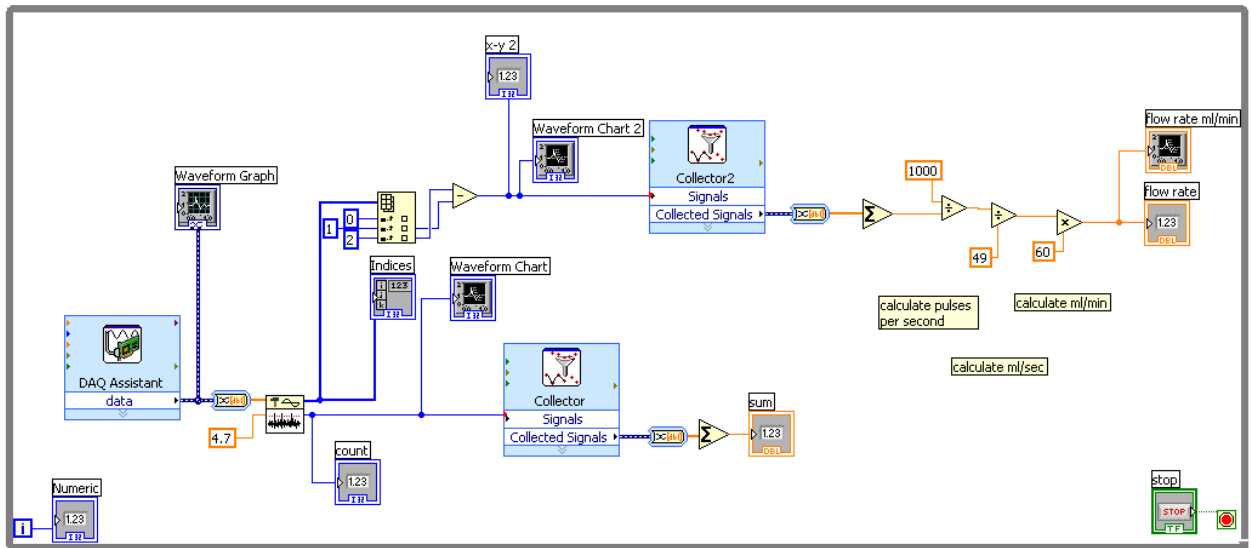


Fig. 10. Block diagram for micro-flow meter interfacing

5.3 Interfacing the spectrophotometer

The spectrophotometer is connected to the computer using USB connection to provide fast data transmission from the spectrophotometer. It uses 2 MHz A/D converter, and the absorbance of the liquid is captured and transferred to the computer at every millisecond via the USB port. In order to capture data from spectrophotometer, OmniDriverSPAM™ was used to acquire the data from spectrophotometer using the developed code in

LabVIEW® environment. However in order to suit the developed code into our application, some changes need to be made.

OmniDeriveSPAM™ provides the code in order to get the full spectrum data from the spectrophotometer and in order to get the value of the required wave length which is the corresponding value needed to found from the input data which has been done in the first step as can be presented in Fig. 11. Second step, calculates the intensity of light at each wavelength (based on the spectrophotometer's manual). Third step, calculates the mean value for specific number of irritation in order to have less noisy measurement and finally at the final step, the pH value can then be calculated via simple calculations (Liu et al., 2006, Martz et al., 2003). It can be observed that the transmission of the raw data in to the required data form was done in few simple steps.

