Web-based Remote Active Presence

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Abstract

This paper describes the work-in-progress of a client-server system to control a moving robot over the World Wide Web. The robot is representing the person that controls it in the remote environment. Visual and acoustic information about the remote site is transmitted to the user who is capable of controlling the movement of the machine. The robot platform is interfaced to the computer using simple microcontroller circuits. A Web server is used to provide the client application to the operator. Since the decision was made, that Java2 would be the only target implementation language both client and server are platform independent.

The engineering objective is to perform robust real time manual control over the Internet connection characterized by varying bandwidth and latency. Although the presented system is completely different from full size professional robots, the problems encountered by senior students designing it are similar to ones faced by design engineers at NASA who prepare full sized vehicles for their trip to Mars. The current version of the project can be visited at the Web site at http://sant.bradley.edu/~olekmali/projects/telebot/.

Introduction

This paper describes a successful project that can be utilized as a senior engineering student project with both software and hardware components. The scope of its software portion lies in:

- Utilization of the latest Internet technologies for both data and control signal transmission.
- Programming an embedded computer system that controls the remote manipulator.
- Development of easy to use graphical user interface at client side.
- TCP/IP network socket programming.

The scope of hardware portion lies in:

- Interfacing computer and embedded system to wireless links.
- Interfacing the embedded system to the hardware responsible for movement of the manipulator.
- Developing or modifying available high bandwidth links for multimedia transmission from the manipulator to the network-connected base computer.

The preliminary results of the smaller pilot project that was focused at simple control of a robotic manipulator over Internet connection have already been published[1]. This paper introduces expanded project, with developed multimedia feedback and embedded manipulator controller of increased reliability.

Historical background

The idea of remote controlled operation has been long under investigation. Goertz and Thompson[2] demonstrated their first "master-slave" teleoperators at the Argonne National Laboratory in 1954. The other pioneer work of Ferrell and Sheridan[3] was published in 1967. Recently tele-operation became again the subject of very intense research due to the development of uniform and robust communication platforms with the Internet as the outstanding example. Applications of such technology include inspection and exploration of hard-to-reach places and hostile or toxic environments[4,5].

Most current tele-operating systems are either basic extensions of direct manual control[4] or model-based supervisory control[3,6-10]. A simple example of both approaches would be to consider how to move a remote vehicle from point A to B. Direct control requires operator to send the steering signals to the remote vehicle continuously while it is moving. In the latter case the remote vehicle would drive autonomously and require only its new desired destination. The first approach has obvious drawbacks such as reduced stability of the control loops due to long delay caused by fully remote operation and dependence on the continuous connection between controller and controlled object. In the latter case, there is no need for high-speed reliable continuous communication. Real life control problems are usually characterized by long feedback delay, limited communication bandwidth and frequently limited knowledge of the environment model.

The "Mercury Project" is probably the first successful implementation of the teleoperation via the Internet. A simple robotic manipulator with CGI program interface and video feedback was developed by Goldberg et al. in 1995[13]. The successful working model of the model-based control for a complex system of multiple bulldozers was reported by Yeuk and Stark[14] in 1999. Most Web-based controllers implemented on the Internet utilize *a priori* known environment and the model describing the system. The Web-controlled robotic manipulator developed at Bradley University is targeted to model such real life environment.

In addition to solving manipulator control problem, fast and low-latency multimedia transmitting is necessary to achieve the full effect of remote presence. Available Internet-based broadcasting software is characterized by high latency - commercial broadcasts may be delayed in favor of buffering to prevent transmission interruption during periods of network timeouts. On the other hand, available videoconferencing software, or voice-over-IP is provided only in the ready to use applications that are difficult to adapt to the specific needs of the system and incorporate as an element of a larger program[15].

Web-based Controller Architecture

All aspects of the problem that are described in the previous section are reflected in the designed system that was implemented and is in operation at Bradley University. The Bradley Office Explorer system consists of seven main components:

- Remote control interface that runs inside a Web browser of a remote user's computer.
- Web server providing the remote interface for downloading as a Web page with embedded Java applet.
- Robot server written in Java, interfacing the remote clients connected using a custom TCP/IP protocol.
- Video monitoring system providing visual feedback. Currently only one view is available, either from the side or from camera mounted on the robot.
- Remote controlled robotic manipulator interfaced to the network-connected base PC.
- Operating system providing the interface for the robot server to the Internet and the robots seen as the I/O devices of the computer.

