

Performing Experiments by Remote Control Using the Internet*

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A system was developed two years ago in which students could perform experiments by remote control via the Internet. The prototype enabled students in a laboratory in Liverpool in England, United Kingdom, to perform experiments using equipment that was in a laboratory located in Wismar, Germany. Similarly, students in Germany were able to control equipment in a laboratory in the UK. Although the prototype system was successful, it required the use of specialist software both in the laboratory in which the equipment was being controlled and at the client site where the students were located. Furthermore, the students could not see the actual equipment; all they could see were mimic diagrams and virtual instruments. A more sophisticated arrangement has since been developed which only requires specialist equipment at the site where the equipment is located. At the client site, all that is required is a version of the Netscape browser that can accept JavaScript. Furthermore, a facility has been added which creates a window on-screen at the client PC through which the experiment can be viewed directly by means of a camera attached to the server.

INTRODUCTION

Remote control (both the operation and observation) of installations and systems has been a technical reality in the automated industries for many years, particularly in process control industries. Due to the stringent demands of industry, a variety of bus systems have been developed to operate at the different hierarchical levels found in automated systems. One of the most commonly used applications for remote control systems involves client-server architectures. The general structure of a client-server based remotely controlled laboratory is shown in Figure 1.

The server controls the actual experiments, measurement equipment or automated systems and

has to handle all requests from the client side. On both sides (client and server), special programs usually have to be run in order to operate the particular application involved. This means that any change of the system requires specialised knowledge.

At the highest level (Intranet), Ethernet-based systems are frequently utilised to transfer data, using different protocols. With the rapid development of the Internet within the last ten years and its associated transfer control protocol/Internet protocol TCP/IP, as well as the use of hypertext documentation as a basic technique on the World Wide Web (WWW), new possibilities have arisen to use the net for remote

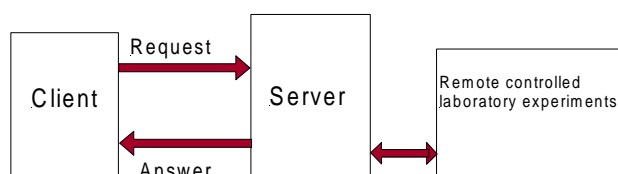


Figure 1: General structure of a remote-controlled laboratory using client-server architecture.

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control. With the aid of software development packages, such as LabVIEW®, it is now possible to design http-based client-server solutions for remote control problems with modest expenditure.

The goal of the remote-control project of Liverpool John Moores University at Liverpool, England, United Kingdom, and Hochschule Wismar – University of Technology, Business & Design, in Wismar, Germany, is to increase the attractiveness of laboratory work in the education or research endeavours of engineers – particularly in the main subject areas of electrical and electronic engineering – by remote-controlled experiments. An attractive consequence of this development is that resources are saved because both partners need not cater for the whole spectrum of possible (and mostly expensive) experiments, which also have to be updated and maintained. On the other hand researchers could investigate their own probes themselves. However, a further aim of the project is to enhance the imparting of knowledge by using the techniques of automatic control systems and the new software technologies of the Internet.

As pilot processes for the remote-controlled experiments, complex tests involving sensors and automatic control systems were chosen. At Liverpool John Moores University, for example, separate experimental arrangements were set up using a fibre-optic sensor and a multi-level tank-control system; whilst at Hochschule Wismar test rigs involving ultrasonic and eddy-current sensors were built.

The concept and the advantages of using an http-based client-server system for remote control have already been discussed in previous publications [1]. Also initial approaches to the problem that used virtual instrumentation (graphical programming) have already been reported [2][3].

As an example, the remote control of Hochschule Wismar's ultrasonic measurement equipment, together with an http-based client-server system including the visualisation (online) of the dynamic runs of real experiments with web cameras, is described in the rest of the paper.

REMOTE CONTROL SERVER

Client-server systems have some general advantages when compared with simple remote-access systems (RAS). These advantages include:

- Having better security.
- Having higher functionality.
- Can be administrated better on the server side.

With the introduction of the hypertext markup language, and the associated hypertext transfer

protocol, the possibility existed of communication between client and server via graphical elements (image maps). The performance and functionality of http-based client-server systems is extended through server extensions such as Java, the common gateway interface (CGI), JavaScript, standard query language (SQL) and many more for the exchange of variables and the preparation of dynamic HTML documents. Figure 2 shows the general structure of an http-based remote-controlled experiment based on the LabVIEW® Internet Toolkit.

