

## A Novel E-Laboratory for Remote Monitoring and Control

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**Abstract:** An internet-based laboratory for control engineering education is designed and implemented in this paper. This e-laboratory has a physical setup which is constructed for the research of multi-protocol conversion. Configuration software WebAccess is utilized to build the Human-Machine Interface (HMI) and the web server. With this B/S (Browser/server) structure, users can monitor and manipulate the physical setup during and beyond the regular working hours from any web-enabled location. A distinctive feature of this e-laboratory is its flexibility. Firstly, three types of control loops are constructed for flexible implementation of various control algorithms that can be developed by the users. Secondly, some new functionalities can be added easily by reconfiguring the intelligent controller and upper-level computer software. Experiments under different networked environment indicated that such e-laboratory is suitable for the research of NCS (networked control system). This laboratory is primarily designed for control engineering education, though the architecture can easily be extended to many other areas.

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### 1. INTRODUCTION

With the rapid progress in internet techniques, online education has been gradually introduced into the education field. Many schools, colleges and universities are transforming their educational models to bring about the benefits of the booming IT (Information Technology) era. Online courses, visual laboratories, online-test, networked courseware and also many other methods that are based on the internet have been widely adopted. This transition is also evident in the engineering education where the theory needs to be tested and reinforced via experiments (I.E. Allen and J. Seaman. [2003]).

Currently, two streams of design exist for the internet-based laboratories. The first category uses web-based simulations (virtual laboratory) (R. Klempous et al. [2004]), and the second enables the students to carry out remote control of physical setups (remote laboratory) via internet (D. Bonatti et al. [2007]). While the visual laboratory provides a simulated or virtual environment, thus cost-effective, the disadvantage is the lack of interactions with physical setups. For the remote laboratory, it uses physical instrumentation, therefore offers more realistic training and education environment. For example, students could use web browser to get access to the physical system in a remote location, and operate the system and run the experiments. Here, video monitoring is usually made available. Therefore, having the remote access to a real laboratory instead of simulated one offers the following advantages:

1) No time and geographical restrictions - student can get access to the e-laboratory from anywhere at any time. It

is more flexible to carry out the experiments and more flexible for the interaction between teachers and students.

2) Cost-effective sharing of experiences and resources - laboratorial resource can be shared among universities. Consider that the experimental facilities and instrumentations are always expensive, hence e-laboratory enables cost-effective sharing of laboratory resources and experiences that are geographically scattered.

3) Openness to wider communities and groups of people. For example, for disabled people who may be due to health reasons are unable to attend classes, the e-laboratory offers an alternative. Also it is an attractive means to train unemployed people.

4) Safe and hazard-free environment. E-laboratory also offers a safe and hazard-free experimental environment. Some experiments can be hazardous or can be extremely noisy. Therefore, e-laboratory system allows the students to carry out the experiments without exposing to the hazard and noise.

E-laboratory also offers many other advantages, such as low-cost maintenance of equipments, effective protection of some high-precision or expensive facilities, all-around and unabridged data. Detailed survey of the remote laboratory can be found in M. Ishutkina et al. [2004], where feedbacks from the students who performed the traditional laboratory was used as the baseline to evaluate the remote laboratory. It shows that the remote laboratory provides the similar functionality as the traditional laboratory. But to some extent, the remote laboratory is more flexible for instructors and students. All these suggest that the e-laboratory is a most useful means for modern education.

In the past years, many efforts have been made in the development of e-laboratory. For example, a remote laboratory based on LabVIEW software was developed for electrical engineering education S.H. Al-Shoaili and H. Eren. [2005]). Some apparatus, such as induction motor, DC-Dynamometer, digital load cell and in-house developed control box, are connected to the web-server computer and configured by LabVIEW. Students can get access to it via web-browser to perform some electrical experiments. A web-enabled remote robotic laboratory was reported in (M. S. Cohen and T. J. Ellis [2004]), where the network sensors were used to build the distributed architecture, and on the client side, a Swing-based Java applet was used to develop the user interface. A Remote Monitored and Controlled Laboratory (RMCLab) for electrical engineering experiment was described in (K. Efstathiou et al. [2007]) and (MD. Karadimas and K. Efstathiou. [2006]), which offers flexible monitoring and control in various experiments. In (Chaabene et al. [2006], a PC was used as a web server and an embedded web server was then used to build a remote laboratory. While most of the developed e-laboratories were developed for electrical experiments, few were reported for control education, especially for process control engineering.

