

# Sharing a Process Control Experimental Rig Online

**Mahmoud Abdulwahed**

Engineering Centre for Excellence in Teaching and Learning, Loughborough University,  
Loughborough, UK, m.abdulwahed@lboro.ac.uk

**Zoltan K Nagy**

Chemical Engineering Department, Loughborough University, Loughborough, UK,  
z.k.nagy@lboro.ac.uk

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***Abstract:** Laboratory education is an essential part of engineering degrees. Laboratories are normally expensive, hence sharing them online is a way of reducing institutional cost and promoting collaborative work. This paper reports on developing a remote access mode of one process control lab rig that has been installed recently in the chemical engineering department of Loughborough University. The work has been done in a context of research project on Laboratory education conducted by the author.*

## Introduction

The importance of laboratory experience in engineering education curricula has been emphasized in a large number of science and engineering education articles (Johnstone and Al-Shuaili, 2001; Hofstein and Lunetta, 2004; Feisel and Rosa, 2005; Kirschner, 1988; Ma and Nickerson, 2006). The essential role of laboratories can be correlated with the fact that engineering is, in general, an applied science that requires very good hands-on skills and involves elements of design, problem solving, and analytical thinking. Well designed laboratories during undergraduate engineering degrees may well improve these skills of the future engineers. Engineering had been taught as a pure hands-on subject up to the 18th century. However, engineering education has benefited from the advances in science and it began to embed deeper theoretical concepts by the end of the 19th century, especially in the US schools initially (Feisel and Rosa, 2005). Since then, the pedagogical emphasis in engineering education has been shifted more towards classroom and lecture based education. In many schools, gradually less attention has been given to the laboratory education, particularly during the last 30 years (Hofstein and Lunetta, 2004; Hofstein and Lunetta, 1982; Feisel and Peterson, 2002). Wankat (2004) observed that only 6% of the articles published in the Journal of Engineering Education from 1993-2002 had "Laboratory" as a keyword. Laboratory pedagogy has been recently reported to be a fertile arena of research for the coming years (Hofstein and Lunetta, 2004; Feisel and Rosa, 2005), especially in the context of the increasing need to make more use of the new developments in information and communication technology (ICT) for enhancing the laboratory education. The impact of laboratory education on students' learning is often not recognized (Roth, 1994). One reason for rethinking the role of the laboratory in engineering and science education is the recent shift towards constructivist pedagogy in which the importance of knowledge gained via experience is emphasized. Furthermore, constructivist pedagogy places larger role on student autonomy in the learning process. This is particularly important in the view of the recent increase in the needs of industry for engineering graduates who are autonomous and equipped with good hands-on skills. Enhancing laboratory education can serve as a motivating factor toward engineering career. Generally labs are expensive equipments. They are installed in universities after high cost but used for few hours over the year. For instance, a modular process control rig was installed in the chemical engineering department for using in undergraduate instrumentation and control course. The rig cost was about £15000, it is used for about 30 working hours a year. Experimental rig redundancy is very frequent among universities. In

many cases, there is experimental rigs redundancy among the departments of the same universities, in particular for the case of control engineering experimental rigs, since control engineering is taught in many engineering departments. This represents an extremely non efficient economical model in engineering education, it is also one strong motivation towards the recent popularity of remote labs as enablers of sharing rigs and reducing costs. One main advantage of online laboratory is the ability of sharing resources with other universities and hence reducing the economical costs. Sharing remote experiments among universities will eliminate buying new hardware, allocation costs, and will enrich the students experiential education. The costs of new experimental rigs is heavily consuming the higher education institutes budget, especially in some engineering disciplines where technology is advancing quickly and there is continuously demand on universities to follow and embed these advances in the curriculum. This lead indeed in the 70s and 80s some institutions administrators to minimize the laboratory work in the undergraduate curricula (Kirschner, 1988). With the new advances in networking and internet, the idea of sharing experimental resources for cost minimization can be traced to early 90s (Kondraske et al., 1993). The awareness of this potential kept being reported since then (Ma and Nickerson, 2006). One example of sharing experiments across the Atlantic is the Cambridge-MIT remote experiment in chemical engineering undergraduate course. There have been some companies now that coordinate remote experimentation of database of test rigs distributed among several partners, one example is the Norwegian Cyberlab company (WWW2).