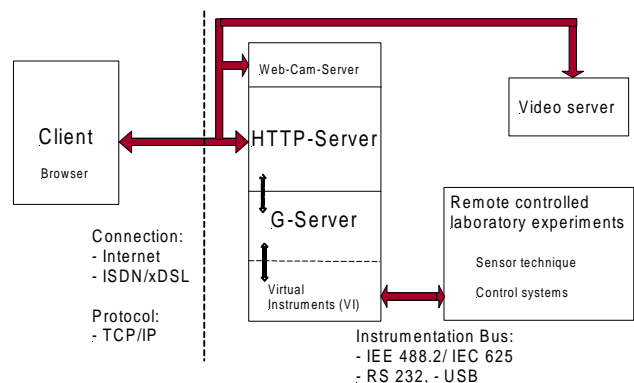


Figure 2: Structure of the realised http-based remote-controlled experiment.

The server itself has to fulfil several important tasks:

- Firstly, the server controls the experiment. In the actual version, the control of the experiment works with the graphical elements, the so-called Virtual Instruments (VI), which were developed using the graphical programming language G by means of the LabVIEW® software development environment [4][5].
- Secondly, the server has to do duty as an http server at the disposal of requesting clients, which means that the transfer of a requested HTML document, in which the graphical elements are embedded, is also one of its tasks. The conversion from the graphical elements of the VI of the LabVIEW® control program (such as input/output) into the HTML document is performed by a G-server. The G-server is a part of the Internet toolkit, which also provided VIs for the use of other Internet services, such as the file transfer protocol (FTP) and e-mail [5].
- Thirdly, a video-stream server also runs on the other port alongside the main server to operate a standard web camera. The second remotely controlled high-resolution camera (with zoom, direction and position all being controllable) is connected via a separate video-stream server. This second server is capable of transmitting images and

sound (a videoconferencing system) at high resolution to enable fine-detail visualisation of the dynamics of the processes that are being controlled.

So at the remote location there are really three servers running: one http, one G-server and one video-stream server. There is also a separate fourth server that is used for video editing; this also contains an HTTP facility.

The functionality between client and server can be extended with elements such as CGI and Java. Through this technology, the access rights of clients to stored data from the server of password protection and much more can be achieved.

CCD camera systems have been used for the visualisation of the dynamic actions of the experiment and can be embedded within the VI as a static picture (JPEG, BMP). But it has been found during experiments that a better transfer quality is achieved if a separate (second) http server and streaming video are used [6]. This is the reason for the high-resolution camera and the third video-streaming server mentioned earlier.

On the client side, such as from a random PC in the Internet, the HTML document, which was sent by the server and had been transferred, will be displayed in a browser, and some – also transferred – contents (such as Java applets) will be executed.

It is important for the approach used for the Internet control that the clients' browser is able to implement the server-push technology (like Netscape Navigator) because the G-server uses this technology to display the (graphical) control VI, and the client receives a display of the interface and access to the control of the experiment program.

Client and server are connected via the Internet but could also communicate via ISDN, for example, because the TCP/IP protocol is also available there. The big advantage in using an ISDN connection is the guaranteed robustness and for this application a transfer rate of 64Kbit/s per channel is sufficient. To work using only one channel and a standard web-camera is quite close to the limit of the technology: the data transmission rate of 64Kbit/s gives an image refresh frame rate of one time per second. By using the two-channel transmission available with the ISDN system a frame rate of about three times per second is achievable and gives good results. In future, the new digital telephone systems, based on asymmetric subscription lines such as ADSL or xDSL, will solve any transmission rate problems because the downstream bandwidth will be more than adequate.

The graphical programming language G under the software development environment LabVIEW®

including the Internet toolkit is available for the operating systems Windows 98, Windows 2000, NT and Linux. However, at present the http servers of the remote control project in Liverpool and Wismar are only running under Windows 98.

The server controls the experiment itself over a local network, such as over the parallel measurement bus IEEE 488.2/IEC 625 and serial point-to-point connections over RS232 to the laboratories' machines and instruments. Using the graphical programming language G and the Internet toolkit from LabVIEW®, the engineer is able to design particular measurement and control programs (VI) with REMOTE-CONTROL through embedding them in a remotely-controlled HTML document. No special knowledge is needed to do this because the G-server is part of the Internet toolkit.

