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Development of a remote-access laboratory: a dc motor control experiment

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Abstract

This paper presents the development of a remote-access control system which allows users to perform control experiments through Internet. A dc motor control module is used as an example to illustrate our design. The system is composed of an internal distributed system and an application system linked by a data acquisition (DAQ) interface card. Web server, video server and Laboratory Virtual Instrument Engineering Workbench (LabVIEW) controller server are designed based on a client–server structure. The experiment can be accessed from http://www.acae.cuhk.edu.hk/~accl/ibc/.

Keywords: Internet-based control; On-line laboratory; Distance learning; Internet; Engineering experiment; Education

1. Introduction

Since 1990s, there have been consistent efforts in developing web-based education environment at many institutions around the world. An innovative real-time remote-access control engineering teaching laboratory was developed and demonstrated at Oregon State University in 1998 [1]. A remote laboratory called VLAB on an oscilloscope experiment was setup at The National University of Singapore in 1999 [2]. Later, a web-based control experiment on a coupled tank apparatus was further developed [3]. The Process Control and Automation Laboratory at Case Western Reserve University developed a Bytronic Process Control Unit, referred to as the process rig, over the Internet [4]. The user can login parameters using a web browser from a remote client to a Laboratory Virtual Instrument Engineering Workbench (LabVIEW) G web server, which was connected to the process rig via a PLC control module. An interactive on-line laboratory for remote education called Automated Internet Measurement Laboratory was established at Rensselaer Polytechnic Institute [5]. The laboratory developed a course module on semiconductor device characterization, which could be freely accessed through a web browser. Other relevant developments can be found in [6–8].

At Chinese University of Hong Kong, we have been developing a web-based remote-access control laboratory since 1999. Our purpose is to create an experiment setup that can be accessed anywhere at anytime by students with access to any web browser. This paper will describe our development using a dc motor control experiment as an example. In contrast to the work reported in [1–8], we focus more on the system security, database technique enhancement and stability of operating system. In addition, we have aimed to achieve a good integration of varieties of computer languages and operating systems to enhance the flexibility and user-friendliness of our experiment setup.

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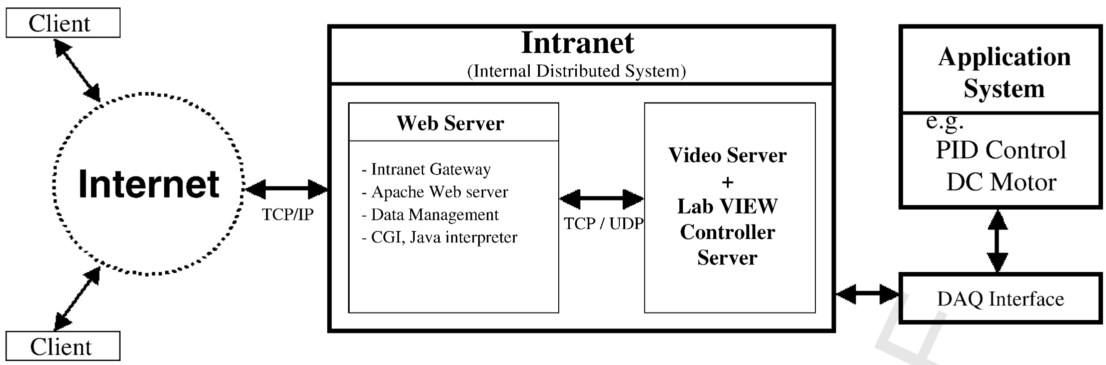

Fig. 1. Basic structure of experiment setup.

The rest of this paper is organized as follows. Section 2 describes the overall system architecture including both hardware and software. An application example, that is, a dc motor control experiment is described in Section 3. Finally, Section 4 offers some concluding remarks, and points out some thoughts for our future work.

2. System architecture

The core of our work is to provide a server side system that can communicate with laboratory instruments so that a control experiment can be interactively carried out from the client side. Fig. 1 illustrates the general structure of the experiment setup. The system is composed of several components: an internal distributed system which includes a server machine linked with Internet, an internal controller PC linked to the server only, and an application system which is controlled through the PC in this Intranet through a data acquisition (DAQ) interface card. LabVIEW from *National Instruments* is used as the controller interface software. A chain client–server structure design enables each component in the system to perform tasks individually,

