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Cambridge Weblabs: a Process Control System using industrial standard SIMATIC PCS 7

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Abstract

Continually assessed project work forms a core part of the Chemical Engineering curriculum at Cambridge. We have designed and built a remotely controlled chemical reactor that has been used and evaluated in undergraduate chemical engineering education. The purpose was to provide a pedagogical and authentic experience to students with essential training when laboratory usage was impossible or impractical, and be able to run and share the experiments as a fully functioning chemical engineering plant. A state-of-the-art SIMATIC PCS 7 Process Control System from Siemens is used for controlling, monitoring and providing results output. We describe the experimental setup, the hard- and software used, the teaching assignment and finally the results of the student evaluation. We also describe the challenges on the sustainability of the weblabs.

1 Introduction

Hands-on laboratory experiments have enormous educational value, but traditional teaching laboratories are expensive and have complex logistics regarding space, staff, scheduling and safety. The internet gives an option to include real laboratory experiments in teaching at any time and the experiments can be performed from any place with internet access. The experimental equipment can be easily shared and used around the clock from anywhere in the world. This drastically changes the economics of providing laboratory experiments to students and, potentially, a huge number of experiments can be available for use, including experiments on expensive equipment, rare materials and at remote locations.

Weblabs, internet-accessible remotely operated experiments, have been around since the late nineties and projects using both solutions developed in house [2, 9] and commercially available software [7, 8, 10, 12, 13, 21] have been reported as well as review type articles [3, 4].

Remote operation is widespread in industry, both in research and production. Processes found in today's chemical industry are usually operated remotely from control rooms using computers communicating in networks. The current chemical engineering curriculum offer students little training in what they are likely to meet when leaving the university and weblabs can provide access to real equipment and real data using up-to-date technologies for remote operation. Hence, they offer students essential training for what they are likely to encounter in their professional life. Weblabs also provide students with teamwork and communication skills.

We have created a powerful tool for use in chemical engineering education. A chemical reactor combined with industrial process control hard- and software. By operating a chemical process remotely with up-to-date technologies widely used in industry, the students not only get the traditional benefits of visualization of chemical engineering theory but will also gain insight how processes are controlled in the real world. Chemical reactors are at the very core of chemical engineering education and they appear in a wide variety of courses with applications ranging from simple residence time distributions to complicated, non-ideal mixing, reaction kinetics, modelling and biotechnology.

The University of Cambridge has developed a unique internet-based system to facilitate experiments that can be conducted remotely over the web. Controlling, monitoring and providing results output for this groundbreaking development is a state-of-the-art SIMATIC PCS 7 Process Control System from Siemens.

Furthermore by making the experiment available on the internet, rather than an intranet, the experiment can be accessed and performed from any computer with an internet connection opening up new possibilities for sharing experiments.

2 History of the Weblab at University of Cambridge

The Cambridge weblabs were developed as a result of collaboration between the Chemical and Biotechnology Engineering department at the University of Cambridge and the department of Chemical Engineering at MIT. In early 2003, the iLabs project coincided with larger scale collaboration known as the Cambridge-MIT Institute [1]. As a result, the MIT heat exchanger experiment was included in the course of Chemical Engineering at Cambridge, and ultimately became a reciprocal sharing arrangement which lasted 3 years [18, 19]. During this period, the Cambridge weblabs team was able to extensively explore the ways in which online laboratories can be used and shared, which inspired the development of a unique internet-based system to facilitate experiments that can be conducted remotely over the web [16, 22].

The purpose was to provide essential training to students of chemical engineering and related subjects when laboratory usage was impossible or impractical, and be able to run the weblab as a fully functioning chemical engineering plant. The designers assessed several control systems to use in order to identify the one that would be most relevant to Chemical Engineers. When it came to sourcing a hardware and software provider it was decided to call Siemens at Manchester. They have an organization to develop relationships between Siemens plc and educational institutions at all levels called 'Siemens Co-operates with Education' (SCE). As a result, Siemens were willing to support the Weblabs team by providing the majority of the hardware, software, financial sponsorship and technical support needed to complete the project.

In January 2006, SCE delivered a complete SIMATIC PCS 7 [20] package to the University of Cambridge. The kit comprises: a SIMATIC AS-400 DCS controller; three industrial PCs; three Siemens Coriolis flow meters; temperature probes; various input/output modules; and fully functional control software. The flow meters and temperature probes in the PCS 7 system communicate over PROFIBUS PA to the three PCs, whereas the other devices use digital or analogue input/output modules. The whole system is controlled by the SIMATIC AS-400 DCS controller.

The Cambridge weblabs are built around a small reactor. So far, two experiments have been developed: one on chemical reaction engineering and the second on process control. The reaction weblab was developed by Cambridge alone, however the control weblab was developed as a result of collaboration with the Chemical Engineering department at Imperial College, London. Since 2006, the weblabs have been an assessed part of the Chemical Engineering course at Cambridge and has also attracted use in undergraduate and postgraduate courses at Imperial College London, the University of Birmingham, the University of Surrey, the University of Newcastle, Loughborough University and the National University of Colombia. Given that they are one of the most technically advanced experimental setups of their kind in the world, they were also adopted as a flagship experiment for the Library of Labs (LiLa) project [15].