This paper presents the specifications and basic structure of an internet-based remote laboratory that is developed within the Shanghai University. A remote monitoring and control system (RMCS) is built and various experiments have been carried out through LAN and WAN from several geographically distributed regions and countries.

## 2. E-LABORATORY DESIGN ISSUES

E-laboratory enables free or controlled access to physical experimental systems through internet. It usually uses the C/S (Client/Server) model or B/S (Browser/server) model, which make it easy to build e-laboratory in many education fields. To construct an e-laboratory, commercial software, such as LabVIEW, MatLab, Java, Visual Studio, configuration software, can be utilized. Some criteria also exist for building an e-laboratory server.

### 2.1 Overview

Most e-laboratories are built on C/S (Client/Server) model or B/S (Browser/server) model. In the C/S architecture, a client software package is installed to connect with the server(Chirico et al. [2005]), which can be inconvenient for end-users. Compared with the C/S model, B/S model uses a web browser to enable free or controlled access to the physical system in the server side. The B/S architecture is described in fig. 1. On the server side, necessary facilities needed for implementing the experiment are connected to a web server. On the client size, only a web browser, such as Internet Explorer, Netscape, Firefox, is need to get access to the laboratory server. Under this architecture, students could run the experiments from anywhere at any time via internet.

### 2.2 The server side

In most e-laboratory, the web server runs on a PC, though sometimes it may run on an embedded system (D.

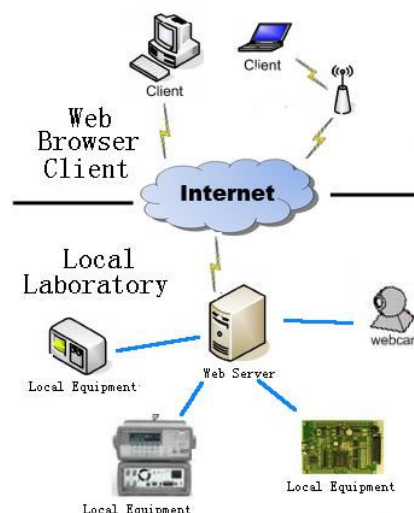


Fig. 1. Architecture of the web-based remote laboratory

Srinivasagupta and B. Joseph. [2003]). To design the web server, two architectures are often used. The first is to use single server to manage the equipments and client access synchronously. Commercial software, such as LabVIEW, Java, configuration software, can be used for this purpose. The other is the dual server configuration. Here, one server is designed to manage client user access, and the other server interacts with the physical experimental devices. In the later architecture, the both servers may run on the same computer (K. Efstathiou et al. [2007]MD. Karadimas and K. Efstathiou. [2006]), or on separated computers (Chirico et al. [2005]).

### 2.3 The client side

The client environment is always controlled by the server. In a web-based remote laboratory, three programming technologies are applicable, namely the Java applets, CGI programs and ActiveX controls. The CGI coded program is less interactive as it accepts input from user, executes the program for controlling the instruments, and then show the response and measurement result. During the measurement process, users have to wait. Whereas, the ActiveX control needs to be downloaded and they may use some MegaBytes to store, therefore may lead to increased connection cost and time. Java-based solutions have the same drawback as they require the user to download the Java Virtual Machine (C. Landi et al. [2006]).