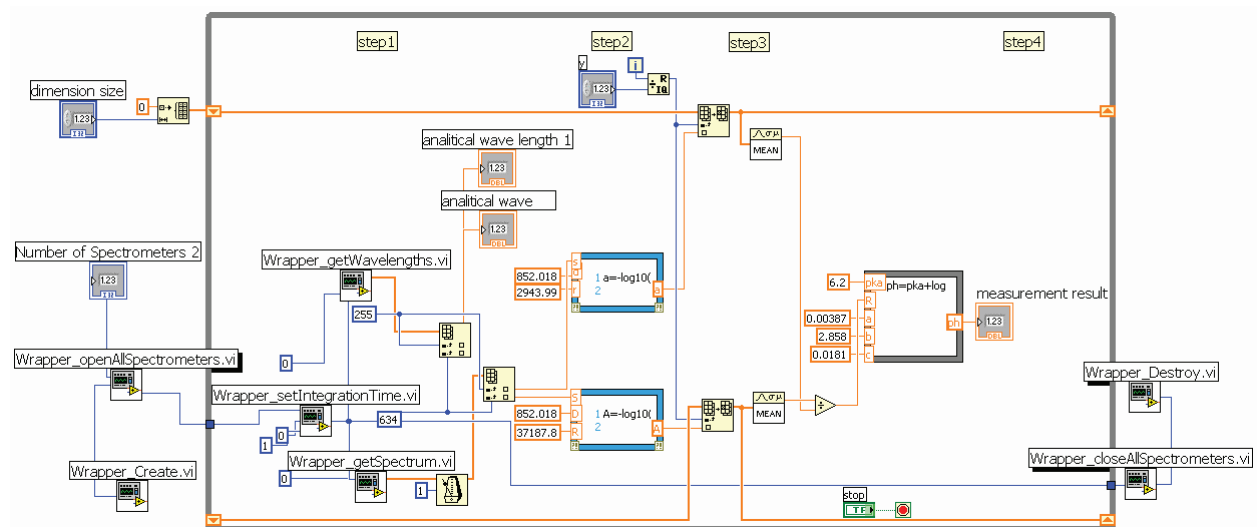


Fig. 11. Block diagram for spectrometer interfacing

6. Building a LabVIEW® user interface for a Simulink® model

As mentioned earlier, controller was developed in SIMULINK® environment and thus in order to be able to control the developed experimental setup, the connection between the designed controller in MATLAB® and LabVIEW® is essential. Thus, a low level programming using SIMULINK® interface toolkit (SIT) is applied in order to provide communication between MATLAB® and LabVIEW®.

The SIT, provides a platform not only to run any simulation in SIMULINK® environment via LabVIEW® but also to read and write data from SIMULINK® blocks as the simulation is running. Figure 12 shows that using SIT, we can locate and run any SIMULINK®'s .mdl file. In addition, any desired value can also be fed into any specific block in that .mdl file. For instant, Fig. 12 shows how any desired value can be written into "constant2" block in the mdl file. Then using `read.vi`, we can get output from any block in the mdl file.

Using this valuable tool, SIMULINK® can be used as the controller while the measurement data is feed into the measurement blocks in SIMULINK® using LabVIEW® and controller output signal also can be easily transferred to LabVIEW® and conditioned then sent to the final control element to do the corrective action.