3 PCS 7 Controlled Experiment

3.1 Reactor system

Figure 1 shows the diagram of the piping and instrumentation for the reactor given to students. Physically, the reactor and its ancillaries are mounted in a cabinet for conve-

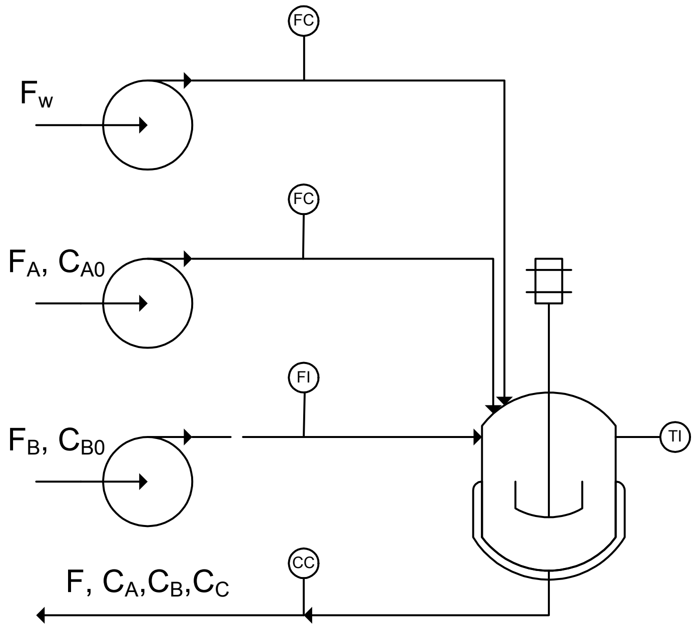


Figure 1: *Diagram of the piping and instrumentation diagram for the reactor.*

nience and safety, as shown in **Figure 2a**. The reactor itself and the peristaltic pumps are mounted in the front face of the cabinet, whereas supply tanks, flow meters, heater, dosing unit etc are enclosed with easy access provided through rear doors.

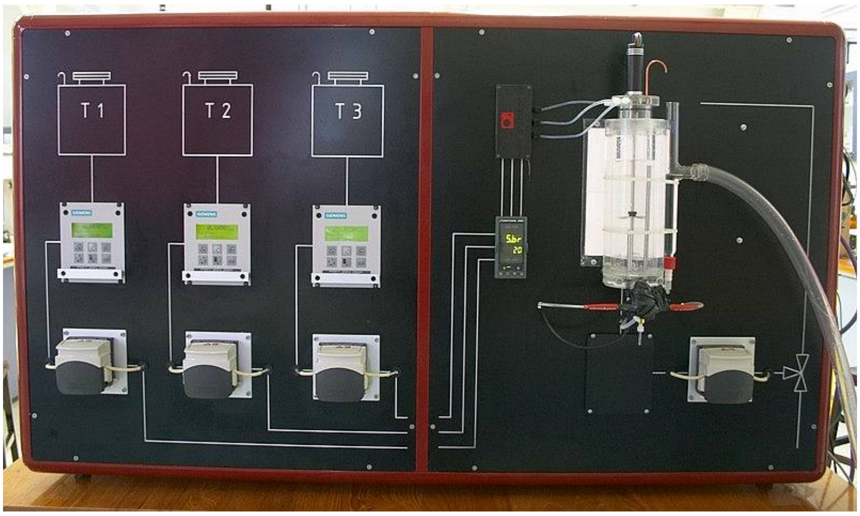
The reactor is manufactured from Perspex, has a variable volume of 100-300 ml and can be operated at controlled temperatures up to 50°C. A dead-zone can be created in the bottom of the reactor by a movable effluent pipe and by varying the depth and speed of the stirrer, as depicted in **Figure 2b**. Three feed streams can be controlled individually by Siemens Coriolis flow meters and peristaltic pumps.

Sodium Hydroxide (NaOH) and Phenolphthalein in dilute aqueous solutions are used as reactants. One of the products is bright pink, and the progress of the reaction is monitored by measuring the intensity of light at 550 nm passing through a flow cell with a spectrophotometer. For residence time experiments, Rose Bengal, which absorbs light at the same wavelength, is used.

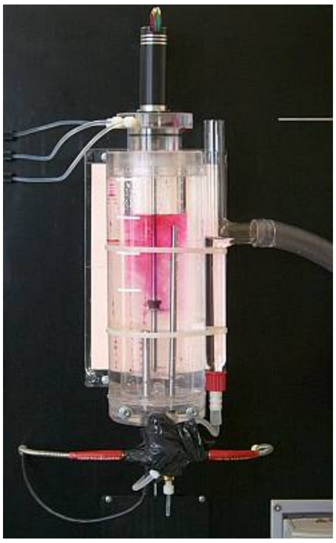
3.2 Control hardware

The layout of the control system is presented in **Figure 3**. The Siemens Coriolis flow meters are so called “intelligent devices” communicating with the system, together with the temperature probes, via a Profibus PA network. These devices are easier to install and configure, and can provide a lot more information than traditional devices. The peristaltic pumps and the stirrer are connected to an analogue output module and the relays for the dosing unit, heater element and heater circulation pump to a digital output module.

The intensity signal from the spectrophotometer is entered into the system via an analogue input module. The Profibus PA signal is converted to a Profibus DP signal in a



