Web-based remote experiments with a real technical plant in chemical engineering education

A. Klein; C. Hausmanns and G. Wozny

TU Berlin, Institute of Process and Plant Technology, Sekr. KWT 9,
Strasse des 17. Juni 135, 10623 Berlin, Germany

Abstract

This paper deals with the development of a web-based process control system for laboratory plants for training of students over the internet and demonstration purposes. The system is described in detail on the example of a fully automated distillation column for the separation of ethanol-water mixture. Finally, the successful evaluation of the tool is exemplarily presented for a troubleshooting task as a didactical scenario. The process-user-interface is implemented using the tomcat container with a JSP application and the OPC interface API.

Introduction

As [Auer, 2004] states, active working with experiments in problem solving scenarios is assumed to help learners to acquire applicable knowledge for practical situations. The seen advantages and disadvantages of online experiments over real on-lab experimentation on the one side, and completely virtual labs (simulations) on the other side have been figured out by [PROLEARN 2004]: “In a local [on-lab] experiment, students operate real devices and manipulate and measure real objects while being directly co-located with the devices and objects in the same room. In a remote experiment, students and devices are at different locations and students work through a computer that is connected online to a real experiment device. Virtual experiments contain software simulations of experiments and pre-recorded measurements, pictures and videos but do not manipulate real objects.”

[Urbas, 2005] states that an advantage of remote labs over on-lab experimentation is seen in the greater accessibility. Learners are enabled to conduct experiments from wherever they want and they are able to use experimental facilities from anywhere without moving. Thus, didactical scenarios with a student who is resident in Europe conducting experiments in a United States lab, supervised by an Australia-based professor are feasible. With pooled remote access labs, students can benefit from a greater availability of different type of lab equipment. Due to the higher utilization of experiments, even for the owner it is worthwhile to open his local capacities to a broader community. The missing hands-on experience puts the online experiments at a slight disadvantage with local experiments. This is seen in the missing achievement of skills to prepare the equipment etc. Engineering students can conduct complicated experiments, while they are not able to use a screwdriver properly. Complexity is reduced, and the students will never have to conduct real troubleshooting, since they are not the ones to adjust the equipment if something goes wrong.

In contrast, simulations show a further reduced complexity since the system will only respond according to its predefined model. Nevertheless, complexity reduction is a basic didactical principle, and the power of simulation is seen in the interactive illustration of theoretical concepts.

[Michaud et al., 2001] propose different didactical applications of online remote labs:

- Teachers can use it during lectures for demonstrations
- Students can use it during scheduled lab sessions as an experiment sharing tool
- Students can use it outside class as a flexible self-training tool

[Ferreira and Müller, 2004] conclude their overview on remote labs with the following statements:

- Remote experimentation cannot be a replacement for on-lab experimentation (nor for simulation).
- The goal should be to provide learning activities with embedded remote experiments (and not remote experiments by themselves...)
- There are pros and cons in remote experimentation (just as it happens with all other approaches...)
- Networks of remote labs are able to provide a rich multi-cultural environment and widen the resources offered by each university to its students

In the field of teaching process and chemical engineering, practical experience plays an important role. Currently, many institutions for engineering education are making great efforts to provide a web-based access to real experimental facilities to their students [Carnevali & Buttazzo, 2003; Erbe & Bruns, 2003; Zeilmann et al., 2003; Michaud et al., 2001, Henry & Knight 2003]. Since practical training is also a very time consuming task for both, students and teachers, and therefore often neglected, the Department of Process Dynamics and Operation (d|b|t|a) and the Center of

Human Machine Systems (ZMMS) of the Berlin University of Technology are searching for new ways of giving access to the laboratories and integrating this field to the existing curriculum [Wozny 2003].

Such remote laboratories are expected to have a significant pedagogical benefit, especially compared to virtual laboratories, which are based on simulations [Alhalabi et al., 2000]. In particular, remote labs are considered as advantageous for being closer to reality, providing real-time, noisy data and a higher degree of freedom for the learners. This is assumed to increase the involvement of the learners, enabling a "thrilling" learning experience and stimulating higher order thinking skills. This paper focuses on the technical realization and the implementation of an online column within a teaching course for students.