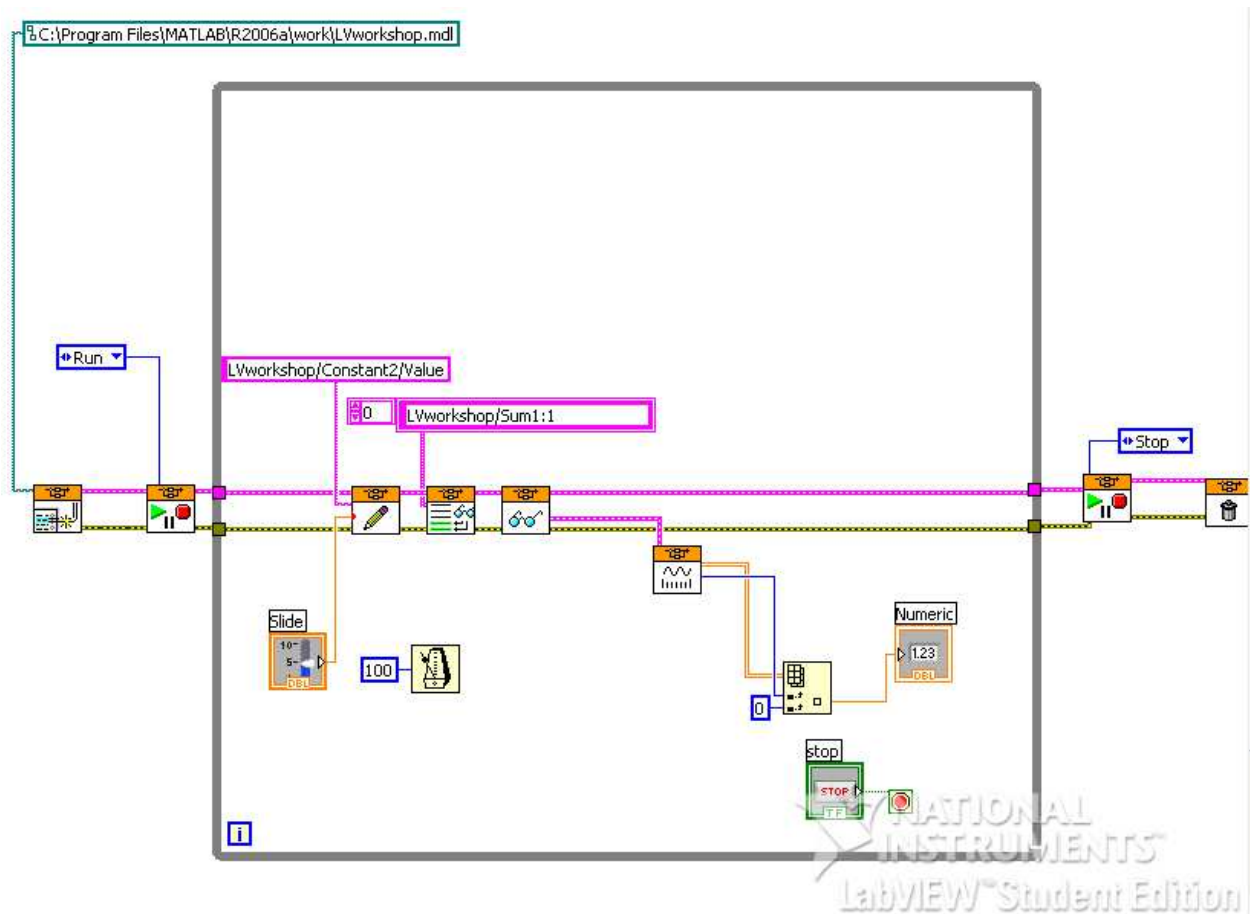


Fig. 12. Block diagram for linking SIMULINK using SIT

7. Control system

After interfacing all the control components using LabVIEW® and also linking LabVIEW® to SIMULINK environment, it is essential to include all the parts in a single VI and provide suitable connections for each part. Figure 13 shows the schematic diagram for data communication of the experimental rig. As can be observed from the diagram, SIMULINK® and LabVIEW® environment can communicate via the SIT toolkit. It is clear that LabVIEW® acts as interface between the experimental rig components and the embedded controller in SIMULINK.

A signal probe need to be placed in SIMULINK model in order to enables SIT to communicate with the file as can be observed from Fig. 14. A PID plus first order low pass filter design is used as the controller of the system (Barzin et al., 2010). Using the developed structure using SIT, the controller output can be taken from the Sum block in the SIMULINK® file and transferred to LabVIEW® to be sent to the final control element (syringe pump). In order to be able to apply the step change to the system, set-point value should be adjustable while the SIMULINK® model is running. To address this problem, set-point input block is also connected to LabVIEW® which enables the user to make any change in set-point value. Measurement input signal can also be transferred to the measurement block in the control loop via LabVIEW®. Thus, the controller easily can access to the updated measurement results every 50 milliseconds as the .mdl file is running.