(a) *Flow meters, controllers and reactor.*



(b) *Non-ideal reactor.*

Figure 2: *The experimental setup at University of Cambridge.*

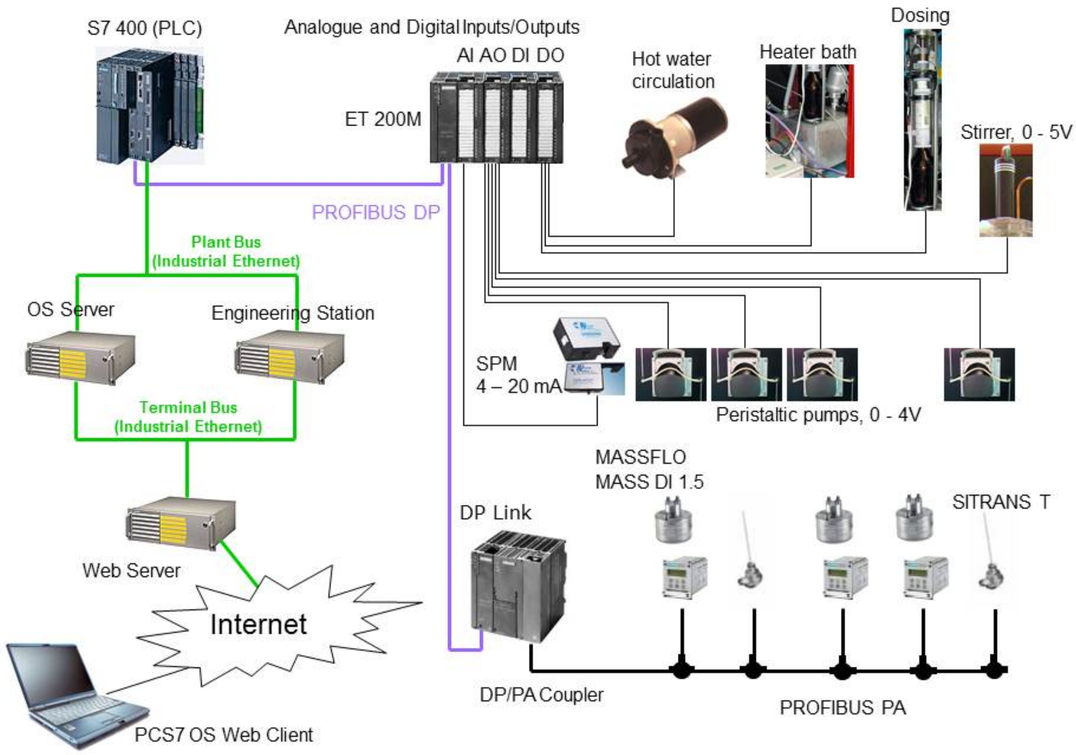


Figure 3: *Layout of the control system.*

DP/PA coupler and all inputs and outputs are then communicated to the S7-400 PLC via a Profibus DP link. To program, broadcast and operate the system, three industrial PCs are used. On the engineering station the operating system is programmed and the operating interface designed and uploaded to the PLC.

The operating system server communicates with the PLC and broadcasts the operating system to the local Ethernet network. The web server runs a html based version of the operating system and broadcasts this to the Internet [16].

3.3 Control software

After configuring and networking the PCs, connections are established between the devices in the experimental setup and the controller using the SIMATIC manager. The properties and controls for the devices are configured in the Continuous Function Chart (CFC) as shown in **Figure 4**. The CFCs are a kind of “drawing board” used to create the entire software structure of the control unit [20]. They use drag-and-drop pre-configured blocks that can be edited to the required parameters and are interconnected. The corresponding block icons are combined with a visual representation of the experimental setup in the graphical user interface (see **Figure 6**), the working area for the operator.

