Internet-enabled Parallel Port Driver*

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Simple PC-based measurement and control systems may be economically implemented using the parallel (Centronics) port available on PCs. The techniques are simple to implement yet have a wide range of application in laboratory teaching. This paper reports on a parallel port driver that is enabled over the Internet. It extends the functionality and application of a driver previously described [1] and is particularly useful in distance-mode laboratory experiments. The driver and its application model are also recommended for institutions that are operating under tight budgets and those in which students are encouraged to perform laboratory exercises at their homes.

INTRODUCTION

THE CHALLENGES of delivering high quality engineering education, affordably, are great. Along with the pressure to keep pace with an explosion in technology, engineering education must provide practical training, usually at great expense. A key consideration for the choice of laboratory equipment to support practical training is the extent to which the equipment is technologically current. Other considerations include cost and flexibility.

Practical components of engineering education programs typically require the use of dedicated equipment duplicated at a number of laboratory stations to cater for the high throughput of students. The case is often easily made for the use of flexible, inexpensive tools in favor of their expensive, high performance alternatives.

Computers have long been used for the training of theoretical subject matter in science and engineering curricula [2–5]. PCs are increasingly being used in teaching institutions for laboratory training [6–8] in engineering. Their versatility, ubiquity and extensive software support make the machines a natural choice for a general laboratory virtual instrument center. Their flexibility allows their use for a variety of purposes outside of laboratory exercises, for example Internet access, word-processing, computation and administration. Thus PCs may, in principle, be put to use twenty-four hours per day and their cost easily amortized over their technological lifetime. Commercial data acquisition cards for hardware interfacing, however, are still quite expensive. Additionally, the facilities provided by commercial data acquisition products are often more powerful than necessary for laboratory teaching applications.

The parallel port requires no expenditure on hardware interfacing products to provide basic functions, yet can be used to implement a number of useful data acquisition, control, debugging and development tools. The port has come to represent a versatile interface between a computer and external hardware for inexpensive laboratory projects. It supports both input and output and may be controlled via high level as well as low level software.

This work documents a technique developed at the Instrumentation Laboratory, in the department of Electrical and Computer Engineering of the University of the West Indies (UWI), for applying the parallel port to simple data acquisition and control experiments using Internet technologies. We are particularly interested in the use of Internet technologies for distributing the laboratory facilities to accommodate laboratory work at the students' residences and also for distance education.

APPLICATION OF INTERNET TECHNOLOGIES IN LABORATORY EXERCISES

Though the use of the Internet in teaching has received much attention, its integration into laboratory instruction is not well established. Reported cases of the use of Internet technology in laboratory-based training typically implement server-side control of hardware. In this case, the hardware itself resides at the remote server. At the University of the West Indies, we have a keen interest in the application of Internet technologies to client-side practical training. In this manner, the hardware resides at the location of the student.

UWI has incorporated Internet technologies into laboratory instruction for the following purposes:

- electronic regulation of laboratory sessions;
- interactive laboratory exercises;
- hardware simulation of distributed instrumentation environments;
- course administration utilities.

There is tremendous interest in advancing the use of Internet technologies to support laboratory-based distance education programs.

The existing utilities for laboratory-based training using Internet technologies have been realized by a suite of tools designed at the U.W.I instrumentation laboratory. In particular, we have produced our laboratory exercises as hypertext documents with links that initiate hardware actions. The simplest interface between the computers and the supporting hardware is the parallel port.

THE PARALLEL PORT IN LABORATORY EXERCISES

The parallel port and supporting software routines for data transfer and handshaking have long become a standard for printer communications. It consists of an 8-bit output data port along with four output lines for handshaking and five input lines for monitoring status conditions of the printer.

On the PC, the parallel port is addressed using three registers: data, status and control. The data and control registers can be interrogated individually from a high level language such as C, C++ or BASIC. The data written to the port appears directly on the output lines of the interface. Data input to the computer can also be read directly to a software variable via the status register.

Built-in software routines that execute primitive computer hardware and peripheral operations exist as part of the PC BIOS. Routines are available for initializing a printer, writing a byte of data to the printer and reading its status. The relevant registers are located at hardware addresses that depend on the architecture of the machine and the printer port in use. The computer provides software facilities for up to three ports. The port registers may be controlled directly or a printer may be emulated.

At the University of the West Indies, the parallel port has been used extensively in laboratory exercises for bit-wise digital input/output, data transmission and digital control. Bit-wise output from the buffered parallel port has been used to switch on motors and initiate sequences of operations in state machines. Direct interfacing to TTL digital circuitry is often used. Process switches have been interrogated using single input lines. Pulse coded serial data has been monitored from flow meters and optical shaft encoders.

