2000

Exploration of the Internet Controlled 'Rent-a-Factory' Concept

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Keywords

exploration, internet, controlled, rent, concept, factory

Disciplines

Physical Sciences and Mathematics

Publication Details

L. Bate & C. David. Cook, "Exploration of the Internet Controlled 'Rent-a-Factory' Concept," in ACRA 2000 - Proceedings of the Australian Conference on Robotics and Automation, 2000, pp. 123-128.

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Abstract

There are several robots and other devices which can now be controlled over the Internet. It is possible that an expansion of this concept ultimately leading to an Internet controlled factory could assist Australia overcome the 'tyranny' both of distance and of small production volumes. This paper discusses initial work being performed to investigate the relevance and practicality of the Internet for remote factory operations. A review of current Internet controlled equipment is presented. New experimental work involving the development of a web based graphical interface enabling clear observation and control of an Adept-One robot over the World Wide Web is also described.

1 Introduction

Internet control of equipment has been implemented by several people to provide a novel experience for general internet 'surfers'. This has produced a body of knowledge about the behaviour patterns of such users, and developed some interesting insights into the design of interfaces between the Internet and manufacturing equipment.

The goal of this paper is to explore the technologies that are available in the area of equipment control to begin to understand, and quantify, the degree of control and monitoring of real manufacturing processes which can be achieved across the Internet. The eventual aim is to learn from these experiences in order to develop a telemanufacturing site for commercial purposes.

Two problems besetting Australian manufacturers are their distance from other world markets and the low production volumes if only our domestic market is serviced. The ideas being explored in this paper are intended to overcome both these problems.

The problem with distance is at least partly a problem of control and communications. If people physically far away could achieve genuine 'instantaneous' control over ordering, invoicing, design, manufacture and production then the physical relationship between a factory and its user would become less important. In principle, if the user of a factory could be sure that he was getting what he ordered with the specifications, reliability, quality and price he wanted then he would not be particularly concerned about where it was made. If in addition he could track his order through a factory, and even see his parts being manufactured, and be able to make modifications whenever he felt like it simply by accessing the Internet, he would be even less concerned. The user would not have to own any production equipment, he simply rents a factory, and pays only for the time he uses it.

Such an Internet controlled 'rent-a-factory' would be accessible from anywhere in the world. Soon, users will even have the potential, via the Internet, of high bandwidth access to 'their' factory by phone, whenever and wherever they wish, thus making it easier for the factory owner to sell time in his factory to customers all over the world. This provides a much greater production volume than obtainable domestically, and so the owner would be able to afford a more fully automated and flexible system which in turn would attract more customers.

The factory owner will be interested in having his factory work ('rented') 24 hours a day. Flexible design, automation and manufacturing using robots and other equipment will be of prime concern. Quick set-up times, flexible jigging, computer aided design, automatic error recovery, etc will all be required. The factory will have to be controllable via the Internet to be able to make, for example, one family of parts from 1am-5 am, and another from 6am to 1pm, etc. Much of this technology is available now, at a price, but the extent to which a large manufacturing system can be controlled and monitored from the Internet is still not known.

Using the Internet as an inexpensive communications channel presents many challenges. Firstly, due to the intrinsic nature of the Internet protocols used, the transport medium cannot provide a real time protocol. Secondly, the Internet is at present a low-bandwidth link so long time-varying delays are quite common. Thirdly, the response obtained is dependent on other traffic, on the particular mode of Internet access available, and other unpredictable phenomena. Methods need to be developed to work around this in order to enable adequate remote site monitoring and no loss of real-time control of particular manufacturing equipment or processes.

Along with this, the issue of security when using the Web as an inexpensive communications channel has to be addressed. A customer has to be guaranteed that operation of a plant cannot be sabotaged in any way and that no sensitive operational data can be downloaded by a competitor. This is of particular interest if the Internet factory is to have multiple users, some of whom could be competitors.