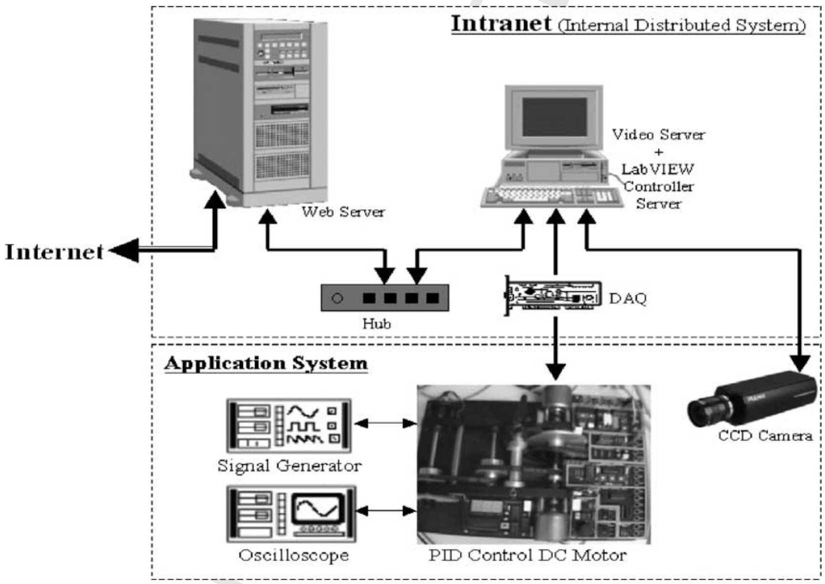

Fig. 2. System hardware components.

which offers a great flexibility for different applications.

Fig. 2 shows the overall system hardware architecture which is mainly composed of two parts: the simple internal distributed system and the application system. An internal distributed system is a collection of heterogeneous computers and processors connected via a network. The system here consists of a server machine which acts as the gateway for accessing to Internet, and a PC which acts as a digital controller and functions as the video server. A hub is used to connect the Internet accessible gateway, the web server, and other PCs in this Intranet system. Due to security concern, only the gateway server is directly linked to Internet. Other PCs are masqueraded and assigned with virtual IP address known only by this server machine. Our setup only allows the client to access to the web server to enhance the security and performance of the system.

The Apache web server on Mandrake 7.0 Linux operating system is used to perform such jobs as providing web pages, user authorization and user conflict checking. The architecture and task description of our web server is illustrated in Fig. 3. The highly stable performance of Linux operating system can greatly enhance the stability of our overall system, which is one of the main concerns of a user who is conducting an experiment. Our approach is in contrast with that described in [3,4] which employs the LabVIEW G web server in Windows OS. This is because that the Linux operating system is considered very reliable. Moreover, using the Linux operating system may reduce the loading on the memory and increase the execution speed of the server machine.

A JVC color CCD camera with the MATROX METEOR2 PCI frame grabber is used to take the video in real-time. InetCAM video capture software is used as the video server interface. It is simple and requires no plug-ins. The video server is located in the controller PC to save computing resources.

A PC that runs software LabVIEW is used as the interface in controlling the application system via the DAQ card that is plugged onto the PC. In general, DAQ is the process of converting a physical quantity (such as temperature or pressure) into an electrical signal and measuring the signal in order to extract useful information. Fig. 4 shows how a typical DAQ card is positioned.

The DAQ card can act as a D/A converter and A/D converter, and it has both an analog output channel and an analog input channel. The output channel, which is connected to the input of the dc motor module, sends the control signal to the motor. The analog input of the DAQ card is connected to the output of the motor, and sends the digitized measurement of the dc motor to the computer which will process the control signal and

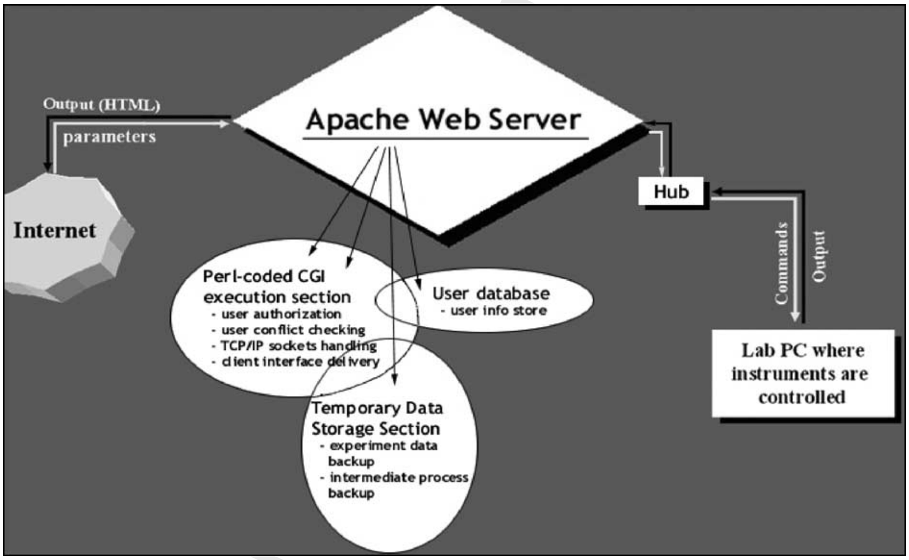

Fig. 3. Web server architecture.