The configuration of the http-server for a simple remote control is possible with minimal effort; but the access control for the requesting clients and the manner of their access to the control program demands attention. This will necessitate additional programming, like CGI scripts. For this technique, LabVIEW® also possesses virtual instrument toolboxes.

REMOTE-CONTROLLED ULTRASONIC MEASUREMENT EQUIPMENT

In the first phase of the remote-control project, simulated control programs (VIs) were used to test the performance of the http-based client-server system. In the second phase, real and complex computer-controlled experiments were designed [1]. At Hochschule Wismar, complex experiments involving the remote control of ultrasonic and eddy-current sensors have been designed (see Figure 3).

These experiments are available for use by students on the main courses in the electrical engineering schools. They are also available to researchers, both in Wismar and in Liverpool. Further experiments

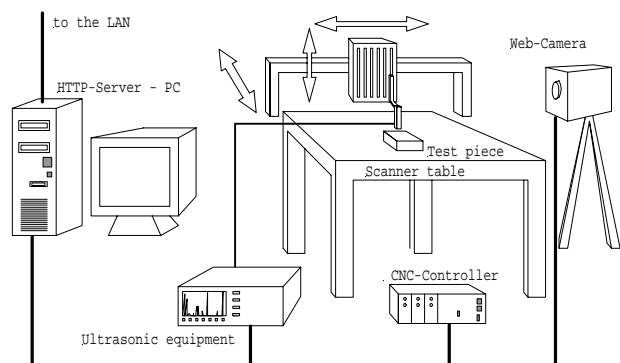


Figure 3: Remote-controllable ultrasonic measuring equipment [6].

are currently being designed and will be available later this year. A coupled-tanks control experiment has already been designed and built in Liverpool. Initial testing has been completed and preliminary results are reported in this paper in a later section.

The ultrasonic measurement experiment consists of industrial ultrasonic equipment USD15D and two cameras (a web camera and high resolution remote controllable camera) to observe the dynamic responses. With the help of these cameras, it is possible to obtain fine control over a 3-axis drive mechanism that manipulates the ultrasonic sensor.

With the continuously tuneable ultrasonic test probe, a frequency range from 0.5 to 15MHz is possible. The sensors can work in impulse-echo or in continuous mode. All experiments are designed in such a way that the ultrasonic sensors have to be water-coupled. Figure 4 illustrates the position of ultrasonic test probe, the received echo impulse, an ultrasonic test probe (10MHz) and one of the real used test pieces for the experiments.

The ultrasonic equipment and the scanner are controlled by the server over a serial interface (RS232). With the equipment for the ultrasonic sensors a variety of experiments are possible. Simple ultrasonic distance sensors were the first to be tried, including 1-D measurement signals, such as profile measurements on surfaces, building up in stages to 3-D measurements on solids.

Figure 5 shows the three developed LabVIEW® programs (VI) that are necessary to control this experiment: first the configuration for the scanner (starting position, number of steps in x and y directions, and

the step-width = scanning area of the probe), the second is a program for (human) hand control of the 3-axis scanning mechanism, and last – but not least – the program to control and communicate with the ultrasonic equipment USD 15D (eg reading the ultrasonic data streams and storing them on the server).

It is essential for the actual development of the project that real data rather than simulated measurements are recorded and transferred to the PC. The users can then repeat an experiment as often as they wish and, if necessary, under various configurations in order to be able to evaluate the results of different instrument settings.

In order for this to be accomplished, a manual remote-controlled installation is planned. This installation (positioning of the ultrasonic sensor or the eddy-current test piece and other configurations) makes an online visualisation of the experiment necessary. It has been found that with a standard web camera of 320 x 240 pixels and a reasonable picture transmission quality a continuous data transfer rate of at least 7kbyte/s is needed. In this context, the access rights for the clients from the server-administration are an important part of the functionality of the experiment. Furthermore, it can also be influenced by which clients have the access rights and the ability to control the experiment. Administration would be easier over ISDN but also more expensive.