Fig. 1 illustrates the data flow and interaction among the components.

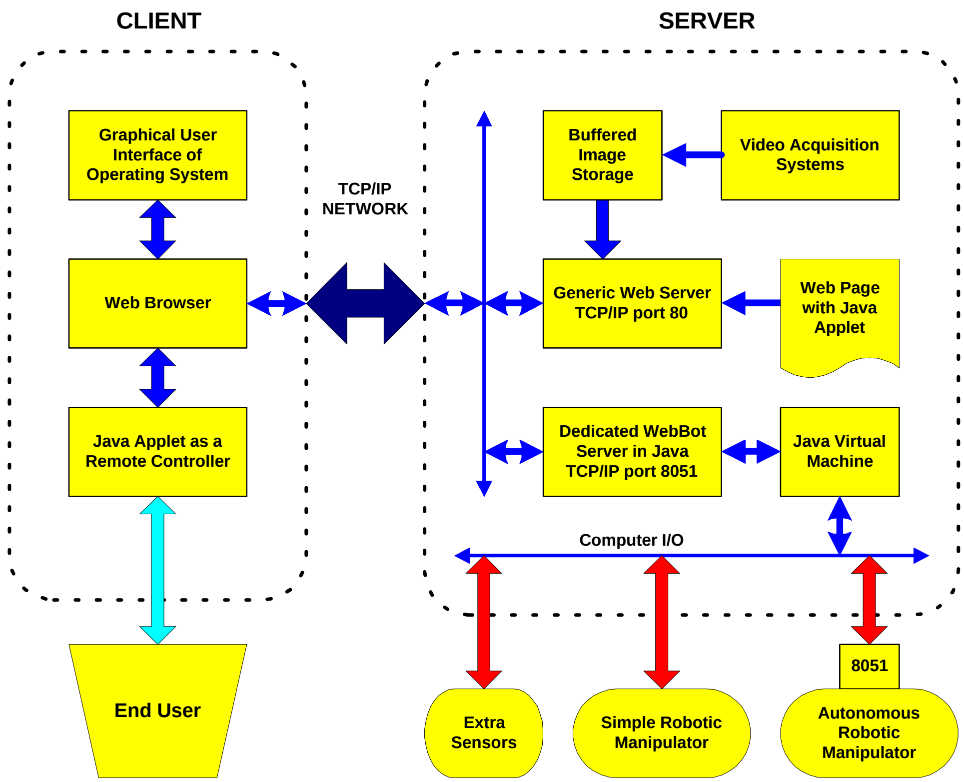


Fig. 1. Data flow and interaction among the components of the Web-controlled robot system.

The server computer runs a standard Web server, which allows the client computer to download the Web page with embedded remote control applet. After being downloaded, the applet runs two processes. One of them takes care of video stream update. The standard HTTP protocol is used for image transmission alternatively to the custom protocol that allows high frame-rate transmission over high bandwidth connection. As soon as a new image is available from the server it is downloaded, and user-end display refreshed. The custom server replaces a Web server and standard image capture program. Such servers are available as shareware[16] or freeware[17], and do not have to be developed in house, unless very high frame rate is desired.

Streaming video server from Real Networks was once considered as the video server. However, high latency caused by buffering in several stages of the transmission process made it impractical for feedback purposes. In case of interactive control it is more important to receive new frames as soon as possible rather than to receive smooth uninterrupted but significantly delayed video stream.