The Online Distillation column

In this paper, a web based laboratory is presented used to access and conduct experiments with chemical process plants [Klein 2004]. The process used for this experiment consists of an ethanol water distillation column with 20 glass-trays and a set of video cameras for visualization which is set up at the Department of Process Design and Operation d|b|t|a at the Berlin University of Technology. Due to its simplicity and nontoxic properties, the ethanol-water mixture is a standard learning example in teaching process behaviour. The distillation tower is 3.5 m high and has a diameter of 35 mm. It is automated and controlled by the process control system (PCS) ABB Freelance 2000™. To facilitate interoperability with other applications, Freelance includes an OPC-server which is based on the DCOM™ standard. The technical aspects of the communication between the plant and the user will be described later. The plant is equipped with 21 sensors that measure the temperatures on every second tray, flows (products and feed) and pressures (pressure drop and absolute pressure). Four actuators (feed flow rate, feed temperature control-on/off, heat duty and recycle stream) are mounted in the plant which can be controlled on-site via the PCS Operator Console as well as via OPC over the Internet by a remote user.

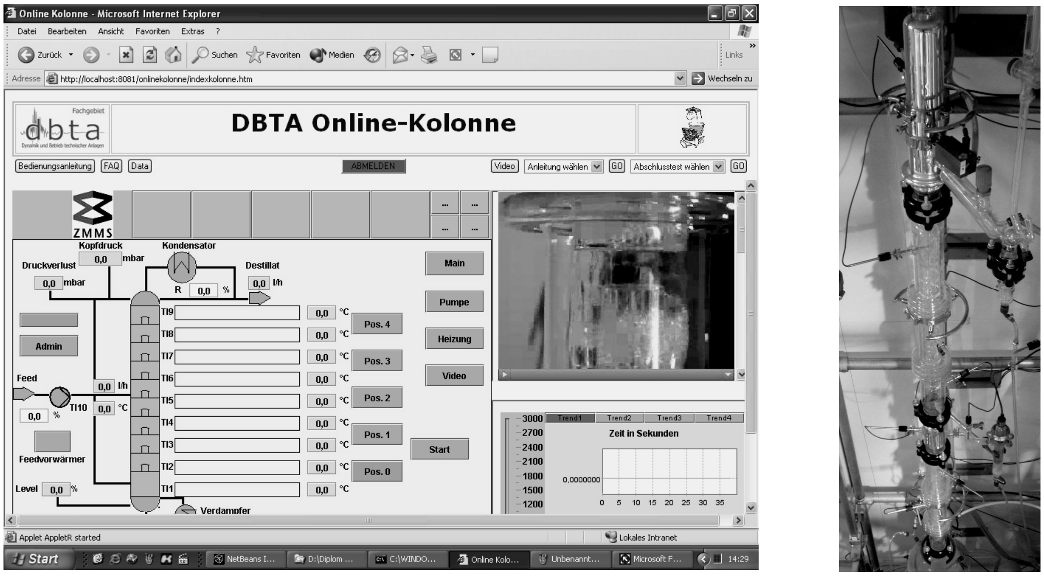

Figure 1 Web interface and online column

Besides the control of the actuators and the observation of the sensor data, which are visualized by a java-applet in the browser, users can visually observe the column using a video stream also. The camera is movable between five fixed positions and shows the interesting parts of the column like the reboiler, feedstage and condenser. The live streaming video signal is captured with a broadcaster and sent to the user either directly or – for the use in virtual classrooms – via a streaming server. The used media format is quicktime, that is broadcastet by the Sorenson Broadcaster and served by the open-source Darwin^{TM} streaming server by Apple^{TM}. As shown in Figure 1, the camera positions are driven by the PCS and are also controlled via internet.

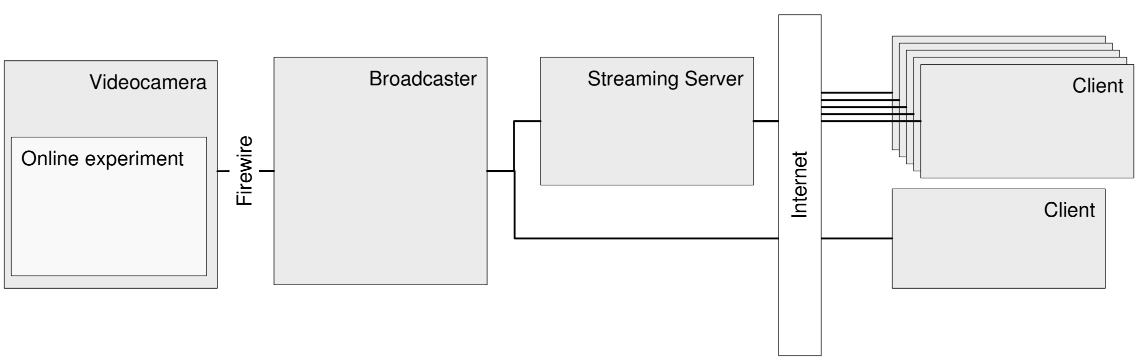

Figure 2 Communication structure: Broadcastingsystem

Technical background

For remote experimentation, the process can be controlled in real-time via internet using a Java applet called PE/SSE[1]. Real-time data trend diagrams are displayed for the observation of different sensors like temperature, flow, pressure and concentration. Additionally, the streaming web cam picture is displayed. The user is connected to the process control system Java and OPC Technology [OPC]. Figure 3 shows the communication structure in detail.