## Online Laboratories

The evolution of internet and networking technologies has left a growing impact on the laboratory and experimentation philosophy. Nowadays, we can conduct experiments remotely from other continent. In this section, a snapshot on the new evolving form of laboratory education called online laboratory is given. The idea of implementing controlled lab through the internet for educational purposes can be tracked back to the 1991, when Aburdene et al. suggested a futuristic solution for sharing laboratory equipments through the internet (Aburdene et al., 1991). They expected that this model will be used for operating experiments in the classroom and by other partner institutes. They proposed combining simulations with the remotely accessed experiment as well. They envisaged that this model will initiate a new body of pedagogical opportunities and research, and will effectively foster collaboration among distributed institutes. Aburdene and his colleagues futuristic reading of the ICT evolving dynamics is impressive, most features of the model they proposed back in 1991 has been consequently implemented within a very few later years. The early implementation trials took place in the United States, where by 1993, a realization of remote control of distributed robots over four universities in the US and NASA has been successfully tested (Kondraske et al., 1993). An internet based control engineering laboratory was implemented in Oregon state university using specially developed software and hardware, they called it SBBT (Aktan et al., 1996). Since then the number of internet based laboratories has rapidly increased year by year, the geographic distribution spread to Europe, Australia, and East Asia (Abdulwahed et al., 2008a). Many different IT tools were used for implementing online laboratories. Matlab/Simulink, and RTLinux were used for implementing remote inverted pendulum experiment (Garcia et al., 2002). NetMeeting with Matlab based real time tools were used for implementing another control engineering lab (Swamy et al., 2002). Mobile robotics experiments were implemented using the open standards of the Web technologies such as HTTP, HTML, XML and Java with CORBA architecture (Guimaraes et al., 2003). Solution based on integrating Visual Basic, ActiveX controls, HTML, ADO, RDS, and ASP has been used to implement web based load supervision and control system (Chang et al., 2006). LabVIEW was reported as implementation tool for many online labs in Ertugul survey paper (Ertugul, 2000). Trevelyan worked on implementing online-Labs since 1994. He used different programming languages for implementing remote access of the hardware. In the early days he worked with group of graduate students on developing the needed interfaces using C/C++ and Java which needed huge amount of coding and maintenance later on (Trevelyan, 2002). They used Java for a telerobot project due to its independence of the machine type when operation. However, they realized that the application complexity prevented long term performance reliability. In 2000 and after a survey of alternative solutions, Trevelyan and his team transferred to work with LabVIEW environment, its diverse capabilities have impressed them

(Trevelyan, 2002). The software easy to use for engineering students was noteworthy, as well as, the cost effective maintenance during the project life cycle. Trevelyan relates the discontinuity of many remote labs that used other programming to the high maintenance cost (Trevelyan, 2002). The relative easiness of using LabVIEW is being reported by many articles and specified books. The number of implemented online laboratories reported in the literature has escalated rapidly since mid 90s, it is estimated that many hundreds of labs are currently available online.