Any developments made are not just limited to terrestrial communication. Since the Internet by its nature has varying and often long communication delays, any advances could well be applied to the technologies required for deep space and deep-sea exploration.

2 Literature Review

Existing online robot sites

The University of Western Australia Telerobot site (http://telerobot.mech.uwa.edu.au) went online late 1994, and is an excellent example of the evolution of telerobotic pioneering. This was developed when real time solutions for Internet technology like Java were only just evolving. The site consists of an ABB IRB 1440 robot. The movement requests are entered by the remote Internet user and are submitted and executed using the Common Gateway Interface (CGI) program written in Visual C++.

The University of Wollongong has an online Mitsubishi Micro-Robot affectionately know as Robotoy (http://robotoy.elec.uow.edu.au). Movement requests entered by the user are passed to a CGI program written in Perl.

The Adept Garden Robot (http://telegarden.aec.at) is another example. This site consists of an Adept SCARA robot, very much like the one used for the experimental work reported on in this paper. Movement requests entered by the user are passed to a CGI program written in C by a Java front end. The overall appearance and ease of use of the website is much improved with the use of Java, but the actual underlying system is very similar to the Western Australian Telerobot.

The Puma Paint Project is another very successful demonstration of remote telerobotics via the World Wide Web[Stein, 1998](http://yugo.mme.wilkes.edu/~villanov). Essentially its World Wide Web interface is very similar to The Garden robot. A Java front end submits requests to a Sun4 workstation which runs a RCCL, a package which allows direct control of the robot via a Sun4 workstation with the use of C.

These are just a few of the many telerobotic sites that have been set up to explore the technologies available with the result of producing entertainment for people on the internet. These sites contain many attributes that assist the implementation of the 'rent-a-factory' concept.

3 Real-Time Factory Control

All current online telerobotic implementations use a system where the operator makes a movement request then waits for the result before making the next request. Such a system is unacceptable for a "Rent-a-Factory" concept (fig. 1), since it will not provide sufficiently timely or comprehensive information for a real-time manufacturing process [Scott, 1996].

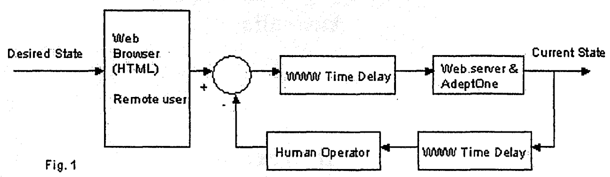

Figure 1 The system block diagram of a Telecontrol System with the closed loop system across the web, this is the common Telerobotic approach

The factory's control system should be confined to the server side only. Hence, the remote user only sends start, stop and set point commands over the Internet (fig. 2). By using this method of supervisory control, most of the problems and safety issues associated with the delay the Internet introduces with real time control are avoided.

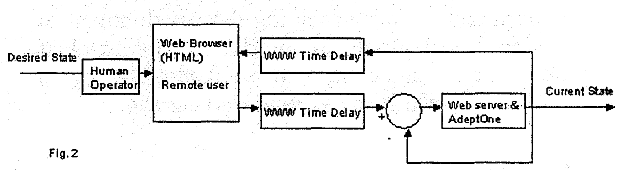

Figure 2 With the closed loop system residing totally on the server the closed loop control of the system is dramatically improved.

However, the control provided from the server side needs to be robust enough to keep the factory going during delays in the Internet, and needs to be sufficiently comprehensive that all information likely to be required via the Internet is readily available. The remainder of this section describes suitable control and communication schemes using Ethernet and Supervisory Control and Data Acquisition (SCADA) systems which are readily available commercially.

For a Rent-a-Factory concept to work on the server side, a solid Local Area Network (LAN) system needs to be developed for the factory backbone. A high speed Ethernet is one LAN solution. The main drawback with Ethernet LAN systems is that they are not circuit switched [Wilder, 1998]. Hence they are prone to delay due to variance of traffic loads from the surrounding devices on the network.

