Tele-Monitoring and Control Through the World Wide Web: Issues and Development*

Maki K. Habib

GMD-Japan Research Laboratory
AIM Building 8F
KokuraKita-Ku, Kitakyushu-City, JAPAN
maki.habib@gmd.gr.jp

Abstract:

The Internet and the World Wide Web (WWW) provide low cost and widely available media rich interface that can make teleoperated resources accessible to a broad range of users regardless of geographic location. In addition, Internet based teleoperation with tools supporting human communication and interaction with real world, will inevitably lead to many useful applications in various sectors of the society, professionally and socially. This will lead to improve quality of services, utilise efficiently resources, minimise risk associated with hazardous and dangerous environments, access timely information and expertise that support diagnosis and decision making, and to reduce overall operational and maintenance cost. This paper addresses the technical issues and requirements that affect the design, acceptability and performance of Internet based teleoperated systems. Such issues include, communication and the effect of delay, controllability, reliability, interfacing requirements, command structure along with software and hardware compatibility. Also, consideration is given to monitor and control one or group of equipment/process at a single site and at multiple sites. A framework that supports Internet based monitoring and control systems has been developed. The goal was to design a system that would be versatile, easy to learn and use, and that would allow several users to simultaneously view and control distributed equipment, appliances, utilities, etc. Two applications are selected and implemented to demonstrate the developed system. The first is to monitor, program and control a robot manipulator, and the second is to monitor and control house appliances and utilities available on-site. The developed system is written in Java language and is accessible via a Web browser.

1. INTRODUCTION

As information resources are scattered across the globe and may not be available where they are needed, it is important to look for alternative forms of physical movement of people, equipment, utilities, records and information, preferably through the use of telecommunications and multimedia facilities.

The answer for such need is the Internet and the World Wide Web (also will be referred to as WWW and Web throughout the paper) that constitute a ubiquitous network with a media rich interface that bring a global multimedia information universe into existence with present technology [26]. The Internet and the Web represent the suitable infrastructure technologies that facilitate virtual presence via electronic communications between entities, humans and machines.

1.1 The Internet and the World Wide Web

The Internet continuous to become more integrated into our daily lives. This is particularly true for scientists and researchers, because designers of development systems view the Internet as a cost-effective worldwide standard for distributing data.

The WWW was originally envisioned by its designers to become a collaborative tool for the Internet. However the initial Web was designed as a hypertext distributed information storage system to facilitate the sharing and dissemination of documents between geographically distant laboratories [3-5]. The WWW is a purely information focused environment, consisting of documents and links between these documents. The graphical user interface that could be operated by novice users, the capability to link documents and the platform independence of the content format were the main advantages.

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The addition in 1992 of a simple and friendly user interface increased the Web appeal and usefulness, which in turn has fuelled its rapid growth and remarkable popularity since then. The widespread adoption of the Web has radically changes the use of Internet and dramatically extends our scope and reach, and this impact is increasing as the Web evolves [3].

During the last few years, the Internet has evolved with an enormous speed. The Internet has become a governing technology of the last period of this century, with an enormous impact on global society. It has increased our tele-connectivity by allowing us to electronically connect places and exchange text, graphics, images, sound, and video with anyone whose interest we share, professionally and socially, and virtually anywhere in the world. The explosive growth of the Web along with the evolution of HTTP and HTML and other standards, has enabled many applications which would not have been feasible just few years ago [1-5]. When researchers were asked to predict the future of the Internet, they said that it would support on-line multimedia collaboration, sophisticated information retrieval and remote control of expensive or unique scientific instruments via tele-experimentation [30].

Many users are looking for more interactive solutions in which users can actually control and monitor experiments or processes remotely using a Web browser.

1.2 Interaction over the Web

The WWW offers a suitable infrastructure that integrates computer-based services from multiple platforms and provides a flexible and effective tool for examining and monitoring remote physical environments. The Web has the mechanisms for supporting fill-in forms and virtual documents that let browsers act as remote display interfaces for hardware. This helps the Web makes an interface to the physical equipment available through most computer platforms and hence widely accessible. The adoption of the new Web-based system to provide security, control and monitoring services will allow for a higher level of usage of the Internet for interactivity. This will be an attractive factor since the Web provides a low cost and widely available interface that can make teleoperated resources accessible by a broad range of users. While the richness of the media carried over the Internet demonstrably support information exchange, it is also represents a set of technologies that can be deployed to manage some of the design requirements in teleoperation field. But, even with the rapid adoption of these new tools for human communication and interaction, it is obvious that something is missing. Hence, to get full advantage of the Internet, it would be very desirable to get complete real time physical interaction with the site being visited. Currently, we can find four categories of interactive exhibits on the Web [26]. These are : (i) Computer simulation: this represents the most common interaction currently available on the Web. (ii) Remote sensing: this represents simple form of hardware connected to the Web and used for remote sensing. Examples of this type include, weather sensing, radiation detectors, traffic flow sensors, etc. (iii) Simple remote operation: this represents those machines in which the user has a limited ability to interact with. Interaction is limited to the user sending a single request and receiving a single response. (iv) Complete real time control: there are some examples of complete real time control of machinery over the Web.