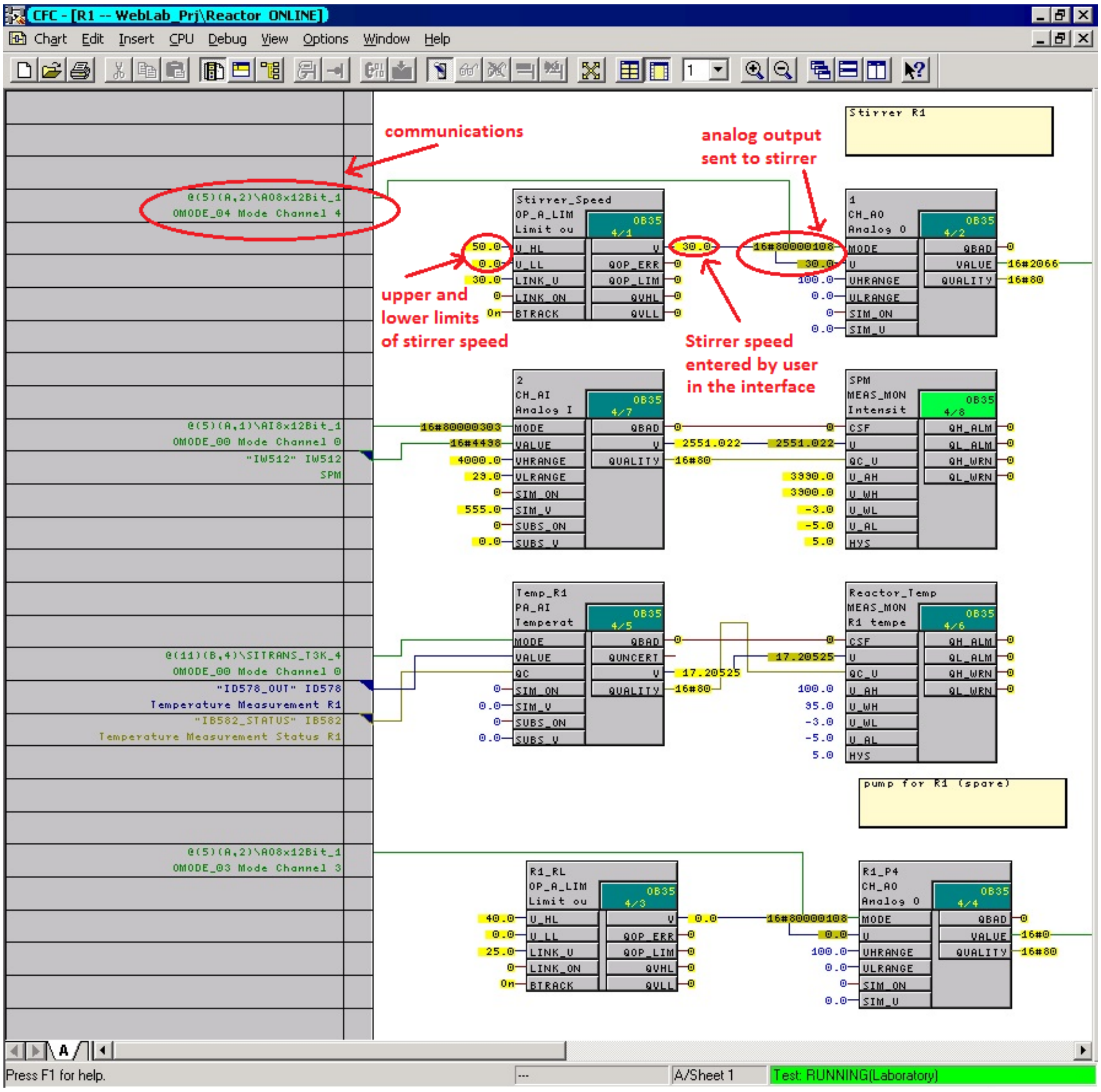


Figure 4: *Example of a Continuous Flow Chart with the layout of the control system. It contains blocks for the control of the reactor stirrer speed and the NaOH pump and the measurement of light intensity. Highlighted in red are some features of the block system for the stirrer speed.*

4 Exercise Assignment

The main purpose of this assignment is to identify a set of parameters for a PID (proportional-integral-derivative) controller to maintain the proportion of absorbed light - and hence the concentration of the product stream from the reactor. By carrying out a real experiment which will involve the remote manipulation of the reactor weblab located at Cambridge, the students should be able to find the differences between a theoretical and real system.

The following reactions occur during the experiment :

$$\text{PHEN} + 2\text{OH}^- \xrightarrow{fast} \text{PHEN}^{2-} + 2\text{H}_2\text{O} \tag{1}$$

$$\begin{array}{ccc} \text{PHEN}^{2-} + \text{OH}^- & \leftrightarrow & \text{PHENOH}^{3-} \\ \text{(pink)} & & \text{(colourless)} \end{array} \tag{2}$$

The concentrations of feed reactant, NaOH and phenolphthalein are 0.20 M and $7.2\,x\,10^{-5}\,M$. In this exercise, we are concerned with the dependence of the system on the parameters of the PID controller. Subscripts A, B, C and W in the piping and instrumentation diagram (**Figure 1**) refer to NaOH, PHEN, PHENOH^{3-} and water respectively.

The students should examine the diagram of the piping and instrumentation for the reactor and identify the controlled variable (concentration of PHEN^{2-} in the product stream), manipulated variable (flow rate of PHEN in the inlet stream) and any disturbance variable(s) (e.g. flow rates and concentrations of water and NaOH and inlet temperatures).

For the estimation of the PID control parameters, the Process Reaction Curve [17] method is used. This is an empirical method for tuning controller settings. The operating system is looked at under open loop conditions, a step change in the manipulated variable is introduced and the output measured.

In the exercise the students are requested to identify this approximate process model. Due to time constraints, obtaining the process reaction curve is not part of the experimental work. Instead, the students are given four data sets from the open loop tests. Sets 1 and 2 involve changes in NaOH pump power. Data set 3 records the change in light intensity following a change in the PHEN pump power, which is the information that is required. Finally, the data in set 4 do not reach steady state, and lack the sigmoidal shape needed for the Cohen and Coon method. Students must select a data set and justify the choice.

Cohen and Coon [5] proposed characterising the system by 3 constants familiar from a first order model plus time delay:

$$\frac{Y(s)}{X(s)} \approx \frac{Ke^{-t_d s}}{\tau s + 1} \tag{3}$$

Where Y(s) and X(s) are the laplace transform of the deviation of the controlled and manipulated variables respectively, K is the static gain, t_d is the delay time, τ is the time

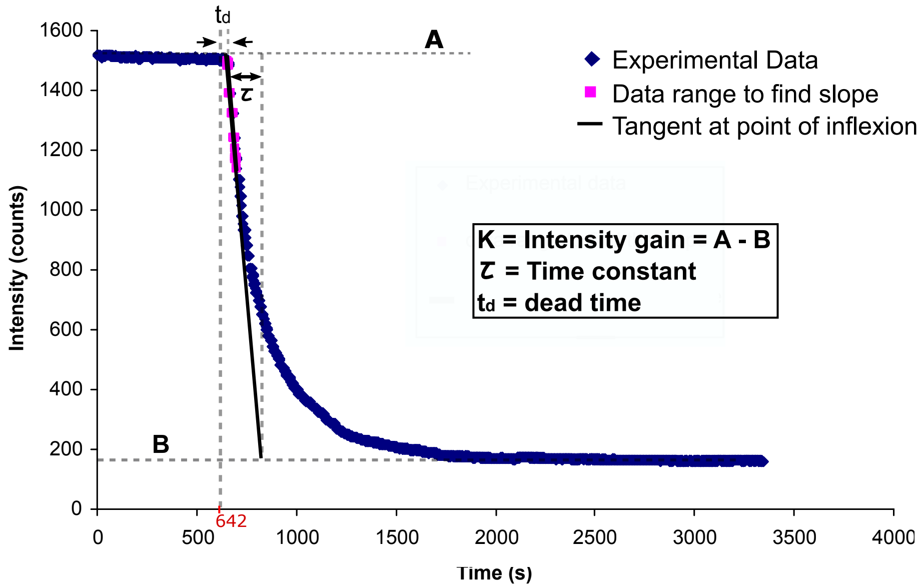


Figure 5: *Light intensity vs. time in an open loop process test for calculation of PID controller parameters. The static gain K, time constant τ and dead time t_d can be determined.*