On the client-side, we use a proprietary developed Java™-based experimental PCS called PE/SSE that is able to run the user interface (GUI) embedded in web browsers [Klein 2003]. The data-exchange between the GUI and the PCS core is based on an open internet protocol for process data transport (PDTP) [Urbas1999]. To connect Freelance2000™ to the PCS core a bridge is implemented between the client side and the server-side process control systems. This architecture ensures scalable and reliable access to our laboratory resources.

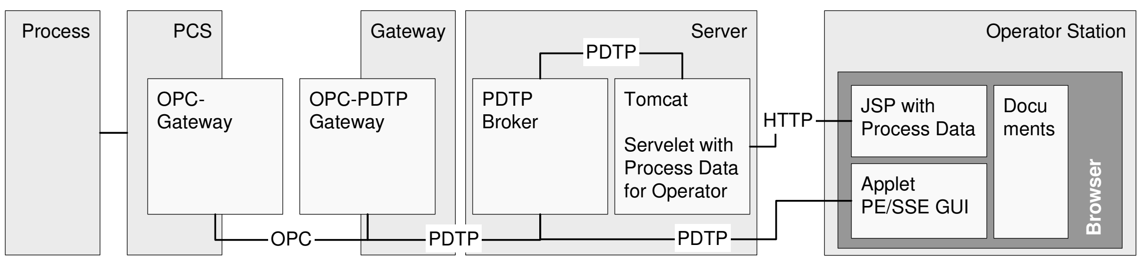

Figure 3 Communication structure: OPC-Server – PE/SSE - Bridge

As shown in figure 3 above, the bridge between client- and server-side PCS consists of:

- OPC-server: This server is part of the ABB Freelance2000™ PCS.
- OPC-to-JAVA-client [JOPC]: This client provides a Java™ api to access the OPC-server.
- PDTP-client: This newly designed compound translates PDTP-variables used by the PDTP-broker into OPC-to-JAVA-client function calls.

---

[1]Process Operation Education and Training/Small Systems Edition

- PDTP-broker: The purpose of this compound is to manage the communication between the PE/SSE-GUI's of users and other gateways. The OPC-variables which have to be sent to the PDTP-broker are defined in a configuration-GUI.

Besides the PCS, we have developed an interface between the broker and commercial simulation environments like gProms™ [2]. With these interfaces at last, it doesn't matter if the data originate from a real process or a simulation, if they are PDTP compliant. Furthermore, the broker handles the user connections between PE/SSE and process (real or simulation). Due to the rights management of the broker, only one user can act as an operator while a lot can view the scenario. Thus, with this system virtual classroom scenarios can be run. The system has been implemented fully scalable with modularized process side broker architecture.

The front end of the inline column has been adopted closely from DIN 19227 and thus is similar to the user interface design of commercial PCS with some additional abilities (Figure 4).

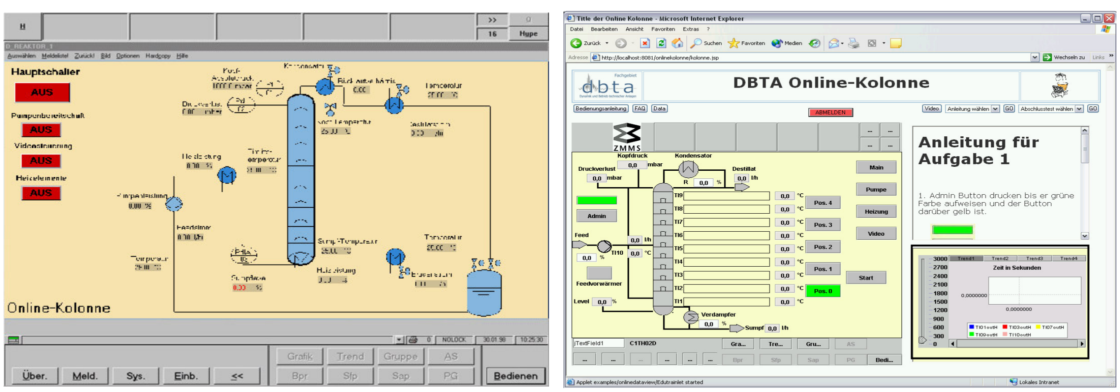

Figure 4 Comparison Freelance PCS and PE/SSE-GUI

With this architecture, the system can be run either as a standalone program on any operating system or as an applet embedded in a web browser. Using its open internal object model, many add-ons for different purposes, e.g. integrated adaptive information and support depending on process data or background information are implemented. For the configuration of PE/SSE, a library of templates is implemented. Since the object model behind the GUI bases on the JavaBeans-standard, it is easy to add new or edit existing components.