However, as the processing speeds of routers approach the wire speed, and with the event of switch routers and Gigabit Ethernet, quality of service will soon be easily maintained and managed. This allows real time monitoring and control of critical process control loops within a factory production line by the use of an Ethernet based LAN [Casey, 1990]. The movement to Ethernet right down to the PLC level of a process control system allows effective routing between levels of control systems [Daniel, 1996]. This also gives the designer flexibility since each level within the process control system can sit on a separate Virtual Local Area Network (VLAN). When communication is required between levels it is a simple case of changing the routing configuration within the router. Due to this evolution many PLC manufacturers now offer Ethernet interfaces for their product range.

Previously, when unmanaged Ethernet Hubs were the only solution, quality of service could not be guaranteed. Any high burst of traffic on one port of the hub would be seen by all other devices on that segment, resulting in an overall drop in response times by all devices connected to that segment. Because of this, previously the only place suitable for Ethernet LAN was the high level network (level 4) where only monitoring or control of set points for the overall process was possible.

Now with uniform architecture throughout the entire process control system, SCADA systems can be easily implemented. There is no need to traverse across LAN to say a device connected via a terminal server, or interfaces with proprietary protocols. Keeping to one standard keeps the task of interfacing various products together much simpler.

The support of this direction by industry is clearly displayed with the movement of all the major product manufacturers to include the support for LAN interfacing of their device.

An interesting research project, which further supports Ethernet for use in real time control systems, is the Demonstration of Advanced Radar Techniques (DART) [Dean, 1991]. Essentially it is a distributed radar system that is monitored and controlled in real time through an Ethernet network.

In the rent-a-factory the World Wide Web needs to connect to the private factory LAN. Once the Internet is added into the connection, guaranteed quality of service cannot be maintained and security issues also arise. In addition to this, it is impossible to develop a single quantitative method to evaluate the response times of the World Wide Web because the Web is made up of numerous routing protocols, over many thousands of autonomous systems.

The only way to achieve a quality of service is to use policy based routing. This can be done through the use of a Virtual Private Network (VPN) on the backbone of the World Wide Web. The web based VPN suffers the same quality of service issues as straight web based traffic, but has greater security due to encryption schemes. A carrier based VPN offers guaranteed quality of service, through the use of ATM or Frame Relay backbones. As a result, the carrier based VPN suffers a lack of portability.

Commercial ready made SCADA systems

SCADA systems provide central monitoring and control of process control systems. They are a well proven solution for process control management in many industries, including mission critical industries such as mining and petroleum.

A SCADA package allows the user to quickly and easily design quite sophisticated graphical overview displays to represent the operating status and performance of a plant. It has the ability to accurately monitor, control and log all alarms and monitor current performance and efficiency, through trending, data logging and periodic event driven reports. The screens provide central or local control for the operator and some packages have ready-made facilities to enable remote Point-to Point (PPP) dialup to access the system from anywhere. The only requirement is that the client has a web browser and Internet connection. This system arrangement is known as a "thin client " application, since you don't need to install any special software, drivers, or custom applications.

SCADA systems also have multi-layered security systems that allow control over who has access to what areas of the plant.

Flexibility with data exchange is one of the points SCADA manufacturers endeavor to support strongly. Most SCADA systems allow for easy real time direct reading and writing to ODBC, SQL and DDE databases. This makes the task of loading plant variables, alarm logging and performance trending very easy to implement via the Internet.

There would be no point having all these options available to the plant's process engineer if the SCADA system did not have the ability to directly communicate with all the plant's devices via a system of flexible and robust I/O. As a result all SCADA systems come with large libraries of protocols, allowing for easy communication from the SCADA system to the numerous variety of I/O devices that are present in a plant. Examples are PLC's, loop controllers, bar code readers, condition monitoring analysers, as well as distributed control systems (DCS). Also if a device's protocol is not supported by the SCADA system, SCADA vendors are usually able to develop one.