constant. With these parameters the PID controller settings (controller gain K_c, integral τ_I and derivative τ_D time constants) can be calculated using Cohen and Coon equations [5]:

$$K_c = \frac{\tau}{K t_d}\left(\frac{4}{3} + \frac{t_d}{4\tau}\right) \tag{4}$$

$$\tau_I = \frac{t_d\left(32 + \frac{6t_d}{\tau}\right)}{\left(13 + \frac{8t_d}{\tau}\right)} \tag{5}$$

$$\tau_D = t_d\left(\frac{4}{1 + \frac{2t_d}{\tau}}\right) \tag{6}$$

Figure 5 shows a plot of an example data set provided to the students. The change in PHEN pump power was at $t = 642$ *sec*. Students should plot a tangent line through the data shortly after $t = 642$ *sec* at the inflexion point to find the slope for Cohen and Coon, and estimate τ and t_d [17].

In order to get the PID controller parameters, the student should find values for static gain K (i.e. the intensity of the final steady state measured response to the step change in pump power), τ (distance between the intersection of the tangent line with the steady state value before the step change and after the step change) and t_d (found by looking at the time between the pump speed change and an effect being observed in the intensity) [17]. Now, the PID controller settings can be calculated using the Cohen and Coon expressions [5].

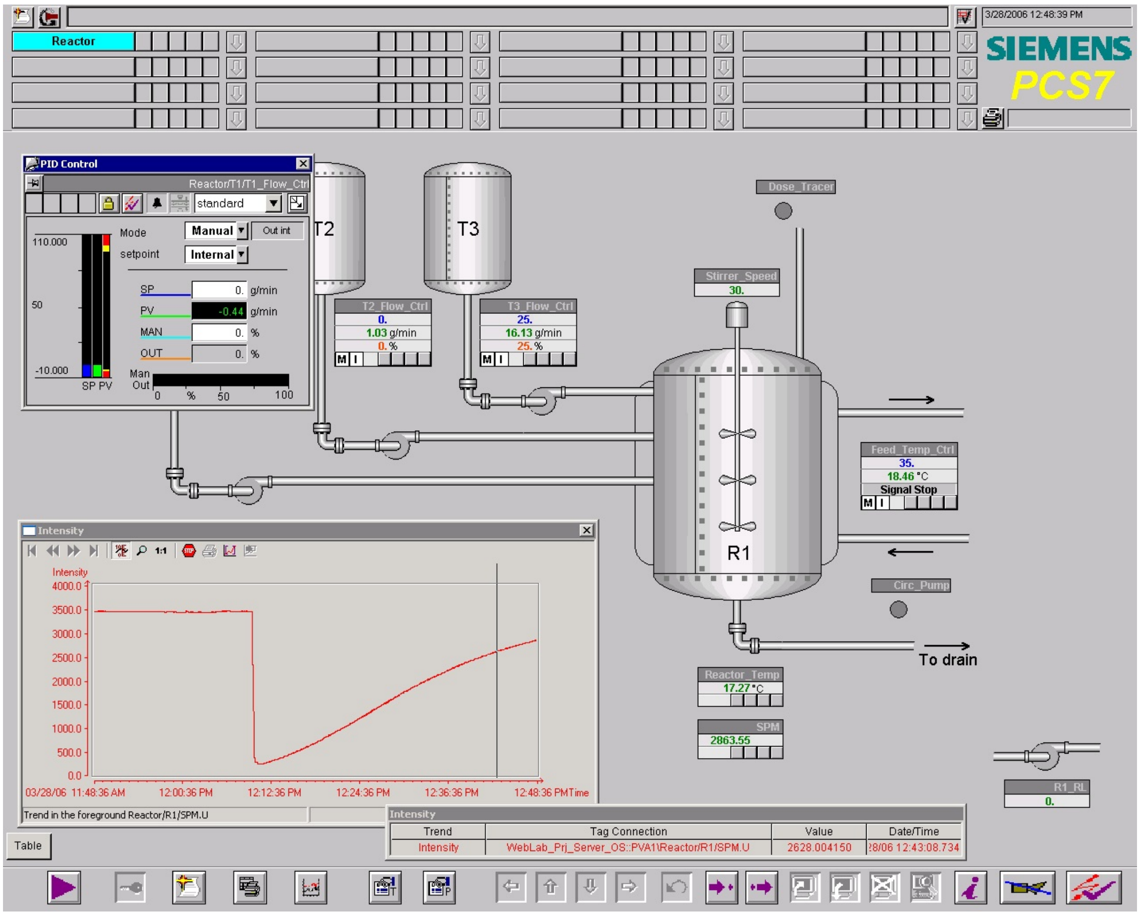


Figure 6: *SIMATIC PCS 7 Graphical User Interface with PID-controller faceplate open.*

4.1 Performing the experiment

The students are organised in small groups (between 2 and 4 students) to perform the experiment. The duration of the experiment is approximately two hours. Students are required to book a slot and sign up via the Weblab webpage or using the LiLa portal [11] (used from 2011).