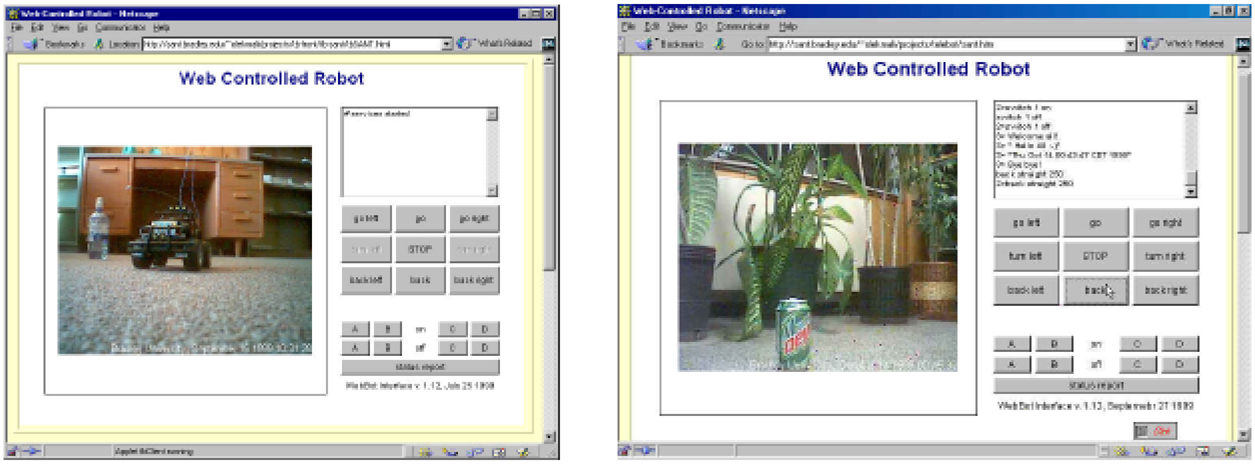


Fig. 2. Graphical User Interface of the WebBot client based on a Java apple with both side (left) and on-vehicle (right) camera views.

The second process in the applets monitors the GUI inputs and translates user input into commands. The range of instructions depends on the robotic manipulator that is currently controlled. They can be inspected by looking at the contents of the text area located in the upper right corner of the user interface. That text area contains reports of the communication and status of the system components. Fig. 2 shows the user Interface for the Office Explorer with both side and on-robot camera views.

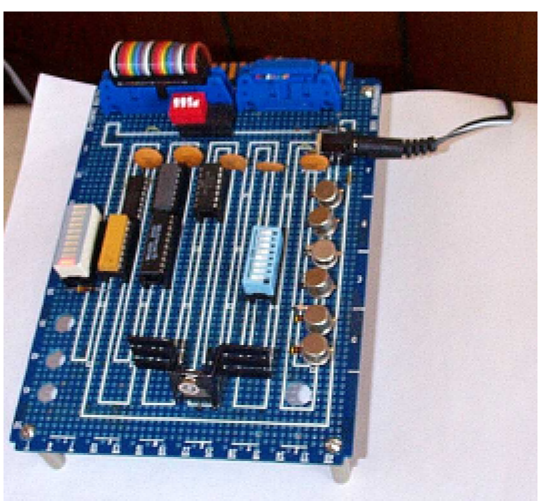


Fig. 3. Interface between networked PC and wireless vehicle controller.

The user instructions are translated and sent to the robot server. A custom, text-based network protocol is used. Use of a text-based protocol versus binary one was made because of its simplicity. Students can easily debug and monitor both client and server using a standard telnet application. A skillful person could even control the robot using only a text telnet terminal and manually download the visual feedback as necessary.

The current robotic manipulators have only basic functionality that allows only for movement. The Office Explorer robot is still under design. It is powered using stepper motors and is controlled by am embedded microprocessor circuit. Fig. 3 shows the interface between network-connected computer and wireless transmitter that send commands to the manipulator. In case when such a link is not necessary, the interface may be connected directly to the button or switches of the robot.