1.3 Prior Work in Teleoperation

Remotely operated mechanisms have long been desired for use in inhospitable environments such as radiation sites, undersea, and space exploration.

The mechanical Gaze system developed in Berkeley University [25] has provided a robotic interface to the outside world via blimps and roving robots over the web. It allows remote Web users to control a robot with an attached camera to explore remote objects. In October 1994, Mark Cox of Bradford University reported a prototype autonomous telescope using the WWW gateway to provide remotely for schools, amateurs and professionals [26]. This seamlessly integrates the telescope into the rest of the Web. Through this system, the Web users can look at an image taken from an observation with the telescope and compare it with one taken from a star database held at NASA. The Materials Microcharacterization Collaboratory (MMC) project [6], was created as a pilot project to fundamentally change the way scientist work together. It provides the integration on the Internet of unique or expensive research facilities and expertise for remote collaboration, experimentation, production, software development, modeling, or measurement.

NASA has developed the Web Interface for Telescience (WITS) as a part of the long-range rover task [27]. WITS enables scientists to participate collaboratory in planetary lander and rover missions from their home institutions [28]. WITS was used for the first time in the 1997 Mars Pathfinder missions [29].

Architecture for an autonomous mobile robot via World Wide Web has been designed [23] to provide multilevel remote control modules (direct control mode and supervisory control mode) for the WWW users. The Mercury project [24] at the University of Southern California was the first to link a robot to the WWW. It allows the low-level control of a robot arm through a standard Web browser, and provides an interesting service called the telegarden. Another teleoperation system at the University of Western Australia has been developed on October 1994 [5]. The authors have demonstrated a remotely controlled six axes robot with a fixed observing camera. The system enables the Web users to control the robot. Other site (http://light.softopia.pref.gifu.jp/) introduces a RemoteEye on theNet with light controller. The system the user to control remotely from a Web browser the status (switching On/Off) of a two dimension array of lights (7x7=49) and the return a live image of the latest status of the lights in the lobby of a Japanese office building.

There are now many machines that are interfaced to the Internet along with techniques that has been developed to facilitate and enhance their performance [11-22].

Various remote control systems has been developed for applications in manufacturing, underwater manipulation, storage tank inspection, nuclear power plant maintenance, space exploration, satellite repair. It is expected that the tele-monitoring and control through the internet will grow rapidly to fulfil the need in many area of applications, such as entertainment, medical healthcare, manufacturing, inspection, training and education, research, hazardous and dangerous environment, underwater (exploration, manipulation, navigation, etc.), space(exploration, manipulation, navigation, etc.), home security, technical services and maintenance, etc.

2. MOTIVATION AND OBJECTIVES

The need to enhance safety, performance, reliability, quality, and to reduce cost, are always constitute the main factors that motivate people to create alternatives and new ideas in various fields.

One of the fields that is gaining a lot of attractions and momentum in the current era of technical development is teleoperation field, where equipment and devices have to be monitored and controlled over vast distances for different purposes. It is important to have such ability in places that are inaccessible to people, places that are dangerous to people to go in, and places where expertise and resources are available. Remotely operated mechanisms have been desired for use in inhospitable environments such as, radiation sites, undersea, space exploration, medical diagnoses, manufacturing and micro-manipulation, remote surveillance, remote diagnosis and maintenance of machinery.

It is very useful for companies, services and research centers, and even for individuals to have the ability to remotely monitor and control the operation of a targeted equipment or a process that integrates more than one device such as production line. Other than this, it is also vital for certain operation or process that need special skills, expertise, special equipment that are not available on-site either because it is unique or it is very expensive. The qualified person can reach and handle the operation through a teleoperation system from any place in the world where the technological access facilities are available.

It is also important to,

1. have tools that provide research and development, production test, manufacturing, monitoring and inspection, and management access to information that companies use to make more informed decisions.
2. maximize engineering test resources.
3. deliver seamless access to live data, which empowers users throughout the company to improve productivity, reduce costs, and increase profitability.
4. share of unique or expensive equipment for collaborative research, training, education purposes. This will enable people to share expensive equipment between several laboratories to reduce the expenses, and doing a collaborative research and experiments.

The Internet technology makes such tasks and applications possible due to its low cost, world wide availability along with its media rich interface that can make teleoperated resources accessible to a broad range of users regardless of geographic location. In addition, Internet based teleoperation with tools supporting human communication and interaction with real world, will inevitably lead to many useful applications in various sectors of the society, professionally and socially. This will lead to improve quality of services, utilize efficiently resources, minimize risk associated with hazardous and dangerous environments, access timely information and expertise that support diagnosis and decision making, and to reduce overall operational and maintenance cost.

Accordingly, a multi-user, real time, interactive, shared environment has to be established which can be reached from anywhere on the Internet with PC-based equipment and standard.

