REMOTE EXPERIMENTATION – NEW CONTENT IN DISTANCE LEARNING

Bjarne A. Foss[#], Kjell E. Malvig[#], and Tor I. Eikaas[*]

[#]Department of Engineering Cybernetics, Norwegian University of Science and Technology, N-7491 Trondheim, Norway.
[*]Cyberlab.Org AS, Trondheim, Norway.
e-mail:, bjarne.foss@itk.ntnu.no, kjell.malvig@itk.ntnu.no, tor.i.eikaas@cyberlab.org

Abstract: *This paper proposes to improve access to laboratory experiments in engineering education by making remote experimentation accessible through the use of the Internet. It is proposed to form a network of providers of remotely operable laboratory experiments, and to delegate many of the technical, managerial and financial tasks involved in operating such a network to a commercial organizing company.*
Further, the paper describes the EU-project ReLAX which aims at making remote experimentation available as a component in distance learning. The project will perform a full-scale evaluation of remote experimentation with respect to didactical, technological and commercial issues.

Index terms – New educational tool, remote experimentation, remote laboratories, control engineering

INTRODUCTION

Internationalisation of education is expanding tremendous both in the market for ordinary education and in the continous and postgraduate education markets. Distance learning and Information Technology based learning are keywords used in that connection. Students are able to take parts of their education from their local base, which makes education more comfortable and reaching out to more rural regions. It also makes oportunities for education institutions, both nationally and internationally, to cooperate by giving special courses from different Campuses to the same students. Each course given by the best specialists. To make students feel confident in bying a high quality product, it is important that it is offered from well acknowledged education institutions who can garranty quality and accreditation. Traditional courses has been offered for quite a long time now, but remote experimentation is a relative new component to improve distance learning.

Learning an engineering discipline is accomplished through a diverse set of activities, such as lectures, tutorial exercises, simulation, and pilot plant experiments. It is widely recognized that efficient learning requires a mixture of theoretical and practical exercises. One of the main features which sets engineering apart form the pure natural sciences, is that engineering is more or less exclusively focused on solving problems in the 'real' world. This real-world focus of the engineering disciplines makes practical exercises particularly important in order to develop an understanding of how to apply theoretical knowledge to real-world problems; [1], [2].

During the last decades there has been a definite trend towards increased use of simulation in engineering education, coupled with a decline in the use of physical experiments. There are several reasons for this. One obvious reason is the fact that physical experiments are costly both to build and maintain. Another reason has been a strong belief that simulators can replace physical experiments. The ability to simulate a process is clearly very helpful in finding solutions to many real-world problems. Knowledge of modeling and simulation are therefore important skills for an engineer. Nevertheless, it is the strong belief of the authors that physical experiments constitute an important ingredient to achieve efficient learning. Real-life processes, even at a laboratory scale, display features that are not captured by simulators. Such features include:

They are physical entities, which can be seen, and often also heard and touched. The typical student therefore finds it motivating to work with laboratory experiments. A successful laboratory experiment is in some sense proof that the student has been able to perform a task which is of relevance to the real world.

With simulators, the relation to the real world is more unclear. It is often necessary to study the simulation model quite carefully if one wants to assess the accuracy with which the different physical phenomena are represented.

There are levels of complexity in physical processes that are hard to capture with simulators. Such complexity can be related to safety aspects (physical equipment requires the 'operator' to take more care), startup or shutdown procedures, or complications related to obtaining the desired information from the system at hand.

The discussion above points to the need for making physical experiments more available to engineering students, and more affordable for

educational institutions. This paper will report on one initiative which aims to achieve this, with the use of modern communication technology. A central component in this initiative is the EU-project ReLAX which will be reported in this paper.

THE CYBERLAB INITIATIVE

The Cyberlab initiative is based on the idea that although a physical process cannot easily be moved, it can be made available for on-line remote experimentation via the Internet. The providers of laboratory facilities will be paid for the use of their facilities, while the customers (users) are relieved of the costs involved in building and maintaining the laboratory equipment. Both therefore stand to gain. This also enables a much more efficient use of laboratory facilities, since much laboratory equipment in universities is at present used for only a fraction of the academic year. A key aspect of the Cyberlab initiative is the realisation that a commercial company is needed for handling many important tasks:

- All aspects regarding booking and reservation of experiment time.
- Handling of invoicing and payments.
- Quality assurance of the experiments.
- Provide functional specifications and software components for remote experimentation.
- Marketing of the experiments that meet the defined quality standards and functional specifications.
- Provide the software necessary for bringing an experiment on-line.