To perform the experiment, the students use the PCS 7 control interface shown in **Figure 6**, exactly as an operator on a real plant would. They can make adjustments to flow rates, temperatures (by adjusting the set point of the relevant control loops) and agitator speed (by direct manipulation of the voltage to the stirrer). They can make observations of the real-time behaviour of the experiment using on-screen graphical or tabular presentation of the data, and they can record the data in .csv (comma-separated variable) format for analysis in any spreadsheet package. For further visual observations there is a webcam focussed on the reactor.

In the first task, the students should set the NaOH flow rate to a specified value and then change the concentration of the product set point (*i.e.* light intensity). They should introduce progressively the controller gain, integral and derivative control, previously cal-

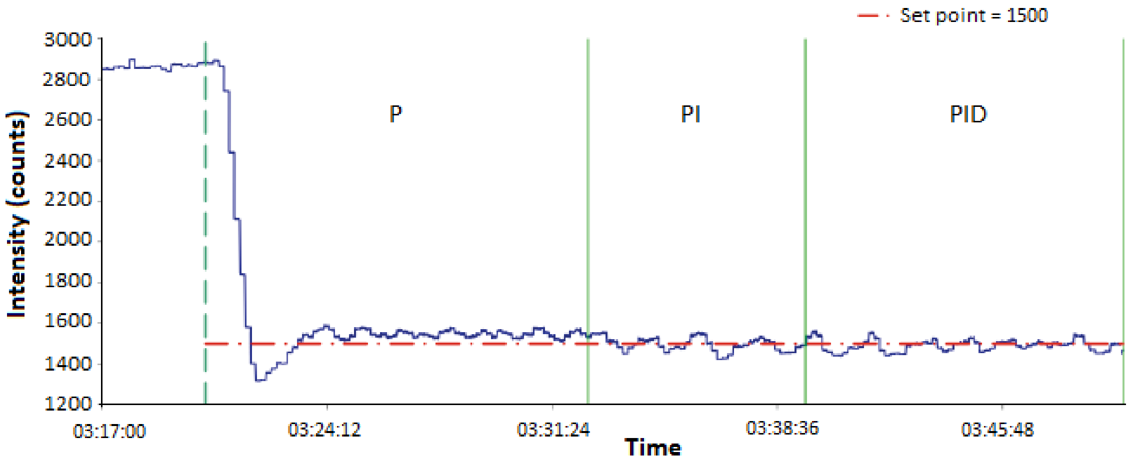


Figure 7: *Example of the response of the system during the implementation of PID control.*

culated, allowing up to 15 minutes in between for the system to stabilize. An example of the system response plotted by a student is presented in **Figure** 7. Qualitative observations of the behaviour of the product concentration after introducing each type of control is requested.

Two additional changes in the concentration of the product set point are performed, each with a 15 min period of stabilization. Students are requested to select an appropriate error response criterion and, for each step change in set point, calculate its value and discuss the advantages and disadvantages of using this criterion. Finally, students perform tuning of the controller parameters. They are requested to discuss briefly how they would perform further fine-tunning of this system, according to their observations.

As well as providing an interface to perform experiments, the PCS 7 software gives the students a valuable introduction to industry standard control systems. They are able to investigate how a control loop is set up, including the associated operating limits and alarms.

4.2 LiLa Project

The LiLa project was an EC funded initiative that aimed to establish a European network of universities to share and display remote and virtual laboratories [14]. Through their system they provided the infrastructure needed to share online experiments, which can otherwise be inconvenient and time consuming. An important reason for joining an online portal is that it makes dissemination of content much easier and allows access for a much wider variety of experiments. Schools, industry and interested individuals will be able to find out about the weblab via the portal, significantly increasing the marketing potential of the online resource.

Through the LiLa portal, students were able to book a slot and log in to the PCS 7 system. This facilitated the scheduling of experiments. Additionally, students can connect to the Library resources where all the documentation needed to perform the experiments including tutorials, is available. The use of LiLa significantly improved administration and communication both within the Chemical Engineering Department at Cambridge and with respect to external users.

5 Evaluation

The experimental equipment is designed to run over long periods of time with minimal maintenance. Once set up and switched on the only thing requiring attention is the level in the storage tanks. Technically, the equipment and interface performed without fault during the duration of the course (fifteen two-hour sessions during three weeks), except for a few isolated cases. Because of the nature of the apparatus, it is inevitable that some physical human intervention is required, occasional maintenance is required to correct faults and update software.

Students are able to communicate with demonstrators or technical support providers via msn live messenger. Scheduling of experiments is done using the LiLa portal.

5.1 Students feedback

Student feedback was obtained in Lent term 2009 by issuing questionnaires assessing usability of experiment and interface, group work experience, meeting educational objectives, and experience in comparison to exercises in other subjects. In the questionnaire the students had to state to what extent they agreed with a number of statements on a Likert scale from 1, “I strongly disagree” to 7 “I strongly agree”. A total of 36 students performed the exercise, and 30 of them handed in a completed questionnaire. Results of the questionnaire are presented in **Figure 8**.

The students were provided with a web-based exercise sheet and detailed instructions on how to carry out the experiment. Time spent with the experiment varied from 90 to 120 minutes. The students were satisfied with the instructions and managed effectively to use the PCS 7 interface. The use of an industrial process control system was very positively received by the students.

They were also positive to working in groups and felt that they could contribute to the group. Due to scheduling limitations the group size varied from three to six students making it difficult to draw any conclusions from the answers. Previous experience with this exercise indicates that groups of three are preferred by the students and also allows all group members to contribute.