Analog inputs have been digitized and monitored using the five input lines of the parallel port to yield 32-level resolution. For the acquisition of 8-bit digital data, twin banks of 4 bits each have been latched and one line from the port's control register used to supply the analog to digital converter's start of conversion input. Continuous conversion rates of up to 200 Hz have been demonstrated.

The parallel port has been used for 12-bit positioning and speed control of electromechanical devices. Digital outputs from the port have been converted to analog and used to generate arbitrary waveforms. Stepper motors have been driven by the parallel port using few external components. DC motors have also been controlled by the buffered, converted outputs from the parallel port.

The versatility of the parallel port has served us well in laboratory exercises and for quick, incidental interfacing requirements in the laboratories over the years. Port control has been effected under DOS and under Windows.

HARDWARE CONTROL USING INTERNET TECHNOLOGIES

Though Web-based instruction (WBI) has received much favor outside of engineering and for the delivery of theoretical engineering material, it has been applied far less to practical engineering course components. Despite this, the popularity of the Internet and, in particular the World-Wide-Web, can be used to great advantage in engineering laboratory programs.

In the instrumentation laboratory in the Department of Electrical and Computer Engineering at the University of the West Indies, laboratory stations have for years been configured around PCs [2]. More recently, hyperlink-activated hardware (hyperhardware) interfacing facilities have been incorporated into the exercises. The incorporation of hypertext and hyperhardware into laboratory exercises has accounted for increased productivity for laboratory staff and increased learning effectiveness for students.

The instrumentation lab exercises, along with other administrative and academic utilities are available from a single http server. This supports browsing and performing of the laboratory exercises from anywhere on, and off, campus. Report submission and automatic electronic marking are also supported. The interrogation and control of hardware through the laboratory exercises is effected through the Instrumentation Hardware Communications Interface (IHCI) and its companion Instrumentation Hardware Communications Language (IHCL), both developed at the University of the West Indies. The software interface resides on each computer used for instrumentation laboratory exercises.

Active links embedded within the courseware are used to initiate the transfer of the IHCL scripts from the server to client machines over the network. The scripts are interpreted by the IHCI, resident on the client machine, in order to effect the required actions. As the actuation and control of hardware is accomplished only through scripts previously written by the laboratory administrator, hardware is protected from damage.

Students are therefore allowed to perform the laboratory exercises off-campus and outside of the administrator's working hours.

CONTROL OF PARALLEL PORT USING INTERNET TECHNOLOGY

The Instrumentation Hardware Communications Interface comprises a manager, a DLL and the command scripts. These are all software components. The manager, installed on all client machines, extracts command parameters from the IHCL code and passes them to the IHCI DLL. The DLL, resident in memory once the IHCI manager is invoked, implements the actual hardware instructions. An IHCI command script is associated with each hypertext link which initiates an interface command. The IHCI manager has been implemented in Visual BASIC 3.0 while the IHCI DLL has been implemented in Borland C++ 4.5.

The scripts, which initiate particular interface control functions, are stored as `.ihc` text files. Each line in the `.ihc` file is of the format ⟨`IH_COMMAND`⟩⟨`IH_OBJECT`⟩⟨`DATA`⟩, where the DATA field may be null or may comprise several sub-fields. Examples of general `IH_COMMANDS` include OPEN, CLOSE, SEND and RECEIVE. Specific `IH_OBJECTS` typically support their own suite of custom `IH_COMMANDS` and may also carry a suite of custom sub-objects.

The parallel port is a valid `IH_OBJECT`. Custom `IH_COMMANDS` for the port include SETPIN, CLEARPIN and READPIN, whose functions are self-explanatory. Custom sub-objects associated with the parallel port include PORTA, PORTB and PORTIN, also self-explanatory. The IHCI manager inspects the `IH_DATA` passed in an IHCL script to ensure that valid pin numbers or port letters have been referenced.

Control of the parallel port via UWI's Internet-based hypertext courseware using the Instrumentation Hardware Communications Interface may be accomplished, for example, through the following IHCL script:

```
OPEN LPT1
SEND LPT1 CLEARPIN 1
CLOSE LPT1
```

Line 1 of the script opens and reserves the `IH_OBJECT`, LPT1. This is followed by the command to send `IH_DATA CLEARPIN 1` to this object, which causes the IHCI to set the logic state of pin 1 of the parallel port to logic 0. The next line closes and releases the parallel port.