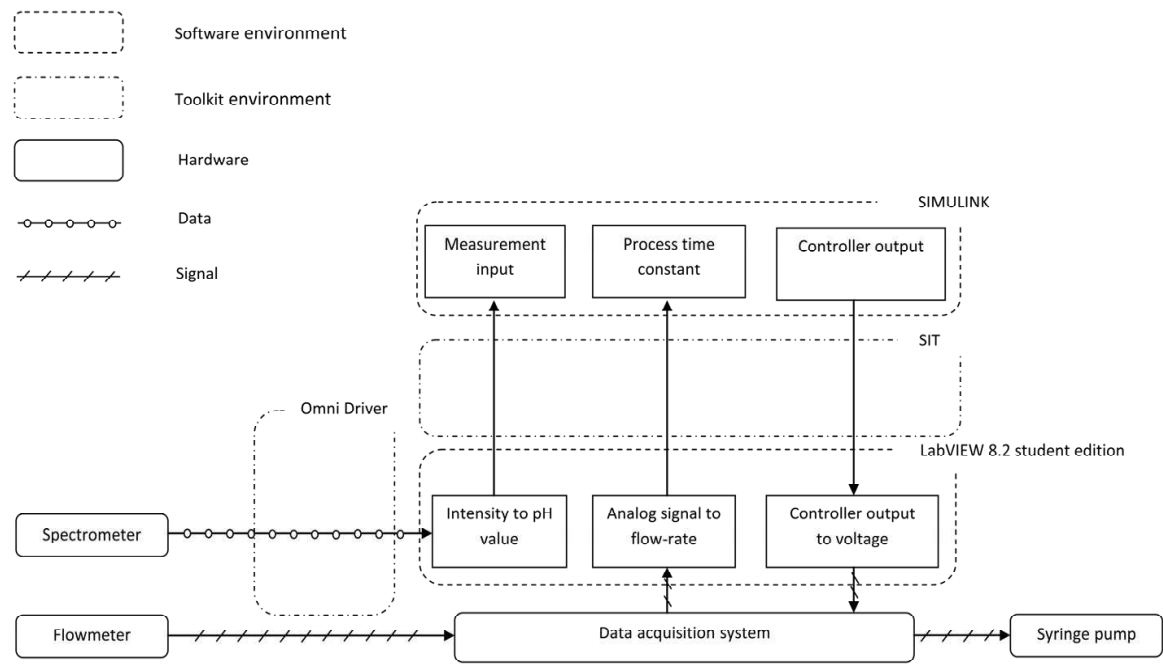


Fig. 13. Schematic diagram for data communication of the experimental rig.

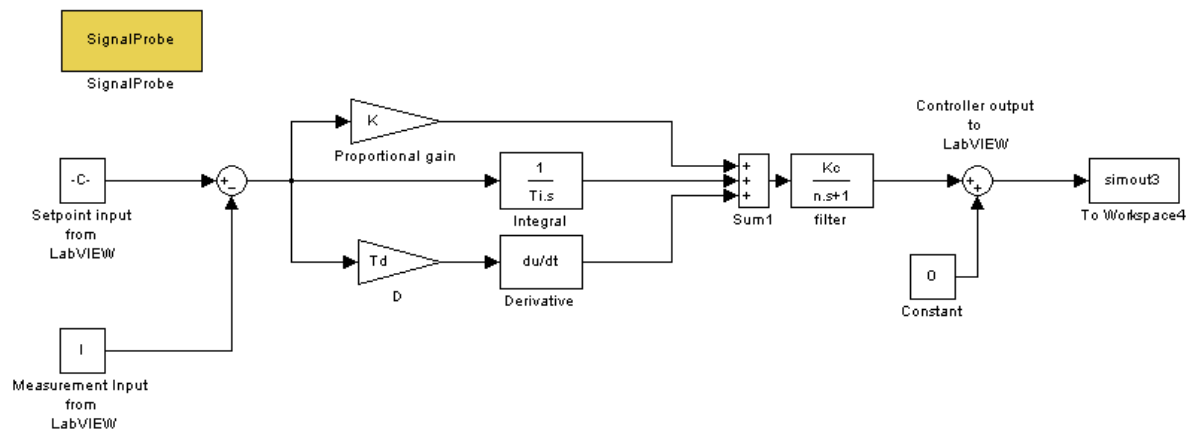


Fig. 14. Controller in SIMULINK environment showing the input and output block

Figure 15 shows the final code in LabVIEW® which is a combination of previously presented VIs. When the VI starts, simultaneously it initiates the `controller.mdl` file in SIMULINK®. Measurement results of the spectrophotometer are transferred from the “Measurement Results” block to the write block in SIT. Write block transfers the data from the spectrophotometer to the “measurement input from LabVIEW” block presented at Fig. 14. At the same time, selected set-point value (which can be set using the slide knob in LabVIEW®) is transferred to the “set-point input from LabVIEW” block which is the set-point value of the control system. This enables for performing any set-point change such as introducing step-change, ramp and impulse while the system is running. Then the controller performs the corrective calculation and the controller output signal is transferred back to the LabVIEW® using the read VI which needs to be transmitted and conditioned to the proper format that can be sent to DAQ system. Controller output signal then sent to the DAQ system using DAQ assistant block which transmits the received signal to its equivalent voltage as has been set up earlier in the syringe pump interfacing section.