The students agreed that the exercise provided an experience of analysing real data, gave an insight into non-ideal modelling and behaviour and also provided an experience in using industry standard process control software. The use of an industrial process control system was very positively received by the students. The students could also leave text comments on the questionnaires and these included: “The experiment was very easy to

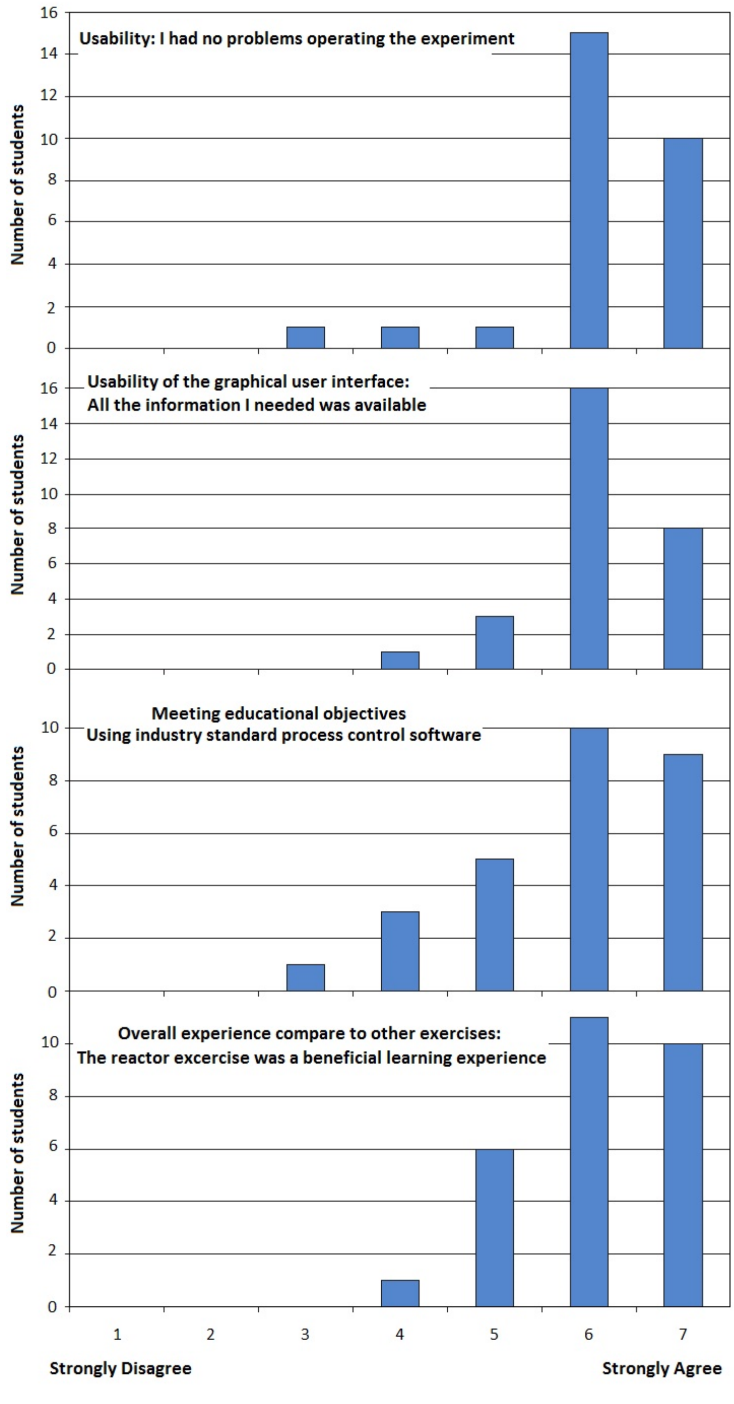


Figure 8: *Students ranked the remotely controlled experiment and its usability.*

use", "Easy to obtain and process data. Clear what was going on" and "Very happy, especially with industry standard software".

5.2 Sustainability challenges

Sustainability is not limited to the creation, associated publishing, management and development of remote experiments; it also requires the ability to continually provide value in terms of learning and professional development. Remote experiments require a careful sustainability strategy as described by *Watson et al.* [22]. High staff turnover in higher education sometimes means that the remote experiment stops working when the technical expertise required to maintain it is lost.

There have been several challenges to address in sustaining the weblabs at the University of Cambridge. Although Siemens have usually been willing to offer the support necessary to implement any upgrades or maintenance required to ensure that the weblabs continue to develop and remain in good working order, demonstrator activities, technician time and bench space are funded by the university teaching budget. The costs of running and maintenance of the experiment are significant, in addition to staff requirements. It it necessary to convince the University administrators of the advantage of using state-of-the-art industrial equipment in teaching instead of inexpensive pen and paper exercises.

Sharing of remote experiments is also limited in scalability, it costs time and money to integrate the system into curricula at other institutions, and to coordinate teaching times at other universities [6]. Institutions are not ready yet to pay for access, since the technology is not yet fully accepted as part of the curriculum. Seeking funding and industry backing, initiatives can grow faster and more sustainably by looking for opportunities to decentralise processes.

5.3 Remote experiments vs. Virtual Labs

Virtual Labs are an alternative to Remote Experiments which can provide engaging interfaces and sometimes offer authenticity at lower cost. They often have to be developed from fundamentals, sometimes from existing software. Pedagogical advantages includes the theoretical understanding of fundamentals, promoting critical thinking and creativity. Additionally, they provide less restrictions to the students with exploratory, trial-and-error learning. However, they lack the realistic industrial interfaces inherent of remote experiment experiences.

By using remote or virtual experiments as a vehicle for engaging with industrial partners, a further dimension can be added to online laboratory learning. Students can gain more relevant skills and experience and may even be able to contribute to the development of a product.