Citect and SCAN3000 are two examples of SCADA packages that contain all the above mentioned features.

The only drawback for using these commercial products as a solution is the cost involved. However they would be affordable even by small enterprises if production volume provided by the rent-a-factory concept was adequate.

4 Use of Video

Transmission of Video over the Internet

Video monitoring will be of special interest to remote factory users and there are quite a number of very good 'off the shelf' products readily available that enable transmission of images from a camera to a remote user's desktop via the Internet.

A very common method for the uploading of static video pictures to a website, from a server that has a camera attached to it, simply involves the use of the File Transfer Protocol (FTP) to upload the captured frame to the target web page. The viewer is required to refresh his/her browser page in order to see updated frames. For practical machine control this is clumsy and slow.

Since an aim of the project is to provide remote users with real time monitoring of the AdeptOne SCARA robot it was felt that true streaming video technologies were the only option, thus discarding the FTP process.

The ideal way to set up the access and broadcasting from the AdeptOne robot, to allow for maximum video streaming speed at the lowest network utilisation cost for visitors to the site, would be through the use of multicasting, using Internet Group Multicast Protocol (IGMP). This is because multicasting allows a server to simultaneously transmit the same data to many different client viewers, instead of each client having its own private connection to the server. The only drawback with multicasting at this point is the fact it has yet to be deployed completely throughout the Internet. As a result, at this point in time, the implementation of multicasting for the AdeptOne robot would be premature.

A tremendous amount of research is currently being undertaken in the area of reliable concurrent multicast over bursty networks, such as the Internet [Su & Wang, 1999]. A few years down the track, multicasting will be available everywhere throughout the Internet, at which time the Internet will appear to be reborn, due to the ease with which a media broadcasting server can transmit to thousands of viewers a program via a single packet stream. More information on multicasting is available from the Internet Engineering Task Force (IETF) which takes responsibility for creating and monitoring these standards, and in turn assigns a number and a document that describes the standard. The Internet Group Multicast Protocol has been assigned the numbers RFC 1112 & RFC 2236.

Hence this leaves two techniques to choose from when developing video streaming, these are:
Server Push - supported by Netscape browsers
Image Pull - supported by Internet Explorer browsers

Server Push is the ability for a web server to continuously push data to the browser; as a result the browser will automatically update the display [Kanitkar & Delis, 1998]. Essentially the server is able to deliver Server Push images directly to a Netscape browser and no further action is needed.

With Image Pull once an image is delivered to the browser and displayed, a request is immediately sent to the server requesting a new image.

Since two completely different processes are involved depending on the browser, the video server needs the ability to detect which browser the user has, and on doing so start the appropriate session connection. Typically this is done by the use of some simple JavaScript coding in order to determine the type of browser being used to view the page.

A very effective way to enable Server Push to run on both browsers is to employ the use of an applet embedded in the HTML page. This method guarantees the video will reach the desktop (provided the browser can run applets). One such commercial solution is InetCAM (http://www.inetcam.com) which utilises server push technology embedded into an applet to allow compatibility between browsers. In addition it supports almost any video source. It is by far the best streaming video software available at present even though it is quite inexpensive.

5 Progress to Date

Experimental Set-up

Eventually the three assembly robots available in the mechatronics laboratory at the University of Wollongong will be linked by conveyors and integrated with bowl feeders and other equipment to form an assembly system able to manufacture a family of parts. However the work performed so far is confined to the interfacing of one of these robots, an AdeptOne, to the Internet.

Internet Control of the AdeptOne Robot

The AdeptOne robot is a Selective Compliance Assembly Robot Arm (SCARA) industrial precision robot and is one of the fastest commercially available assembly robots.

Adept robots can be found on production lines in factories all around the world for small-parts material handling, assembly, packaging, semiconductor and in food industries.