### 2.4 General features

Most remote laboratories are restricted to guided control of the equipment, mainly focusing on measurement recording or viewing of system responses. There is a need to investigate more complex experimental setups that encourage increased interaction, creativity and initiative from the students in designing the experiments, and greater autonomy in manipulating the physical systems and in applying the concepts (P.K. Imbrie and S. Raghavan [2005]). It has been indicated that the level and speed of interactions, clear articulation of expectations, timely feedback and access are some important factors that should be considered

in the design of an e-laboratory(M. S. Cohen and T. J. Ellis [2004]).

### 3. ARCHITECTURE OF RMCS

In this remote monitoring and control system, a small boiler system is utilized as the controlled object. Data acquisition and control parameter settings are managed by a multi-protocol converting system, which connects to local SCADA (Supervisory Control And Data Acquisition) computer. A web camera is used for observing the current status of physical setups. The web server is designed by using WebAccess, a configuration software for industrial control. The software enables the web server and the SCADA server being operated in a single computer.

#### 3.1 Hardware platform

The local platform is a small boiler control system with various sensors and actuators. Here, the boiler is the controlled object where the water level and water temperature are controlled variables. A multi-protocol conversion device is a key element in the local platform. Two Field-bus, namely DeviceNet and Profibus, and an industrial Ethernet, namely the Modbus/TCP, are integrated in the multi-protocol conversion device. As described in fig. 2, water temperature and jacket temperature of the boiler are acquired by DeviceNet nodes D1 and D2; the water level and input flux are acquired by Profibus-DP nodes P1 and P2; the output pressure of the boiler is measured via Modbus/TCP node. The protocols of the DeviceNet and Profibus-DP are translated into Modbus/TCP which can then be easily connected with a SCADA computer. This configuration is showed in fig. 3

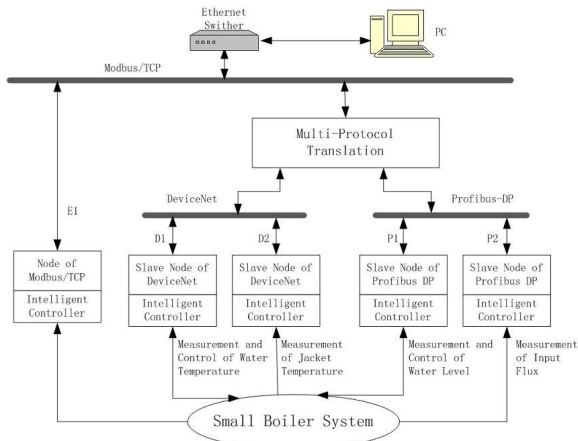


Fig. 2. Architecture of the control system

A web camera is installed for remote monitoring with PTZ (Pan/Tilt/Zoom) control by the users via the Internet. With a web server embedded, this camera can be best described as an intelligent unit. As a result, the camera does not need a direct connection to a PC or any other hardware and software to capture and transfer images. It can send live video directly over Internet and enables users to view and control the camera to monitor the whole process(L.X. Li et al. [2007]).



Fig. 3. The controlled plant

#### 3.2 Configuration software

Broadwin WebAccess is web browser-based software package for industrial automation, HMI and SCADA. It was designed by Broadwin Technology from USA. WebAccess has four components, including a PROJECT node, a SCADA node, a Client and a Thin Client Interface. The PROJECT node is a configuration tool and database server for desktop computers. The SCADA node connects with automation equipments and transport data stream through internet. The Client provides full animation graphics and dynamically updated data in real time. The Thin Client Interface requires no additional software, and enables access to the physical system through PDA, Pocket PC, and any ASP enabled web browser. The PROJECT node and SCADA node may run in the same computer or on different computers.

The interface of RMCS was designed using the WebAccess, and OPC (OLE for Process Control) tools named MBE PowerTool was used for communication between the hardware platform and the WebAccess software. Several primary pages were designed, namely the main view, parameter view, algorithm selecting, real time trend, historical trend, camera view, and help. Two languages, Chinese and English, can be selected after login. The main architecture of software is shown in fig. 4. Apart from the graphic configuration, TCL programming language is used to implement any particular control algorithm.