There are LabVIEW® programs available that the client can download in order to display and interpret the measurements (1-D, 2-D and 3-D data sets). However, the transferred data can also be manipulated by means of other software of the user's own design, including image manipulation tools, appropriate to particular requirements. So it is

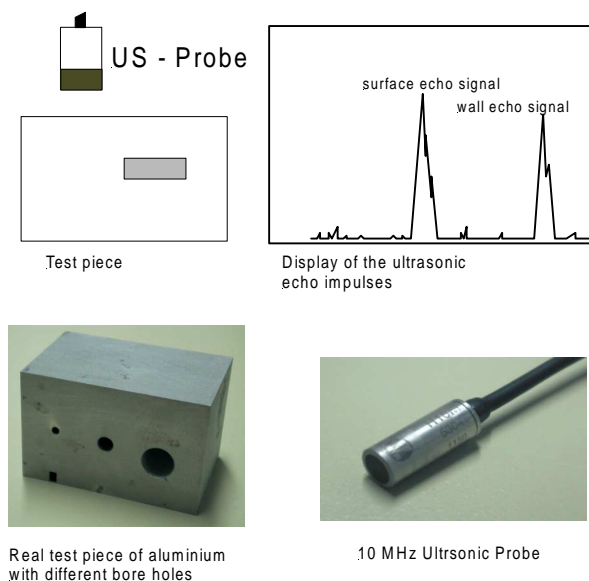
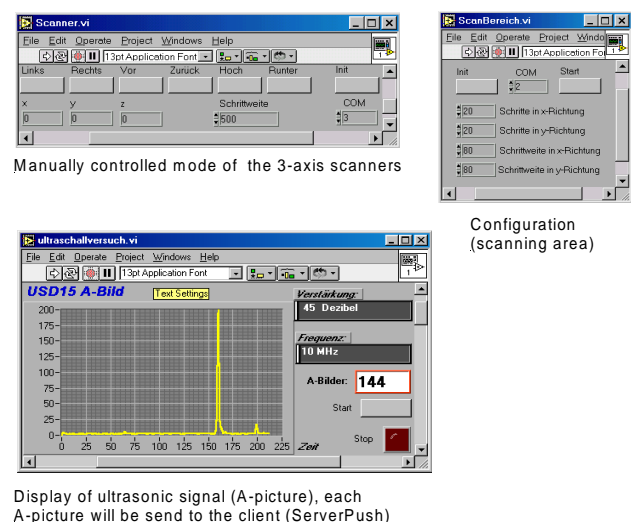


Figure 4: Ultrasonic test probe using impulse-echo technique.



Display of ultrasonic signal (A-picture), each A-picture will be send to the client (ServerPush)

Figure 5: LabVIEW® Programs for the remote-controlled ultrasonic laboratory.

possible, for instance, to test pattern-recognition software or data-visualisation software developed in Liverpool with real ultrasonic data from Wismar. Figure 6 presents the typical results of an ultrasonic experiment with test pieces similar to that shown in Figure 4.

A COUPLED-TANKS CONTROL EXPERIMENT

The Tank Control System is located at the Liverpool John Moores University in the Electrical & Electronic Engineering Department. A coupled-tank apparatus, which was used for students to do experiments in conjunction with a Controller board, was connected to a server and, with LabVIEW® used to acquire the necessary data for online distribution. The aim is to remotely control the tank at a certain level of water height.

In order to do this, the students must calculate the necessary settings using standard control theory methods. First the system track needs to be recorded in order to find out what kind of system it is and how it behaves. After the perception of what kind of system there is in front of the student, the next step would be to design an appropriate controller with suitable controller values for it so that the pump will control the water level for certain user inputs. An added feature is the introduction of a non-linearity so that different time-constants apply for different water levels. Students can choose from several different types of controller, from classical PID to fuzzy logic.

The Tank Control System consists of two tanks, which are coupled through a manually controllable valve, although eventually this will also be controllable via the server. Valves for the control of the outlet water from tank 1 and tank 2 are also controllable using a 450MHz Pentium III operating under Windows 98 (see Figure 7).

A Logitech QuickCan Express camera with a still image capture resolution of 320x240 pixels was chosen since the fine detail imaging of the Wismar experiments was not needed. Alongside the Web camera image was the corresponding mimic diagram created by LaBVIEW® (see Figure 8).

SOME FURTHER DEVELOPMENTS

A further development in Liverpool is an attempt to combine Bluetooth™ wireless technology with a robotic system to enable a further stage of remote control. Bluetooth™ is a cable replacement technology that will enable the experimental rig, in this case a robot rover, to be disconnected from the umbilical cord to the server. Control will still be via the Internet.