The Adept Multibus SC Controller runs the V+ operating system, which is a very well established robot programming language. V+ is a real time and multitasking operating system, which manages the entire system, including IO, task management, memory management and program execution.

Development of remote communication to the Adept

The AdeptOne SCARA robot is directly connected and driven by an Adept Multibus SC Controller. This Controller is running a very early operating system (Ver. 6.7+ software). Since the controller is old, it does not have a readily available Ethernet interface.

The first step towards having the AdeptOne driven by remote users was to develop an Ethernet interface to the AdeptOne. The implementation of this presented quite a challenge in itself.

The solution was to write a host server program to run on the Controller, with its purpose solely being to monitor one of the serial ports on the Controller and act on any ASCII command that is sent to that serial port.

To achieve this successfully, initially a PC with a terminal emulation program running on it was connected to the AdeptOne via its serial port. Once commands sent from the keyboard on this PC could be successfully received and acted upon by the AdeptOne, the next step of the project was to develop a server written in Visual C++ that emulated this terminal session.

The serial port on the AdeptOne was then interfaced to a serial port on a standard PC running the Visual C++ server program. The server program's role is to pass to the serial port on the PC the appropriate ASCII instruction it receives from the web server running on the PC. The web server's role, on receiving an instruction from a remote Internet user, is to pass this instruction to the Visual C++ server.

Web Interfacing

On arrival at the site, the Internet user is presented with a HTML page that contains a user menu and live streaming video of the AdeptOne SCARA Robot (see fig. 3).

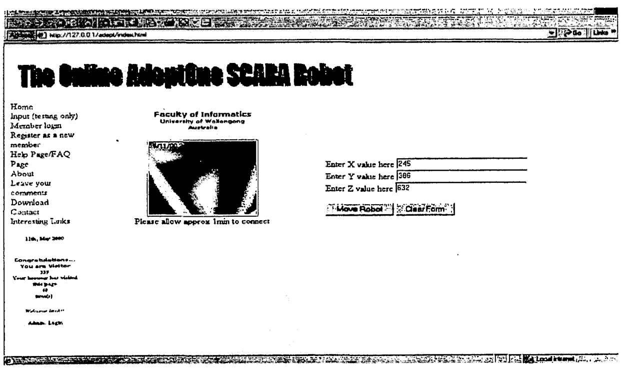

Figure 3

Basic security for the rent-a-factory requires a user to be authenticated before being allowed to submit a movement request to the AdeptOne robot. This is done by a prompt for a username and password. The authentication is done with the use of some simple Visual Basic code to open an Access database and scan a table within it for the username. Once a match on the username is made, the password for that username is checked. A valid username and password allows the user the ability to submit movement requests.

The movement requests are submitted to the AdeptOne robot in the form of X, Y, Z coordinates. These coordinates are passed to the CGI program simply by the use of a GET method. The CGI program is an extension of the original prototype Visual C++ server program mentioned earlier.

The Visual C++ program, on receiving the X, Y, Z movement requests from the user's web page, converts these coordinates to ASCII and passes them out to the RS232 serial communications port on the web server to the serial port on the Adept Multibus SC Controller.

Validity of the entered data is checked at several positions in the process. Firstly, JavaScript on the webpage ensures that all three fields contain data. Then the CGI program checks that the data entered by the user only contains numerals. Finally, the software limit on the Adept Multibus SC Controller ensures that the coordinates are within the range of the AdeptOne workspace. The overall system described is shown in figure 4. The actual AdeptOne robot is shown in figure 5.