---

[2] gProms™ by PS-Enterprise modelling and simulations software for process engineering

Due to the fact that users deal with a real remote plant, security issues are key aspects of remote experiments. Even if we envisage a benevolent user, misconduction can push our experiment into an instable state, which we have to avoid. Unfortunately, our users are engineers and there are only a view things being more interesting for our learners than to go the one efficient way of learning systems interrelationship: analyze system failure. Thus, remote experiments have to imply a inherent safe process design as well as to provide maximum security against hacker attacks. Since the process deals with inflammable substances, it is mounted in a fire protective fume hood. In the online experiment, all valves and the reboiler are designed inherent safe so the system in case of trouble will fall back to a stable state on its own. Additional security is given by using a weak reboiler which causes slow system dynamics and expends reaction time for the operator. To create feasible shutdown-scenarios and to find possible safety risks, a HAZOP Analysis was conducted. Its results on the one hand have been the basis for the design of the process fallback strategy and on the other hand for the automatic shutdown scenario of the PCS.

Safety against hacking is provided by the usage of restrictive firewall settings and network structures, as well as several underlying systems of the experiments components. Additionally Log files are automatically traced to reduce hazard of being hacked.

Evaluation of the tool

First evaluation of the tool has been conducted by [Gauss 2004]. The students in the role of operators have to identify and to fix two disturbances affecting the proper operation of the column. Therefore, the students have to detect the irregularities in the related trend diagrams and gather the correct malfunction cause. At least, the students should initiate the correct reaction and bring the process back into a steady state. The troubleshooting scenario supports the students to go deeper into the relation of theoretical modelling and the physical behaviour of the real process. As the students operate the process, they get a new perspective on theoretical learning content. The results of the evaluation study indicate that the learning scenario was highly accepted by the students [Gauss 2004, Klein 2004]. Troubleshooting performance was influenced by intrinsic motivation and information processing velocity of the learners. In a controlled study conducted by [Gauss 2004], the

acceptance of the scenario and its effects on learning outcome are positively evaluated.
At the d|b|t|a, online experiments are integrated into existing courses like process dynamics and process control, where the lecturer can access the experiment from a lecture, as well as into practical exercises, where for instance students can handle the column themselves to see the effect of certain disturbances on the hydrodynamic, energy balance and the product quality. The results of the experiments can be taken over into MS EXCEL and there be analysed. With this experiment, practical process knowledge can be transferred to the students inside the universitary learning environment.

Conclusions

Active working with Online experiments is assumed to support students acquiring applicable knowledge for practical situations [Auer, 2004]. The seen disadvantage of online experiments not to impart hands on experience is balanced by the greater accessibility and the broadened spectra by pooling of online experiments. Due to the higher utilization of experiments, even for the owner it is worthwhile to open his local capacities to a broader community. In contrast to online experiments, online simulations show a further reduced complexity since the system will only respond according to its predefined model. Technically, there are several methods to offer experiments online. One of the methods using a commercial underlying PCS with a proprietary java and OPC -based has been presented here.
A major advantage of the presented over other methods is the ability to put context sensitive information on the process or modeling theory of the processes elements directly on the elements of the PCS-screen.
Because users handle a real remote plant, security issues have to be considered carefully with remote experiments. The process design should address three levels of security – play for safety – narrow damage down - avoid environmental impact – and thus be considered in a safety analysis like the HAZOP. The results of the analysis lead into a inherent safe process design and some IT infrastructural actions to ensure process safety as well as safety against web attacks.
The implemented experiment was positively evaluated in a formative study and has been introduced into two lectures – process dynamics and process control. Due to

the good motivational effects, other Online Experiments have been implemented using standardized access technologies.

The next step will be to find a self supporting operating structure to finance the mounting, maintenance and operation of online experiments in future.