The quality standards that the organizing company will have to ensure, should cover both the quality of the physical equipment and its instrumentation, the quality of the available interface for remote operation, as well as the educational value of the experiments that are available on the specific laboratory equipment.

The Cyberlab initiative has received a positive response from key control groups on both sides of the Atlantic [3]. The aim is to establish a network of providers of physical experiments. Each provider of experiments may concentrate their effort on maintaining a few high-quality experiments for remote on-line experimentation, while having access to many other remote laboratories from other providers of experiments. Further, other users without their own laboratory facilities, may purchase access to remote laboratories. This latter category of users will include universities that have given up on practical experiments due to high costs, open universities like FernUniversität Hagen in Germany and Open University in the UK, commercial organizations offering continuing education courses, and in-house training departments in engineering and production companies.

It should be noted that there is an intense interest from the EU towards innovative internet-based education concepts, see eg. [4], [5], [6].

Fig.1 visualizes the concept of remote experimentation. A physical apparatus, in this case the refrigeration process at the Department of Engineering Cybernetics at NTNU, can be observed and manipulated in a close-to realtime manner by a student at some remote location. The information flow between the physical system and the student uses the Internet as its communication channel. The student may eg. manipulate the refrigeration process by changing the setpoint of certain online controllers and observe the response on strip charts. Further, the student may save the process data for later analysis and documentation; eg. in a report. The student may have different options to observe the process. One example is the use of virtual reality techniques to enhance the understanding of the physical apparatus and the experiment being undertaken.

THE ReLAX PROJECT

The ReLAX project allows us to develop a remote experimentation network according to the ideas of the Cyberlab initiative, and perform a full-scale evaluation of this network with respect to didactical, technological and commercial issues. The focus area is engineering education within control and cybernetics. During 2000 and 2001 the network obtains the necessary funding from the EU within a trial project "Remote LAboratory eXperimentation trial" (ReLAX) including participants from different countries. The participants are from Norway (Cyberlab.Org AS, Prediktor AS, Norwegian University of Science and Technology (NTNU)), Germany (Ruhr-Universität Bochum (RUB)) and from Switzerland (Swiss Federal Institute of Technology (EPFL)).

The Web-site for the ReLAX project is www.relax-project.com.

Structure of the ReLAX network

The structure of the ReLAX network is based on the Cyberlab initiative. An organising company (Service Provider), the experiment broker, offers a set of laboratory experiments to Customers (universities, individuals and industrial companies) on a global basis through a Web-based trading system, see Fig. 2. The experiments are selected, high quality experiments offered by first rate educational institutions (Providers).

The organising company is responsible for the commercial aspects like quality assurance, marketing, assigning experiments and time slots, brokerage, invoicing, secure electronic payment, etc.

The Provider will connect a laboratory experiment to the Internet through a Web service, and the user interacts with the experiment through some client-side software, eg. a Web browser. The information received from the experiment will typically include time series plots, video and audio information. When the experiment is completed, it should also be possible to obtain comprehensive documentation of the experiment by downloading files consisting of time series of experimental results. Exactly which variables the user should be able to manipulate remotely, as well as when, how and how much the variables can be manipulated, will depend on the experimental design.

The Service Provider will specify key aspects of how the user should be able to interact with the process, and will assist the Provider in connecting the experiment to the Internet, if the Provider requires such assistance. However, all technical specifications will be independent of the actual hardware and software the Provider uses.

Within the network, an external user group will be established and designed to obtain the right interaction with possible future customers from industry and open learning institutions.

Experiment types

The different experiments have to support different concepts in control courses like controller tuning, model development, and the actual programming and implementation of a control scheme or algorithm. In the ReLAX project there are different types of control experiments that can be run remotely. Some typical examples are:

- Experiments where the user acts as an operator for the laboratory process. Typically the user will change the reference values of some control loops and monitor the equipment. Further, the user may change some control parameter settings, such as gain and integral time for a controller. Such parameter changes may be based on intuition only, or result from systematic tuning procedure, which may be supported in the experimentation environment. The experiment may be designed to introduce disturbances, to make the operator function more challenging.
- The user may run identification experiments by perturbing the system and collecting process data. These may be used to identify an empirical dynamical model, to determine parameters in a model of the process, or to validate a model. Both open-loop and closed-loop experiments may be run.
- The user may program a controller and download it to the control system, and then assess its performance by running experiments with this controller. This opens possibilities both for giving students more realistic experience with advanced control concepts, as well as to provide researchers with a test facility for new controller algorithms that are closer to industrial reality than what simulation alone can offer.
- The use of Web technology also allows for a tight integration of tutorial material on the process or the control theory, which the experiments are designed to demonstrate. This is illustrated in Fig.3, where a screen shot of a Web page showing a process layout is depicted. By pointing to key equipment in the process, a pressure-enthalpy diagram pops up, in which a refrigeration cycle is drawn in. It is also explained where the equipment pointed to is located in the pressure-enthalpy diagram.

More details on the experiments can be found in [7].

Telepresence

There are a number of technological and practical issues that need to be resolved in order to give the Customer the necessary feeling of close interaction with the real, physical equipment. The ability to manipulate the experiment remotely, and seeing the results of such manipulations in real time, will contribute to this aim. The feeling of being present at the experimental site can be further enhanced by the transmission of sound and video images from the experiment, and by the use of virtual-reality techniques. We again refer to Fig.2 to illustrate this.

On the other hand, the fact that the experiment is located far away from the experimenter can also be regarded as an educational asset. There are two reasons for this:

- Plants are usually operated ‘remotely’, by operators located in a control room some distance from the physical plant. Hence, running remote experiments actually reflects the real working conditions.
- The trend towards virtual organizations where an operating organization is located in different physical locations is quite apparent in many organizations. This trend can also be anticipated for the most highly skilled technical support staff in many industries. This means that the use of remotely operated experiments is likely to be quite representative of how many control engineers will work in the future.

Didactical issues

An important part of the project is the measurement and evaluation of the educational value of using remote experimentation in distance learning. This will be performed by using remote experimentation in selected courses within the three participating universities, and by using remote experimentation within professional continued education courses.

In particular it will be important to identify how remote experimentation should be integrated as *one* of the components in a distance education course to improve learning as compared with present distance learning courses.

CONCLUSIONS

This paper argues that the Internet makes remote operation of laboratory equipment feasible, and that such remote operation can have substantial educational value if the experiments are properly designed. Remote experimentation has the potential for both making experiments on real physical equipment more affordable, and provide for more efficient use of existing laboratory facilities.

ACKNOWLEDGEMENT

This work was supported by the EU IST Programme under project contract IST - 1999 - 20827.

REFERENCES

[1] P. Antsaklis, T. Basar, R. De Carlo, N Harris McClamroch, M. Spong, S. Yurkovich, "Report on the NSF/CSS Workshop on New Directions in Control Engineering Education", IEEE Control Systems, Vol. 19, No. 5, pp. 53-58, (1999).

[2] Kheir N. A., K. J. Åström, D. Auslander, K. C. Cheok, G. F. Franklin, M. Masten, and M. Rabins, "Control Systems Engineering Education", Automatica, Vol. 32, No. 2, pp. 147-166, (1996).

[3] J.G. Balchen, "Results from a worldwide questionnaire on remote experimentation", Internal report, Norwegian Institute of Science and Technology, 1999.

[4] "Multimedia Access to Education and Training in Europe. Memorandum of Understanding", The European Commission, DG XIII, Nov. 1998.

[5] "Content and Commerce Driven Strategies in Global Networks – Building the Network Economy in Europe", Info 2000, The European Commission, DG XIII/E, 1998.

[6] Societe Europeenne pour la formation des Ingenieurs - document no.20: "Life-long learning in Engieering Education: A Call for Action", 1998.

[7] Schmid, C., Eikaas, T.I., Foss, B.A., Gillet D, "A Remote Laboratory Experimentation Network", IFAC Conference – Telematics Applicatons in Automation and Robotics, Weingarten, Germany, (2001).