## The Armfield Control Rig

The process control lab of the chemical engineering department in Loughborough University contains six industrially like pilot level control plants. It has been supported by an additional modular control test rig, the Armfield PCT40 multifunction process control teaching system. The Armfield PCT40 system provides a cost-effective way of teaching a wide range of process control techniques in a simple basic unit. More advanced aspects of process control can be addressed by adding optional modules to the basic system. It is capable of demonstrating level, flow, pressure and temperature control loops. The plant itself is composed of a variable volume process tank, a hot water tank with electric heater and indirect heating/cooling coil, a hot water pump, two non-dedicated pumps, three on/off solenoid valves and a proportioning valve. The instrumentation includes temperature sensors, two differential water pressure sensors, a mechanical level sensor (float switch) and an electronic level sensor (conductivity). The inlets and outlets of the various pumps, valves and tanks are brought to a connection manifold, which uses self-sealing quick release fittings. This allows the configuration to be quickly changed, offering a variety of different loops. The platform is multifunctional and can be used for research experimentation as well. Figure 1 shows the Armfield PCT40 test rig. A couple of process control principles can be demonstrated with the rig assistance such as: Sensors calibration; Inflow and outflow control; Direct and indirect heating; Conductivity control (Feedback and/or Feedforward); pH control (Feedback and/or Feedforward). The rig is accompanied with an educational software; it is also provided with a DLL driver for users to develop their own software through Matlab, or LabVIEW. The software comes with a set of control engineering experiments however it does not provide remote operation. In our iteration with Armfield, we got to know that they can provide remote operation software with a cost of 5000£. The cost was out of the budget, hence, we implemented a remote operation software for the rig with LabVIEW.



Figure 1: The Armfield experimental rig

## Technical Implementation

### A. The Rig LabVIEW Based Driver

The rig comes with a DLL driver file that can be read in LabVIEW through “Call library function”. There are analogue and digital sensors in the rig as well as analogue and digital actuators. The process analogue sensors are: 4 temperature sensors, 3 pressure sensors, level sensor, flow sensor, conductivity sensor, and pH sensor. The digital sensors are: hot water level sensor, over temperature of hot water sensor, differential level switch on/off sensor, level switch on/off. The analogue inputs are: hot water pump, PSV pump, pump A, and pump B. The digital inputs

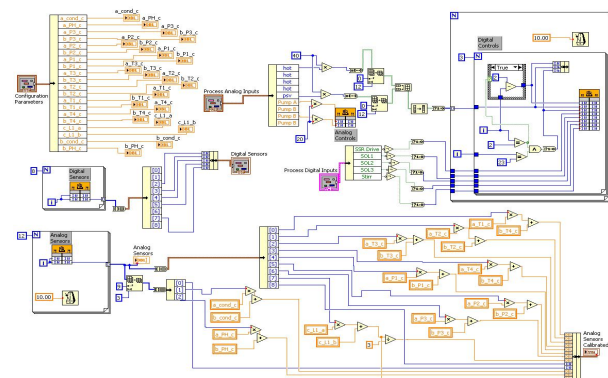


Figure 2: The developed Armfield LabVIEW driver

are: thermostat, stirrer, and three solenoid pumps. All of these can be read or written to through the mentioned function in rather straightforward way except the hot water and the PSV pumps. These are controlled through an electronic chip that requires special coding to deliver the needed input. The coding has been done in LabVIEW as well. Figure 2 shows the LabVIEW driver of the Armfield rig.

#### 4.2 The Rig LabVIEW Educational Software

A PID control educational software was developed with LabVIEW to offer virtual, hands-on, and remote PID and manual control experimental interface of the rig in one package. The software currently provides two control experiments: inflow control of the water level in the middle vessel and outflow control of the water level in the middle vessel. There are four main pages in the software:

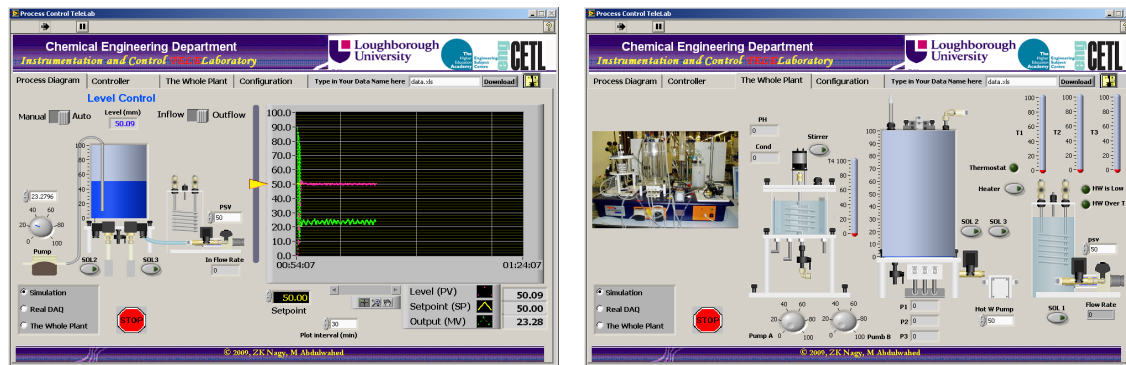


Figure 3: The LabVIEW educational software, the process diagram page.

**Process Diagram:** which shows the process schematic with interactive virtual instruments. It provides the user with possibility of choosing between manual and automatic control, to choose between inflow and outflow control, setting the required setpoint, setting the inflow water rate, or setting outflow water rate. In this page, user can choose to run the water level control process under simulation or real DAQ mode. The user can choose to manipulate the other rig elements manually by choosing the “The Whole Plant” option. The page provides a graphical plot showing the real water level, the setpoint, and the manipulated variable signals. The process diagram page of the software is shown in Figure 3.

**Controller:** The controller page provide the user with possibility of manipulating the PID controller parameters,  $K_c$ ,  $T_i$ , and  $T_d$ . There are two main plotting windows, the first one is for showing the process signal, the second one is smaller and is showing the error signal between the real level and the set point. In the controller page, the user can also choose the “Autotuning” option which runs an automatic tuning wizard. The automatic tuning wizard provides the user with utility for tuning the controller parameters in three modes, slow, normal, and fast controllers which can be applied for P, PI, or PID controllers. Hence giving 9 different options of the controller tuning. The estimates the process noise, then it applies pulse signal for a couple of periods to estimate the process dynamics, and finally, it results in the required controller parameters after executing an internal calculation algorithm.

There are two other pages, the “Configuration” page where the user can configure the rig and the “Whole Plant”. The latter is shown together with process diagram page in Figure 3. In the whole plan page, the user can manually control the analogue and digital actuators and read the sensors signals. In the future, it is planned to add different automatic control loops to this page.

### Two Online PID Control Experiments

With the Armfield rig now, there are two offered PID control experiments, inflow control, and outflow control. These are taught in first, second, and third year courses in the chemical engineering department of Loughborough University, UK. PID controller counts of 95% of the used controllers in industry. It is essential for chemical engineers to master qualitatively and quantitatively its principles. The controller calculates the error between the measured signal and the desired value and changes to

manipulated value (valve position) so that the error is decreased, the amount of change in the manipulated value is a function of the error, this function in the case of PID control has three main components:

$$f(E) = K_c E(t) + \frac{K_c}{\tau_I} \int E(t) dt + K_c \tau_D \frac{dE(t)}{dt}$$

The students are taught the PID control theory in the lecture/ In the lab, they are asked to do a heuristic tuning to have a qualitative awareness of the importance of tuning PID controllers and how using basic tuning strategies might have greater effect on the process performance. The students also experience the disturbance rejection issues, saturation, positive and negative feedback. The rig has been made available online with open access, so everyone can login the experiment and perform any of the two PID control demonstrations, the LabVIEW runtime engine will be needed to operate the embedded LabVIEW application at the client side. Such demonstrations could be applied to provide an authentic classroom teaching (Abdulwahed et al., 2008b).

## Conclusions

This paper reports on our experience of turning an expensive control rig into a shared online platform under low cost using LabVIEW. This development has been a part of a research project conducted in Loughborough University. In this research project, a constructivist pedagogical model of laboratory education, remote and virtual laboratories, and an online portal were developed. The Armfield rig is one another unit that is being deployed for the project support and outreach. It will be made available online, the LabVIEW driver and the software also will be made available to download from the iLough-Lab portal, [www.ilough-lab.com](http://www.ilough-lab.com).

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