References

[Auer 2004] Standard online lab environments using different technologies. http://www.l3s.de/oews2004/index.php?id=701

[Carnevali 2003] Carnevali, G. & Buttazzo, G. (2003). A virtual laboratory environment for real-time experiments. In Proceedings of the 5th IFAC International Symposium on Intelligent Components and Instruments for Control Applications (SICICA 2003), Aveiro, Portugal, July 9-11 (pp. 39-44).

[Conrad 1980] Conrad, W., Baumann, E. & Mohr, V. (1980). MTP: Mannheimer Test zur Erfassung physikalisch-technischen Problemlösens. Göttingen: Hogrefe.

[Erbe 2003] Erbe, H.-H. & Bruns, F. W. (2003). Didactical aspects of mechatronics education. In Proceedings of the 5th IFAC International Symposium on Intelligent Components and Instruments for Control Applications (SICICA 2003), Aveiro, Portugal, July 9-11 (pp. 45-50).

[Ferreira and Müller 2004] Ferreira, J. M. & Müller, D., 2004 The MARVEL EU project: A social constructivist approach to remote experimentation. 1st Remote Engineering and Virtual Instrumentation International Symposium (REV'04), Villach (Austria), 28 - 29 September 2004. http://www.marvel.unibremen.de/fileadmin/templates/MARVEL/documents/REV2004-FEUP-Present.ppt

[Friedrich 2001] Friedrich, H. F., Hron, A. & Hesse, F. W. (2001). A framework for designing and evaluating virtual seminars. European Journal of Education, 36 (2), 157-174.

[Gauss 2004] Gauss, B., Klein, A., Urbas, L., Zerry, R. & Wozny, G. (2004) Learning by troubleshooting – a suitable didactical scenario for online experiments?, INCOM 2004 - 11th IFAC Symposium on

Information Control Problems in Manufacturing, 5 -7 April 2004, Salvador, Brasil

[Grund 2002] Grund, S. & Grote, G. (2002). DERIVE final evaluation results. Retrieved December 9, 2003, from http://www.derive.uni-bremen.de/pdf/D55.pdf

[Henry 2003] Henry, J. & Knight, C. (2003) Modern Engineering Laboratories at a distance, Int. J. Engng. Ed. Vol. 19, No. 3, pp. 403 – 408, 2003

[JOPC] JOPCClient TM, OPI Odense Production Information, Denmark

[Klein 2003] Klein, A., Zerry, R., Hausmanns, C., Urbas, L. & Wozny, G. (2003) Java based Process control of a distillation column via internet using OPC; ECCE-4, Granada [Spain], 21-25. September 2003

[Klein 2004] Klein, A. Hausmanns, C., Urbas, L. & Wozny, G. (2004) Internet-based Learning – the online laboratory Distillation column, EDEN 2004 – Annual Conference 2-6. June 2004, Budapest

[Michaud 2001] Michaud, F., Gentil, S. & Barrault, M. (2001). Expected benefits of web-based learning for engineering education: examples in control engineering. European Journal of Engineering Education, 26 (2), 151-168.

[OPC] www.opcfoundation.org

[Oswald 1987] Oswald, W. D. & Roth, E. (1987). Der Zahlen-Verbindungs-Test (ZVT). Göttingen: Hogrefe.

[Unz 2000] Unz, D. (2000). Lernen mit Hypertext: Informationssuche und Navigation. Münster: Waxmann.

[Urbas 1999] Urbas, L., Entwicklung und Realisierung einer Trainings- und Ausbildungsumgebung zur Schulung der Prozessdynamik und des Anlagenbetriebs im Internet (Development and realisation of a trainings environment for process dynamics and operation via internet), VDI-Fortschrittsberichte Reihe 10 Nr. 614 1999

[Urbas 2005] Urbas, L., Gauss, B., Klein, A., Wozny, G. Online Remote Laboratories. In: Wozny, G. (Edt.) (2005). ELearning in Process and Chemical Engineering – A practical Overview. Edited by Günter Wozny. Berlin, Düsseldorf: VDI Verlag. ISBN 3-18-382803-0

[Wozny 2004] Wozny, G., Klein, A., Zerry, R., Hausmanns, C. & Urbas, L. (2004) Improvement of learning of process technology using modern information technology, PRES 2004, 7th Conference on Process Integration, Modelling and Optimisation for Energy Saving and Pollution Reduction, 22-26. August 2004, Prag

[Zeilmann 2003] Zeilmann, R. P., Gomes da Silva Jr., J. M., Bazanella, A. S. & Pereira, C. E. (2003). A web-based remote laboratory for control education. In Proceedings of the 5th IFAC International Symposium on Intelligent Components and Instruments for Control Applications (SICICA 2003), Aveiro, Portugal, July 9-11 (pp. 51-56).