An example of the use of the IHCI for parallel port control is shown in Fig. 1. The interpreter within the IHCI manager passes parameters to the IHCI DLL which uses it's integrated parallel port driver to activate the registers of the computer's parallel port. These registers control the TTL logic states of the output pins of the port and can thus
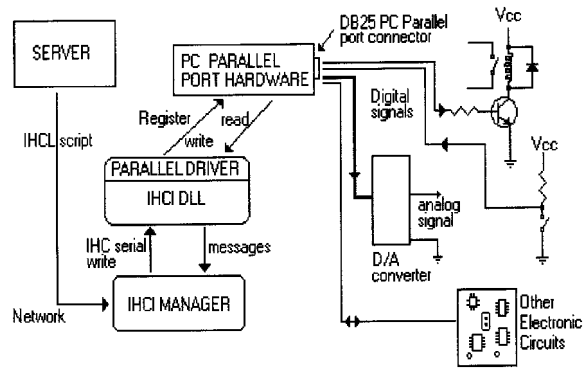

Fig. 1. Parallel port interfacing through the IHCI.

control the external electronics connected to them. In the figure, a relay is driven, a threshold sensor is read, an arbitrary analog waveform is generated and serial and/or parallel digital data is communicated in both directions between the computer and external digital electronic circuitry.

A key feature of the Instrumentation Hardware Communications Interface, as illustrated in Fig. 1, is that the command scripts are downloaded from the server, across the network. Thus the interface commands, executed by the students, are controlled by the laboratory administrator, albeit *in absentia*.

A LABORATORY EXERCISE EXAMPLE

One simple example of how the Internet-enabled parallel port driver has been used is in a laboratory exercise on the evaluation of shielding techniques. This exercise is designed to demonstrate the effectiveness of shielding techniques applied to the protection of electronic circuits. The exercise begins with a review of the categories and sources of noise which typically affect electronic systems. The task is to estimate the level of interference in the laboratory using various lengths of wire as antennae. Capacitive coupling of electric field interference to a short length of wire is demonstrated with the use of microprocessor-based test equipment consisting of a function generator and multimeter, both computer controlled from within the courseware by the Instrumentation Hardware Communication Interface. The frequency of the signal is varied over a range of 500 Hz–20 kHz under IHCI control.

The second part of this exercise demonstrates how an electronic circuit can be shielded from electric field interference by placing the circuit within a metal enclosure attached to the ground reference of the circuit. The IHCI is used to control an electromechanical relay via the parallel port, alternately connecting and disconnecting the enclosure from the circuit ground using active links within the courseware.

FIELD TRIALS

The Internet-enabled parallel port driver was designed to perform its functions with no manual intervention from the students. A key measure of success in the field trials, run over a two-year period, was the degree to which the driver performed its functions transparently and accurately. Indeed feedback on the field trials showed that no problems with the driver were reported.

Field trial feedback was obtained through a mandatory multiple choice questionnaire administered electronically at the end of each laboratory exercise. The questionnaire required that the student enter his/her name and respond to a number of specific questions relating to various aspects of the laboratory exercise format and the PC-based tools. Responses to the questionnaire indicated an overall enjoyment rating of 84% and laboratory reports suggest that learning was substantial.

CONCLUSIONS

Personal computers have become standard fare in many teaching laboratories where it offers hardware control and data acquisition along with graphical display, computational power and interactivity. At the University of the West Indies, parallel port communications has become indispensable for PC-based laboratory instruction in instrumentation. It has been applied, at very low cost, to the hands-on training of a wide range of practical systems: analog and digital electronics, signal coding and transmission, computer monitoring and control.

Enabling the parallel port for use over the Internet, extends its application for a variety of purposes. Students may be allowed to perform simple PC-based hardware interfacing exercises at their homes with the assurance of safety. This distribution of laboratory space reduces the University's requirement for real estate and facilitates custom scheduling of laboratory time for students. The possibilities for remote laboratory training for off-campus and overseas distance education are exciting.

The Instrumentation Hardware Communication Interface suite, developed at the University of the West Indies, also finds powerful application for in-laboratory exercises. In particular, sessions may be scheduled by students at any time and exercises performed, safely, without the need for human supervision. This mode of laboratory instruction represents a profound departure from tradition and enables the establishment of an unsupervised laboratory 'terminal room', similar to the well-established software terminal room.

The Internet-enabled parallel port may also be used to stimulate hobbyist activities in high schools, colleges and communities. We see it as a likely catalyst for an explosion in hobbyist activity. The availability of inexpensive hardware tools along with the active communication links with peers and mentors, enabled by the Internet, represent powerful motivators for students and hobbyists. The centralized responsibility for script authoring and report submission lends itself naturally to automatic on-line marking and a host of interactive utilities. The de-centralized access to running the scripts from within hypertext documents and performing the laboratory exercises remotely offer great appeal. Several semesters of field trials have yielded overwhelmingly positive student response.

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