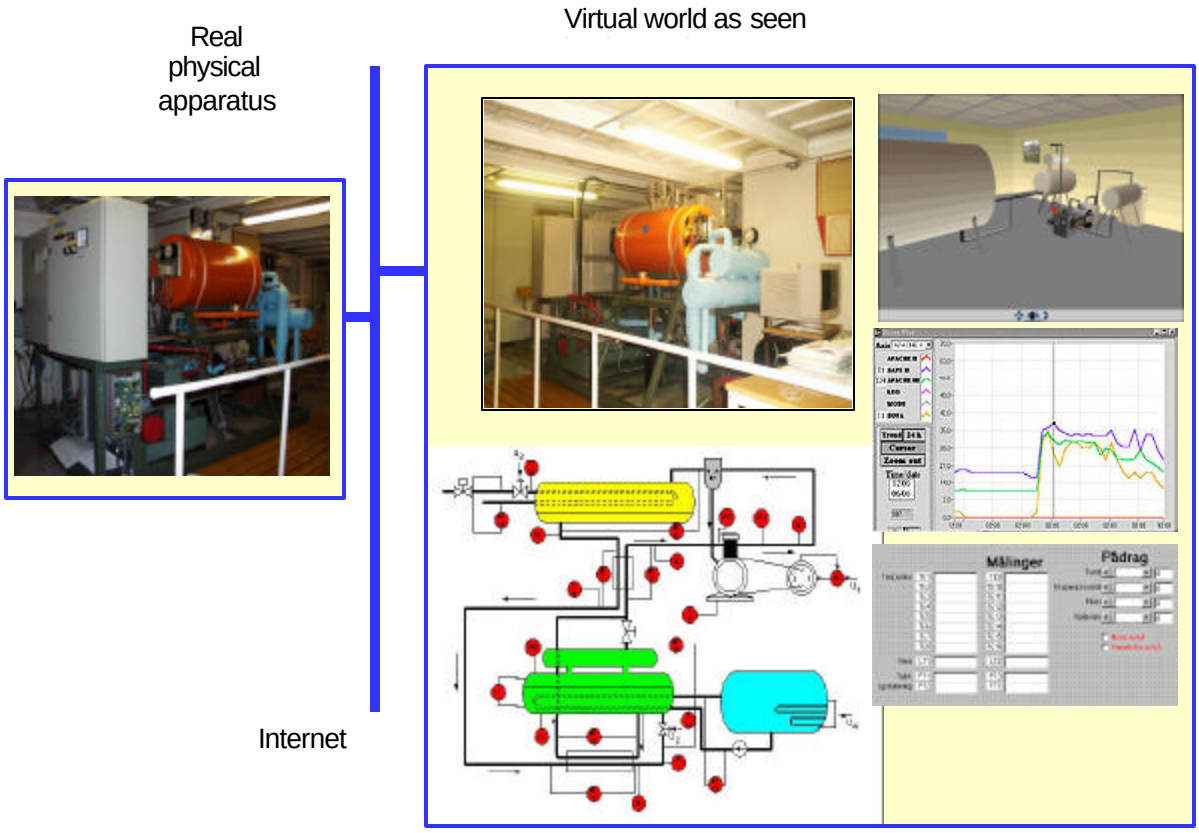

Fig.1. A visualization of the concept of remote experimentation

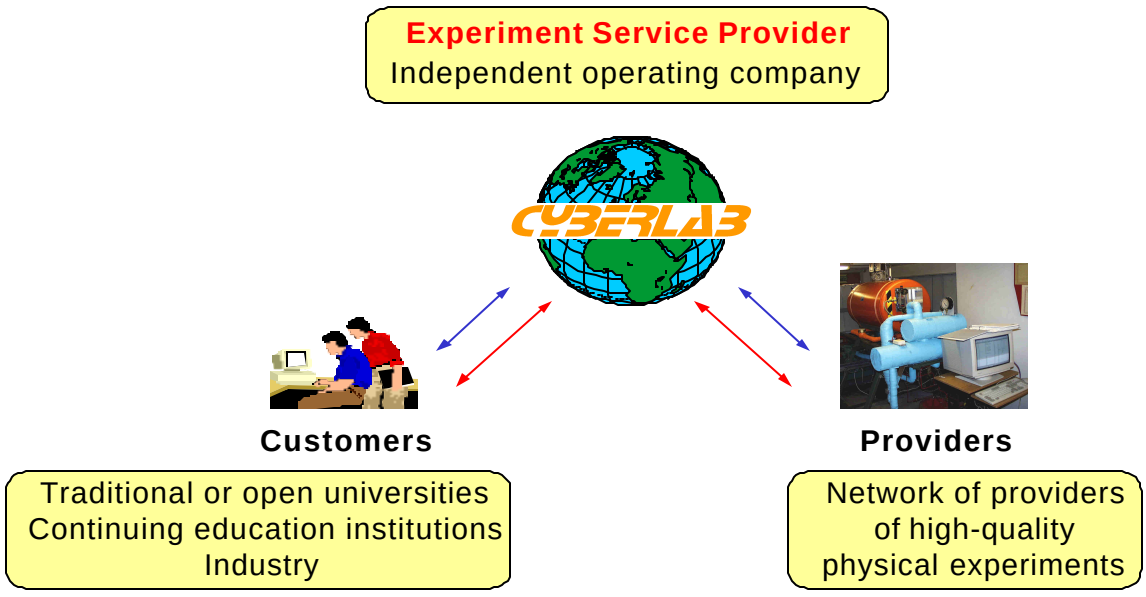

Fig. 2. Structure of the remote laboratory experimentation network in the ReLAX-project.