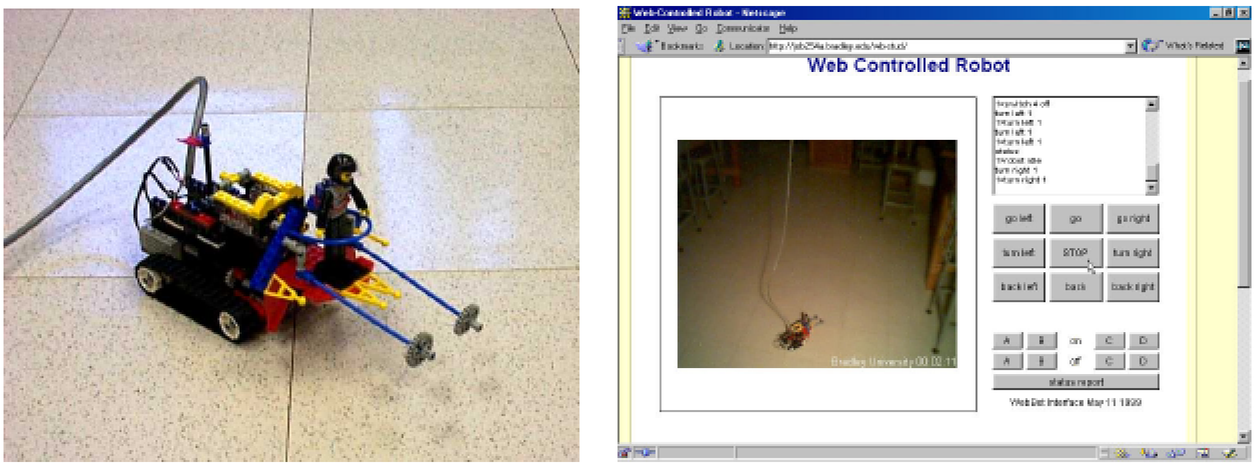


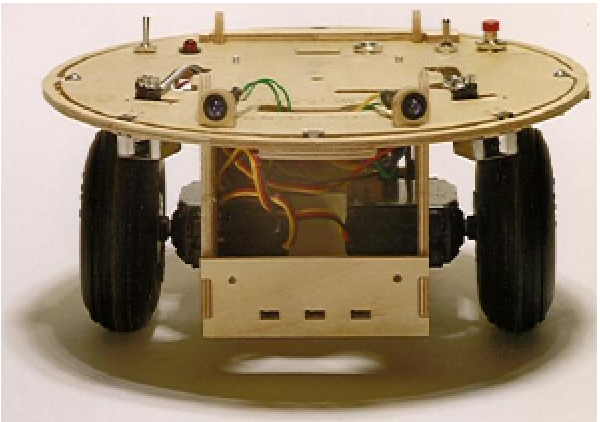
Fig. 4. Robotic manipulators built by students participating in the project.

Several models were built using Lego sets and are powered by Lego motors. They are interfaced by a simple controller connected to a parallel port of the computer that runs the server. These Lego robots are still available on-line. However, they provide only side camera view visual feedback. Although their user interface was updated to the current version, only some inputs are functional. Fig. 4 shows a student project that still is accessible from the Web

Conclusion

This paper has described the work-in-progress of a Java client-server controller for a robotic manipulator. The control software does accomplish its objective of maintaining control of the robot via the Internet connection. The client allows the user to move the robot forward, reverse and to turn it left and right either in place or while moving. Up to four on-off devices may also be placed on the robot and connected to the controller. The feedback information is provided by a video stream from the WebCam. The first Web-based control system has been in operation since April 1999. The second, improved system with on-robot camera has been in operation since middle of October 1999.

At first, the system was intended to be a simple senior design project using a Web server and CGI technology. However, providing the robust control required developing the complete client-server application in Java resulted in an open-ended project, which is further being developed. This year senior students are implementing games of tag two and hide-n-seek using two robots with Motorola 68HC11 controllers. One master student is working on a funded project involving high-speed feedback from the commercial type robot with a PC104 controller. Fig 5 shows robotic platforms of the current projects.



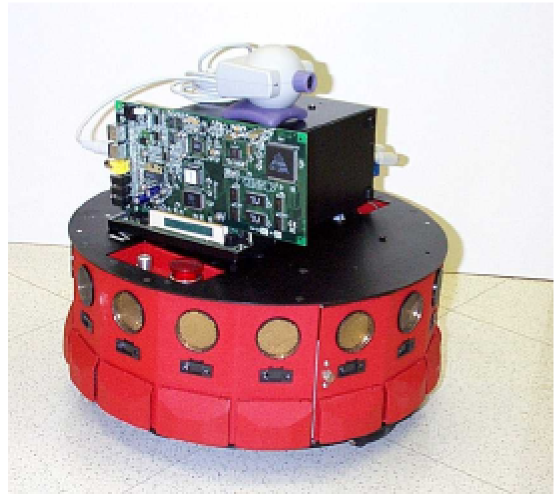


Fig. 5. The robotic and computer platforms for the current remote presence projects.

More information and the actual robots can be found at the project Web site located at http://sant.bradley.edu/~olekmali/projects/telebot/.

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