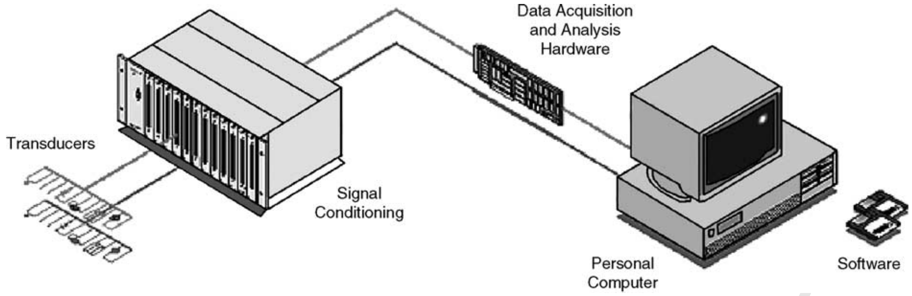

Fig. 4. The typical DAQ system [9].

display the result. The DAQ card can have up to 500 kilo samples per second (kS/s) single channel scanning rate and 12-bit output resolution.

Fig. 5 illustrates the software structure of the system. Hyper Text Transport Protocol (HTML), Common Gateway Interface (CGI), and JavaScript are the languages used on web server side. While LabVIEW's G language and Java are the ones used on the control PC side. CGI is coded by Practical Extraction Report Language (PERL). All networking algorithms are based on a client–server structure.

User authorization and conflict checking as well as database linkage are all handled by PERL language on the server. Its library packages on database management system (DBMS) provide modules to interface with Oracle, Sybase, mSQL, MySQL, Ingres, and others [10]. We use DB_File packages to perform the database management. Whenever a user inputs the parameters, the system can update these parameters in the database. Thus, if there is a network or system failure when a user is conducting a task, the system can retain the most recent data so that the user can continue to conduct the task with the stored data when the user re-logon the system.

3. Application system: dc motor control module

A dc motor control module (MS15) from *L.J. Technical Systems* is used as our application system (Fig. 6). The module enables the user to perform position or speed control of a dc motor by a proportional-integral-derivative (PID) controller. The speed and direction of rotation of the motor can be controlled by either an analogue signal or a pulse width modulated (pwm) digital signal [11]. As shown in Fig. 7, the power amplifier with the dc motor used in

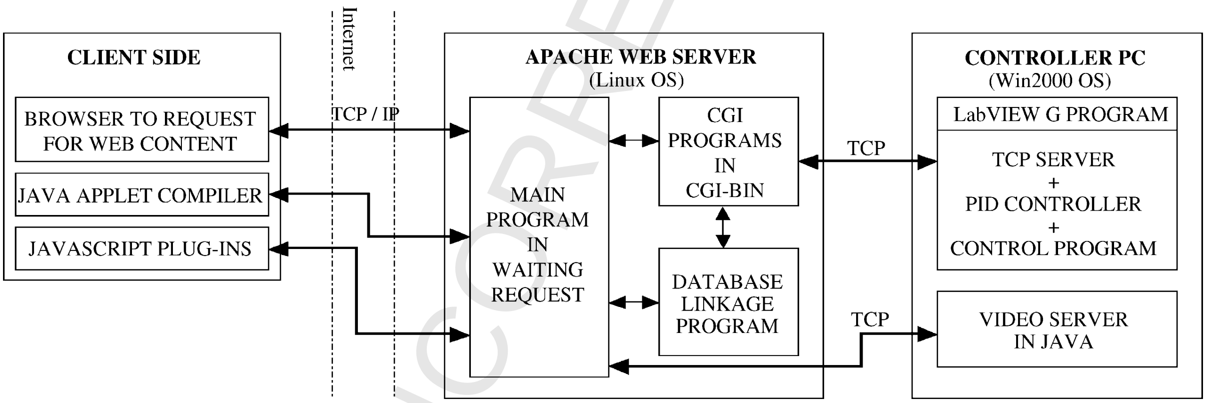

Fig. 5. Software structure.