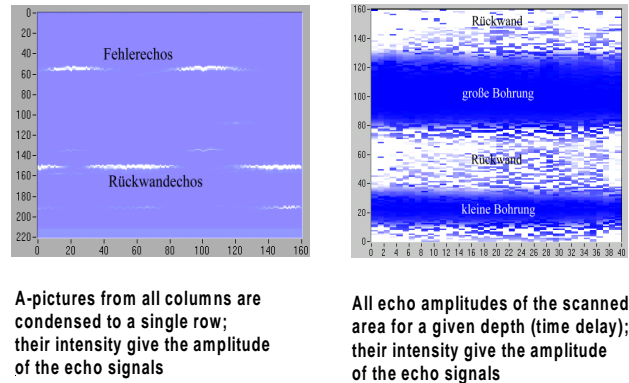


Figure 6: Images from an ultrasonic experiment (impulse echo and test piece, see Figure 4).



Figure 7: Coupled Tank System as seen via the Web camera.

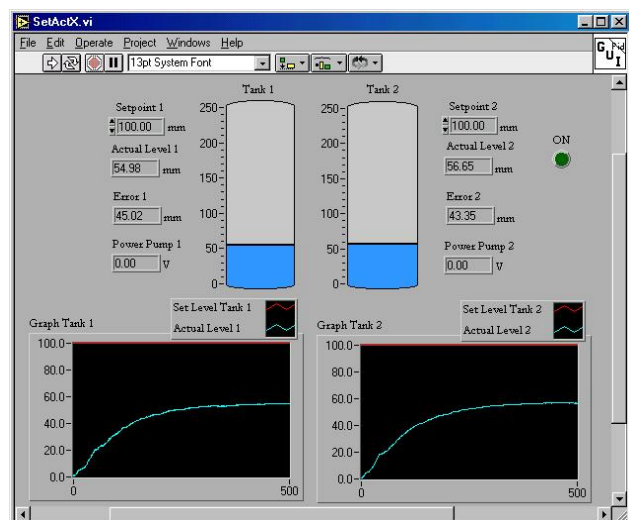


Figure 8: Mimic diagram showing the coupled-tank responses.

CONCLUSION

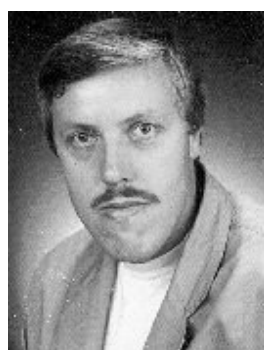
With the aid of the LabVIEW® software, http-based client-server systems for the remote control of experiments were developed, built and tested, for example: a complex experiment using ultrasonic sensors. Both Liverpool John Moores University and Hochschule Wismar are using the remote-controlled experiments within the context of the ongoing internationalisation of electrical and electronic engineering studies (ECTS).

Beside the advantages of saving resources and the greater attraction of such laboratory work for the electrical engineer, the remote-control project has other advantages. Firstly, students learn networking technologies, the new software technologies of the WWW and the associated security mechanisms more effectively. Secondly, they are in a better position to assess the requirements and properties of connected automatic control systems. Furthermore, the industry is also introducing the http-server technology in all fields of process monitoring and control (eg PLC and PC based controllers).

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BIOGRAPHIES



Hartmut Ewald is a Professor of Measurement and Sensor Techniques in the Department of Electrical Engineering and Computer Science at Hochschule Wismar - University of Business, Technology & Design in Wismar, Germany, since 1992. He graduated from the University of Rostock,

Germany, as an Electrical Engineer in 1978, and received a doctorate in Physics 1983 and the Habilitated Doctor's degree in 1991. His main research fields are pattern recognition and non-destructive testing. He received the Marie-Curie-Research Grant (Marie-Curie Fellowship) from the European Union on the University of Limerick, Ireland, in 1998. He is a member of the German Society of Non-Destructive Testing and a member of the Organising Committee of annual ANNIE Conferences (Artificial Neural Networks In Engineering).



George Page was born and went to school in Lancashire in England, United Kingdom. He attended the universities of Wales (at Bangor), Manchester and Liverpool. His initial subjects were physics and mathematics but his current teaching and research interests are in the field of

intelligent control systems and novel uses of the Internet. He has considerable experience in engineering education and has served on numerous national and international committees. He has been an examiner in control engineering for the British Engineering Council, guest editor for several international journals, and is the author of one book and over thirty papers and articles. He has taught for the Open University and for Liverpool John Moores University in the UK. He also has close links with several universities in France and Germany. He returned to the School of Engineering at Liverpool John Moores University from Fachhochschule Wismar - University of Technology, Business & Design in 1999.