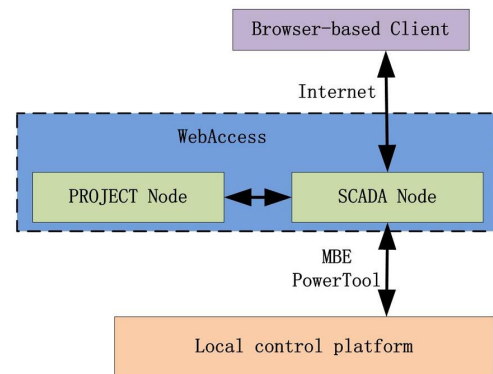


Fig. 4. The software architecture



#### 4. SYSTEM FEATURES

A basic remote monitoring and control system was built using the above mentioned software and hardware. A particular feature in this e-laboratory is its flexibility. New functions can be easily added by modifying the program of intelligent unit, and then configured in WebAccess. As a laboratory for control engineering education, three types of control loop can be configured to carry out various experiments or researches of different nature (fig. 5). When the local control loop is selected, control methods such as PID that run in the intelligent units and their associated control parameters can be changed remotely. This feature allows the implementation of many classical control experiments. If the remote control loop is selected, some control methods like neural network based PID control and Fuzzy PID control can be used to manipulate the local equipments. Under networked learning loop, optimum parameters of local controller can be learned remotely. In addition, the TCL language is a very simple program language that allows users to easily compile the control algorithm of their need into local settings via the internet. Networked control problems, like network-induced delay and online model identification, can also be learned and researched within the remote control loop.

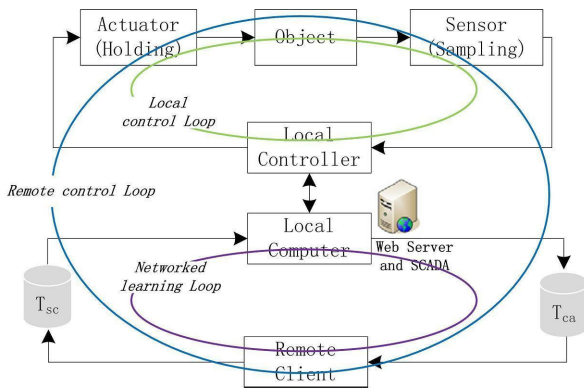


Fig. 5. Two control loops

Security is a vital issue for internet based application. In this remote laboratory, double user identification strategy is made available. That is, in the login page, password is required for all type of users in order to get access to the project node. While the SCADA is started, the same identification procedure is repeated. Other security measures are also supported in RMCS. For instance, remote access code, various security levels for each data point etc.

Data recording and analysis can be quite demanding in an experiment. Errors often occur when recorded by human. In RMCS, points and frequency of recode can easily be set in PROJECT node, 12 curves of real time trends and 12 curves of historical trends can be viewed completely (two curves of real time trends are showed in fig. 6). Record can be downloaded remotely for offline analysis.

#### 5. EXPERIMENT AND FUTURE WORK

During the debugging and testing stage, various problems occurred while accessing this e-laboratory from internet.

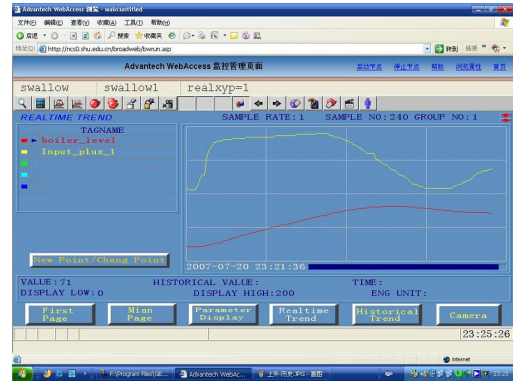


Fig. 6. Real time trend view

These common problems may include:

- Disabled connection from campus network, but still available through LAN (Local Area Network). Communication between computers in the same LAN is permitted, because these nodes share the same IP segment. For instant, 172.168.1.21 can easily get access to 172.168.1.36. But out of this segment, connection is disabled. Invalid IP address is the primary reason.
- Disconnection with the SCADA node while the PROJECT node is still accessible. In this e-laboratory, network port of 80, 4592 and 14592 were used. The 80 port is an http port, which is used for the ASP Web Server. So PROJECT node can be viewed. The 4592 port is the main TCP port for file transmission, and port of 14592 is the subsidiary TCP port for real time data transmission. To get connected with the SCADA node, the port of 4592 and 14592 need to be opened in the server side. The same problem was encountered while accessing this e-laboratory from other countries, and it is shown that any interdiction for port 80, 4592 and 14592 is infeasible in the data stream transmission path.
- Others problems for getting access to the e-laboratory were due to the firewall of the operation system, or the virus which destroys the web browser or forbids internet connection.

Numerous experiments were performed on this system through internet. Control mode and algorithm can be set remotely (fig. 7). While the tests were carried out through the educational network, thanks to the high-speed connection, only small transmission delay existed while the control parameters were changed remotely. Camera's PTZ control can be timely and quickly manipulated. However, when the tests were performed outside the educational network, transmission delay increased significantly. Recently, some experiments were also performed at several British universities including the Queen's University Belfast and the University of Essex. The time for logging in the e-laboratory and operations is listed in Tab 1.

Time (/S)*					
Access Point	T1	T2	T3	T4	T5
Shanghai University	1	3	1	1	2
Queen's University	3	15	8	3	5

- \* T1: Access to welcome page
- T2: Start of SCADA
- T3: Login to View
- T4: Changing between pages
- T5: Camera PTZ control

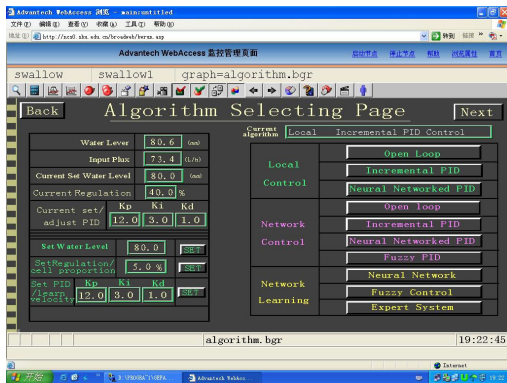


Fig. 7. algorithm selecting page

During the tests, several problems were unsolved and therefore were proposed for the future work. One of the major issues is the operational conflicts in sharing the instrumentation among multi-users. If only the system behaviour and response are simulated, the software itself is able to provide coherency during the running of experiments. However, when the system behaviour is the result of remote control on the physical setup, it is mandatory to guarantee coherency between the actions and results of each user for all the instruments involved in the experiment. Different concurrent commands sent to the same instrument might produce unpredictable behavior. In the presence of a single set of instruments, the problem is management issue. i.e. managing different users and their experiments while identifying inputs and outputs of each user and preserving the state of the laboratory setup (Chirico et al. [2005]).

Finally, online download of the programs for intelligent units is also needed. To configure new functions remotely via WebAccess, more information about the hardware is required. Therefore, intelligent unit must run on another program. Some special algorithm for local control loop could also be added by changing the program of intelligent unit. In summary, the future work will include the enhancement of the functionality and improvement of the user interface.

## 6. CONCLUSIONS

An e-laboratory for remote monitoring and control has been successfully built. A number of experiments have been carried out both at home and abroad to test the effectiveness of this system. The flexibility of this system makes it easy to add new functionalities for further research. Such e-laboratory provides an effective platform for control engineering education, and its architecture can easily be extended to other areas. However, more works are still needed to improve the functionalities and the user interface.

## 7. ACKNOWLEDGMENT

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