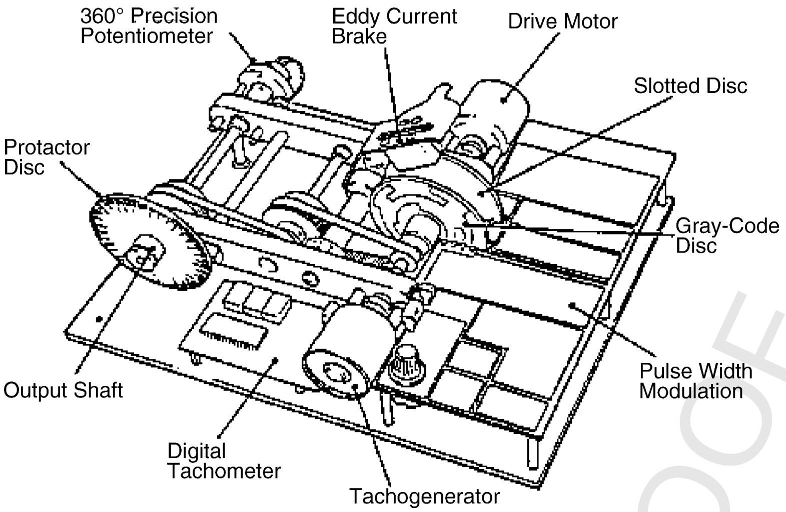

Fig. 6. The dc motor control module.

the system generates a torque T, which is assumed proportional to the input voltage, V_{in}.

Other notations are described as follows:

B	viscous damping coefficient
J	equivalent mass moment of inertia
T	torque produced by motor
θ	angular position
ω (i.e. $\dot{\theta}$)	angular velocity
K_A	amplifier factor
K_M	motor constant

Since $I(t) = K_A \times V_{in}(t)$ and $T(t) = K_M \times I(t)$, by Laplace transform, we have

$$T(s) = K_M K_A V_{in}(s) \tag{1}$$

From the mechanical portion of the system, we obtain a second-order differential equation as follows:

$$J\ddot{\theta}(t) + B\dot{\theta}(t) = T(t) \Rightarrow T(s) = s\theta(s)(Js + B) \tag{2}$$

Combining (1) and (2) gives the transfer function from the input $V_{in}(s)$ to the angular velocity $\omega(s)$ as follows:

$$\frac{\omega(s)}{V_{in}(s)} = \frac{K}{\tau s + 1}, \tag{3}$$

where $\tau = J/B = 0.25$, $K = K_M K_A / B = 54.75$.

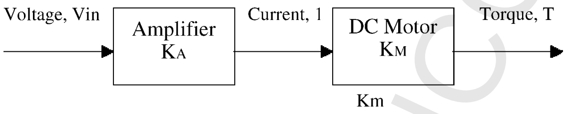

Fig. 7. Block diagram for electromechanical portion of the system.

We consider employing a PID controller to regulate the angular speed of the motor. A PID controller takes the form of

$$u = K_p e + K_i \int e\,dt + K_d \frac{de}{dt},$$

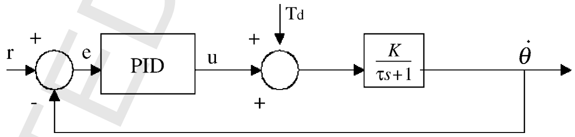

Fig. 8. Block diagram for the PID closed-loop control system.

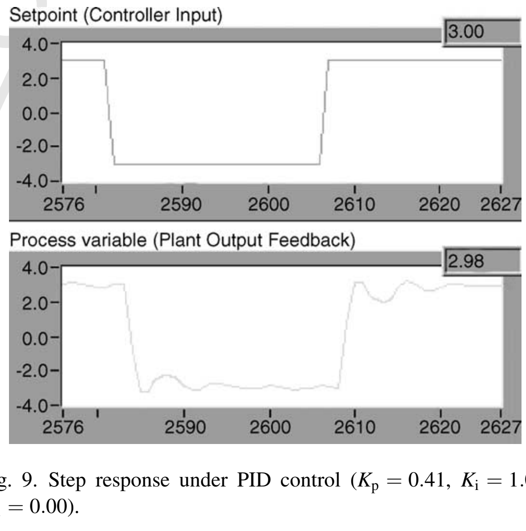

Fig. 9. Step response under PID control ($K_p = 0.41$, $K_i = 1.05$, $K_d = 0.00$).