6 Conclusions

We have designed and built a remotely controlled experiment suitable for teaching reactor engineering and process control. By using industry standard control software (Siemens PCS 7) we can also give students an introduction to real-world control systems. We have installed a webserver, enabling remote access to the experiment from anywhere in the world, thus allowing students at other universities to use the experiment. Evaluation of student response to the experiment shows that industry standard software is a valuable educational tool. Broadcasting of experiments to other universities illustrates the benefits of sharing resources, allowing experiments and demonstrations to replace simulations or pen-and-paper exercises.

7 Acknowledgments

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References

[1] E. B. Acworth. University-industry engagement: The formation of the knowledge integration community (KIC) model at the Cambridge-MIT Institute. *Research Policy*, 37(8):1241 – 1254, 2008. ISSN 0048-7333. doi:10.1016/j.respol.2008.04.022. Special Section on University-Industry Linkages: The Significance of Tacit Knowledge and the Role of Intermediaries.

[2] B. Aktan, C. A. Bohus, L. A. Crowl, and M. H. Shor. Distance learning applied to control engineering laboratories. *IEEE Transactions on Education*, 93:320 – 326, 1996.

[3] S. D. Bencomo. Control learning: present and future. *Annual Reviews in Control*, 28:115 – 136, 2003.

[4] J. Bourne, D. Harris, and F. Mayadas. Online engineering education: Learning anywhere, anytime. *Journal of Engineering Education*, 94:131 – 146, 2005.

[5] G. H. Cohen and G. A. Coon. Theoretical consideration of retarded control. *Trans. ASME*, 75:827–834, 1953.

[6] R. de Campos Giordano. Web labs dilemma in chemical engineering teaching: Hindering or promoting creativity? *Computer Aided Chemical Engineering*, 27:13–14, 2009.

[7] H. Ewald and G. F. Page. Performing experiments by remote control using the internet. *Global Journal of Engineering Education*, 4:287 – 292, 2001.

[8] F. González-Castaño, L. Anido-Rifón, J. Vales-Alonso, M. Fernández-Iglesias, M. L. Nistal, P. Rodríguez-Hernández, and J. Pousada-Carballo. Internet access to real equipment at computer architecture laboratories using the java/corba paradigm. *Computers & Education*, 36:151 – 170, 2001.

[9] J. Guo, D. Kettler, and M. Al-Dahhan. An internet-based distributed laboratory for interactive chemical engineering education. *Chemical Engineering Education*, 41: 24–30, 2006.

[10] G. A. C. LeRoux, G. B. Reis, C. D. F. de Jesus, R. C. Giordano, A. J. G. Cruz, P. F. Moreira, C. A. O. Nascimento, and L. V. Loureiro. Cooperative weblab: A tool for cooperative learning in chemical engineering in a global environment. *Chemical Engineering Education*, 44:9–12, 2010.

[11] LiLa. Library of labs website: Weblabs University of Cambridge. http://www.lila-project.org/content/ucam/index.html.

[12] M. Ogot, G. S. Elliott, and N. Glumac. Hands-on laboratory experience via remote control: Jet thrust laboratory. volume June. American Society for Engineering Education Annual Conference and Exposition, 2000.

[13] M. Ogot, G. Elliott, and N. Glumac. An assessment of in-person and remotely operated laboratories. *Journal of Engineering Education*, 92:57–64, 2003.

[14] T. Richter, D. Boehringer, and J. S. Lila: A European project on networked experiments. In *Sixth International Conference on Remote Engineering and Virtual Instrumentation*, Bridgeport, NJ, USA, 2009.

[15] T. Richter, Y. Tetour, and D. Boehringer. Library of labs - a European project on the dissemination of remote experiments and virtual laboratories. In *Multimedia (ISM), 2011 IEEE International Symposium on*, pages 543–548, Dec 2011. doi:10.1109/ISM.2011.96.

[16] T. Richter, R. Watson, S. Kassavetis, M. Kraft, P. Grube, D. Boehringer, P. de Vries, E. Hatzikraniotis, and S. Logothetidis. The WebLabs of the University of Cambridge: A study of securing remote instrumentation. In *Remote Engineering and Virtual Instrumentation (REV), 2012 9th International Conference on*, pages 1–5, July 2012. doi:10.1109/REV.2012.6293099.

[17] D. E. Seborg, T. F. Edgar, D. A. Mellichamp, and F. J. D. III. *Process Dynamics and Control*, chapter Fitting first- and second-order models using step tests, pages 119–123. Wiley, third edition, 2011.

[18] A. Selmer, M. J. Goodson, M. Kraft, S. Sen, V. F. McNeill, B. S. Johnston, and C. K. Colton. Performing process control experiments across the atlantic. *Chemical Engineering Education*, 39(3):232–237, 2005.

[19] A. Selmer, M. Kraft, R. Moros, and C. Colton. Weblabs in chemical engineering education. *Education for Chemical Engineers*, 2(1):38 – 45, 2007. ISSN 1749-7728. doi:10.1205/ece06018.

[20] Siemens. Simatic PCS 7 distributed control system. online tutorials at: http://w3.siemens.com/mcms/process-control-systems/en/distributed-control-system-simatic-pcs-7/pages/distributed-control-system-simatic-pcs-7.aspxs.

[21] M. Skliar, J. W. Price, and A. Tyler. Experimental projects in teaching process control. *Chemical Engineering Education*, Fall:254 – 259, 1998.

[22] R. Watson, A. Coble, A. Bhave, A. Braumann, A. Smallbone, and M. Kraft. *Internet Accessible Remote Laboratories: Scalable E-Learning Tools for Engineering and Science Disciplines*, chapter Collaborative Sustainability Strategies for Online Laboratories, pages 468–490. 2012. doi:10.4018/978-1-61350-186-3.ch024.