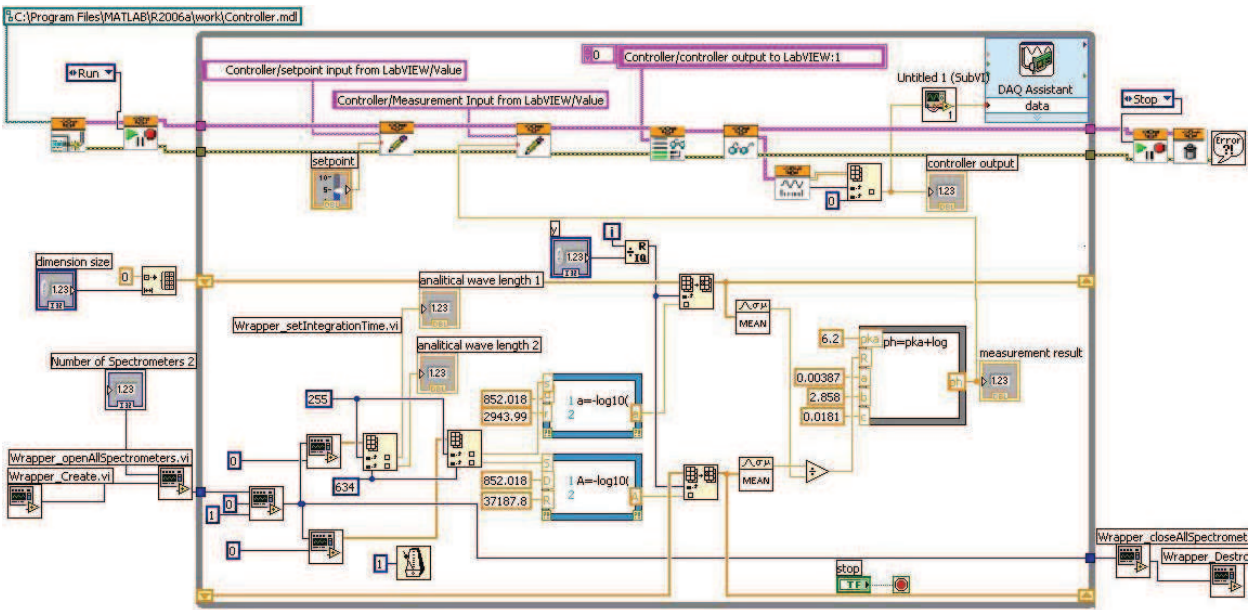


Fig. 15. Low Level LabVIEW® code including SIT and Measurement parts.

Figure 16(a) shows the pH changes of the designed PID controller using λ values equal to 4 and 1.5 which are presented in dotted line and solid line respectively. The step change was performed from pH equalled 5.85 to 6.85 at $t=10$ seconds as denoted by the dashed dotted line. Using λ value equals to 4 seconds (dotted line), the pH gradually increases from 5.85 to 6.85 with no overshoot or under shoot. However, decreasing the λ value to 1.5, faster controller response can be achieved which results in an impressive settling time of 4.2 seconds. Fig. 16(b) shows the controller output during the step change.