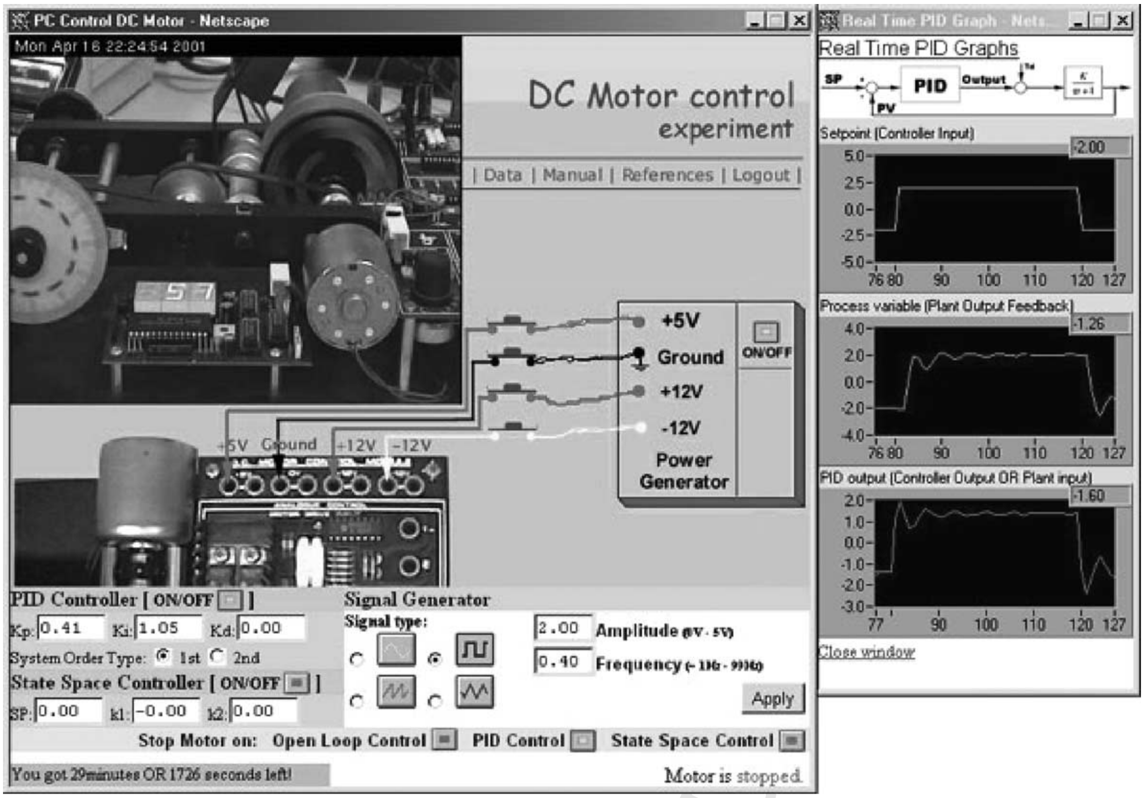

Fig. 10. Web interface.

where the tracking error: $e = r - y$. The controller will be further discretized with a sampling period T_s to yield a discrete PID controller of the form:

$$u(k) = K_p e(k) + K_i T_s \sum_{j=0}^{k} e(k) + K_d \frac{e(k) - e(k-1)}{T_s}, \quad k = 0, 1, 2, \ldots \qquad (4)$$

The closed-loop system under the PID controller is described in Fig. 8.

The values of reference input r, K_p (proportional parameter), K_d (derivative parameter) and K_i (integral parameter) can be changed online. The values of K_p, K_d, and K_i are selected to give a satisfactory motor speed response. The step response of the closed-loop with $K_p = 0.41$, $K_i = 1.05$, $K_d = 0.00$, $r = 3.00$ V and $T_s = 40$ ms is shown in Fig. 9, which shows that this controller can achieve a satisfactory performance.

Fig. 10 shows the web interface. The real-time video window is located on the upper-left corner. The signal generator and PID controller are at the bottom. A user can click on the manual anchor to pop-up the manual window to perform the experiment step by step. Real-time output responses are displayed automatically once the parameter is inputted.

4. Conclusion

This paper presents a general approach in developing an Internet-based control laboratory experiment system. The project involves several different programming languages, operating systems, and hardware suites, and each of them has its own advantages and disadvantages. Thus, the great challenge to the success of this project is how to integrate varieties of computer techniques seamlessly so that a reliable system performance can be achieved. In addition, flexibility, controllability and user-friendliness are also our major concern in designing the system's architecture.

Our future work will focus on simultaneous control, system integration, and laboratory safety. We will also introduce other control application systems such as a magnetic levitation system and a single conveyor parts selection programmable logic control system.

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