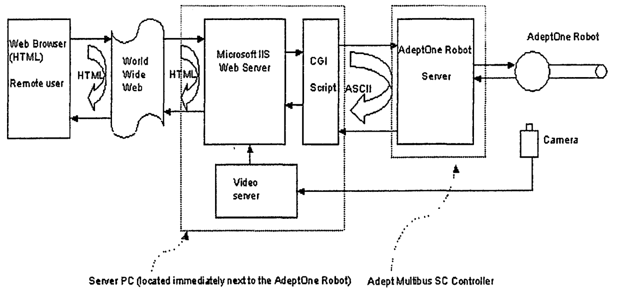

Figure 4

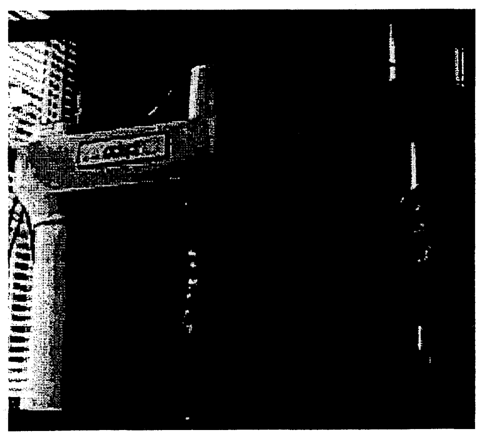

Figure 5

6 The Next Steps in this Project

Wireless Application Protocol

Wireless Application Protocol (WAP) is a new technology that essentially allows access to a micro browser on a mobile phone, instead of using a full size computer to access the Internet.

It is intended that the AdeptOne robot website will allow a WAP device to interface with it. To achieve this, essentially a "mirrored" second site needs to be developed in Wireless Mark-up Language (WML).

The WAP device should be able to issue commands to change the set points of a process control system, start and stop processes, and receive real time data of the process in the form of text to the screen.

Voice control

Recent advances in computing power have allowed for substantial progress in the area of speech recognition. Lightweight mobile phones with in built voice dialing are becoming common in the market place. These advances will filter through to the Internet in the coming years, especially when the Internet has increased bandwidth.

Voice control even in its present form could be implemented as an extension to the AdeptOne website. It would offer similar rudimentary control over the robot as mentioned previously with WAP, giving users a natural feeling environment to operate within.

Vision recognition

Vision control is an important feature to apply to any robot to enable it to function in real time in any environment that is continuously changing. The Adept Multibus SC Controller has a vision recognition system. Exploration of the capabilities of this system along with the avenues of Kalman Filtering and infrared sensing technologies would provide some exciting new capabilities of the AdeptOne website.

Implementation of a vision system would enhance the "Rent-a-Factory" concept immensely, allowing for more processing to be done locally on the web server. This would further reduce the amount of traffic needing to be passed across the Internet to the remote user, enhancing the feeling of real time control to the user.

Bluetooth

Bluetooth is a newly developed wireless technology, which can be thought of as a more secure short range wireless solution to that of infrared. The cost of Bluetooth is such that it places itself in direct competition to the current infrared technology.

Application of the Bluetooth technology in a factory would give a cost effective wireless communications solution between the numerous feedback instrumentation sensors. Bluetooth in place of the conventional 4-20mA instrumentation loops would result in many advantages, both in flexibility and maintenance.

Bluetooth could offer some exciting features to the AdeptOne web site, such as allowing other machinery to interact with the AdeptOne robot wirelessly. An example would be the control of a conveyer.

7 Conclusions

This paper described the rent-a -factory concept and its possible implementation using Internet control of practical manufacturing operations. A review of the present online telerobotic sites around the world was presented and their relevance to the rent-a-factory discussed.

Ways of implementing realistic control, on both sides of the server, of production systems were described, with the requirements of real-time fast control in mind.

Experimental work involving the implementation of Internet control of an AdeptOne robot was described. Some of this work has duplicated previous work in control via the Internet, but the inherent delays in feedback arising from communication delays on the World Wide Web have been taken more fully into account.

The next steps in this project will be to expand the equipment controlled and to reduce the feedback delay. Several observations were made on appropriate technologies to be used in the future to assist with this. Ultimately a complete closed loop with the desired safety and other limits at the factory site will be required. This, together with the Internet, should enable a convincing demonstration of the rent-a-factory concept.

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