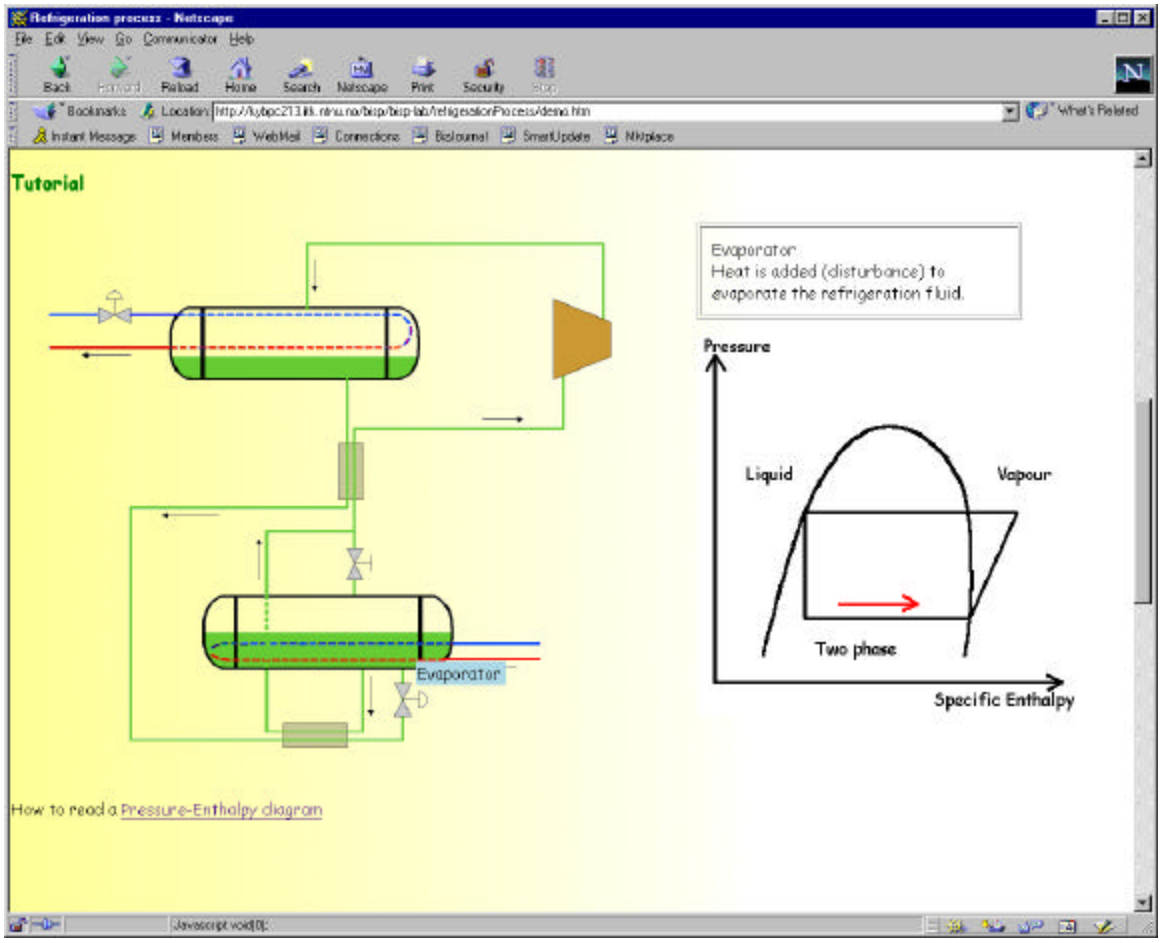

Fig.3. Tutorial material on the process, in this case related to thermodynamics, is integrated with drawings showing the process layout.