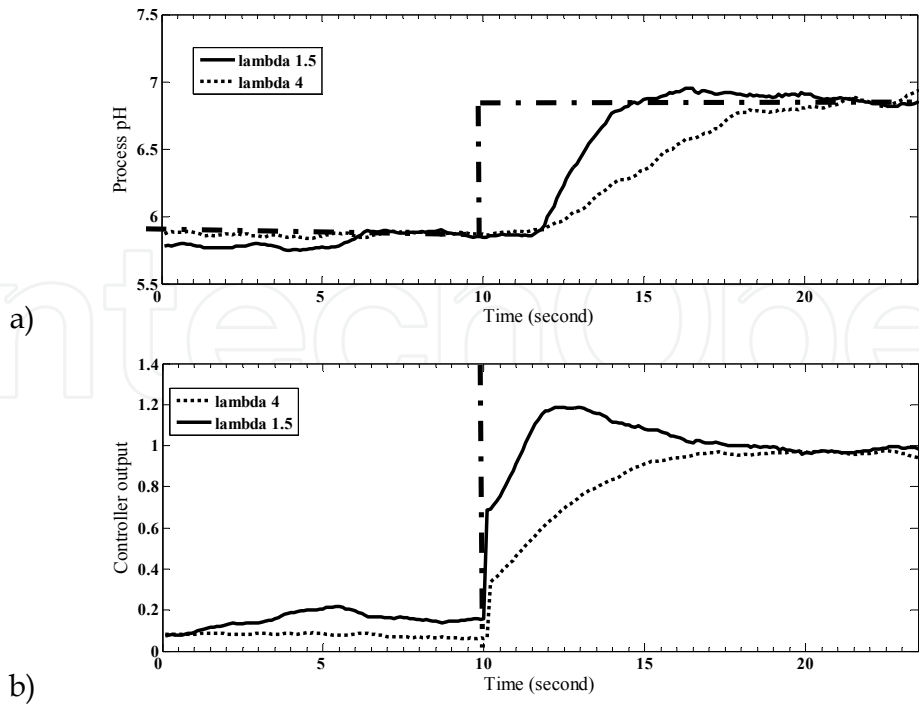


Fig. 16. Experimental results for step change in the set-point of the system at desired closed loop time constant equal to 4 and 1.5 seconds. a) process pH, b)controller output of the system.

Controller output transmitted to corresponding voltage in LabVIEW® and then applied to the final control element to increase or decrease the flow rate of the manipulated variable of the system (which is sodium hydroxide in this case study). From the figure it is clear that for λ equal to 4, the controller output increases gradually. As a result, input voltage to the final control element and consequently the flow rate of the strong base increases steadily, thus, the pH value of the system does not change too fast. Whereas for λ equal to 1.5 seconds, an abrupt change can be observed at the controller output which resulted in much faster change in pH value of the system.

Desired closed loop time constant λ	Controller gain (K_c)	Rise time	Settling time
4	0.27	11	8.3
1.5	0.52	4.7	4.2

Table 1. Effect of λ on the controller parameters

Table 1 shows that using λ equals to 4 results in a small controller gain ($K_c=0.27$). As a result of using a low value for K_c , a slow set-point tracking with a corresponding rise time and settling time equals to 11 seconds and 8.3 seconds is achieved respectively. Reducing the λ to 1.5 increases the controller gain to 0.52 and consequently a faster setpoint tracking with a corresponding settling time of 4.7 and rise time seconds of 4.2 seconds is obtained.

8. Conclusion

This study presented the difficulties of process control for miniaturized intensified systems and in order to address the problem, LabVIEW® and MATLAB® is proposed to be used tandem to provide suitable mean perform suitable control action on the system. It is presented that interfacing different measurement and final control elements can be speeded up using LabVIEW® software. Additionally, using SIT toolkit enables user to transfer measurement data from LabVIEW® to the embedded control in SIMULINK and also apply the controller output to the system via LabVIEW®. High performance of the proposed software structure (LabVIEW® as interface and MATLAB as controller) also demonstrated using the experimental results.

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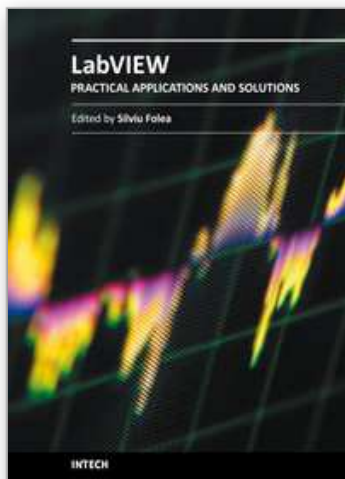
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Practical Applications and Solutions Using LabVIEW™ Software

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The book consists of 21 chapters which present interesting applications implemented using the LabVIEW environment, belonging to several distinct fields such as engineering, fault diagnosis, medicine, remote access laboratory, internet communications, chemistry, physics, etc. The virtual instruments designed and implemented in LabVIEW provide the advantages of being more intuitive, of reducing the implementation time and of being portable. The audience for this book includes PhD students, researchers, engineers and professionals who are interested in finding out new tools developed using LabVIEW. Some chapters present interesting ideas and very detailed solutions which offer the immediate possibility of making fast innovations and of generating better products for the market. The effort made by all the scientists who contributed to editing this book was significant and as a result new and viable applications were presented.

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