This paper addresses the technical issues and requirements that affect the design, acceptability and performance of Internet based teleoperated systems. Such issues include communication and the effect of time delay, controllability and reliability, interfacing requirements, command system mechanism along with software and hardware compatibility. Also, consideration is given to monitor and control one or group of equipment/process at a single and multiple sites. A framework that supports Internet based monitoring and control systems has been developed. Two applications are selected and implemented to demonstrate the developed system. The first is to monitor, program and control a manipulator, and the second is to monitor and control home appliances and other facilities available on-site. The developed system is written in Java language and is accessible via a Web browser.

3 TELEOPERATION SYSTEMS: ISSUES AND REQUIREMENTS

A teleoperation system has various components and requires knowledge from many different areas. Too develop an efficient teleoperated system, it is necessary to focus on the issues and requirements that affect their performance. Solutions should be balanced, i.e., superior performance in one area will be of little value if other factors limit overall system performance.

3.1 Time delay and Real Time Applications

Controlling equipment, machinery or a process in the real world and in real time requires monitoring a situation remotely through sensors, sending control commands to the target equipment and finally observing the results within a suitable time to direct the physical machine to its goal.

Real time applications are quite different from standard data applications, and require service that cannot be delivered within the typical data service structure.

Communication time delay and data loss are the most serious problems facing real time application over the Internet. These problems need to be addressed properly and solutions need to be introduced to overcome it.

Current data networks typically use packet switching as means of dynamically allocating network resources on a demand basis. Packet switching has been widely used because it facilitates the interconnection of networks with different architectures, and it provides flexible resource allocation and good reliability against node and link failure. However, packet switching provides little control over the packet delay at the switches. This clarifies that computer networks introduce a time-delay that is best described by a time-varying random process. Difficulties facing real time packed switched communication protocols are: Throughput; where an application may face a congested network and not able to exchange data consistently. Delay; where its upper bound depends on the network traffic. Delay jitter; where the network load may induce large delay variation and packet scrambling, and Packet losses; where routing hosts may discard packets that overflow the input buffers.

The main consequence of the predicted increase in documents, users and uses of the Web is a potentially huge increase in Web traffic, which in turn might lead to serious congestion in the Internet. Multimedia applications, with their novel traffic characteristics and service requirements, pose an interesting challenge to the technical foundation of the Internet.

In the Internet various protocols are in use. However these protocols don not guarantee that signals are exchanges between a sender and a receiver synchronously. Usually the band width and communication propagation delays of the network are influenced by the load of the network and are dynamically changing[8].

In the information space the synchronization of signals is not important. However when robot/equipment are connected to a network, real time operation and synchronization of signals are serious and important issues.

There are different ways to minimize the serious impact of the time delay of real time this problem,

1. Make sure that enough network resources are available to support the anticipated workload. The appropriate dimensioning of network and server resources does this.
2. Optimize the flow of requests and replies between users and servers. This can be done using either multicast document delivery or Web caching does this.
3. Reserve a bandwidth to ensure that time sensitive data is delivered in a timely fashion.
4. Keep the delay constant in order to maintaining the stability of the control system
5. Assign a supervisory level of control to the equipment, device or the process side. This can be achieved by adopting a multi level control mode policy.
6. The good understanding of the problem is essential for the proper design of network algorithms such as, routing and flow control algorithms.
7. High level commands
8. The role of the machine intelligence through the autonomy
9. To minimize the impact of the delay, the World Wide Web should be designed with the intention of making it easy for users to interact with the process. The status of the process should be updated in real time. The parameters and the scene should be updated only when there is a change.

To achieve real-time performance, research in this area has to focus on adding real-time features to standard packet switched networks.

3.2 User Interface

An important factor for the acceptance of remote services and cooperative applications is the presentation of the user interface.

The design of a good user interfaces for teleoperators is a demanding task because of the requirement for real-time reproduction of motions and actions.

The selection of a good user interface is of critical important to the success of any teleoperation system. The interface needs to be available over a wide range of machines, should preferably be graphical and must be to integrate process/equipment control with on-line and multimedia based educational and instructional material. It is important to have a consistent user interface over different platforms and operating systems.

The WWW provides a standard graphical interface to the Internet, which is independent of the platform and the operating system.
From the task description, a suitable interface should be constructed. It is necessary to add features to the interface allowing the operator to acquire more information about the state of the task. The interface has to be easy to understand and to use (in order to attract many people with different background to use).

There is a need to have a user interface with features that allows observation of system performance, operator situation awareness, workload and the various control modes. Specific visual and functional characteristics of a potential interface facilitating different levels of human and computer control over a teleoperator. Providing visual information of a remote site to an operator will improve the safety and enhance the efficiency of operation.

Some of the features that a good user interface may include:

1. Enable users (scientist) to collaborate on and control wide range of application from anywhere in the world.
2. Being aware that the web users are untrained (not like in the case of traditional teleoperation), the intuitiveness of the web interface gets more and more important.
3. It is important to create a physical feeling of interaction for the operator while interacting with the remote device or process. Such thing can be achieved through a haptic interface where the physical information of torque force, and visual can be sent as a feedback to the operator at the time when he is interacting with the process.
4. The need to have features and easy to use tools that enables users to develop high end, professional user interfaces
5. For complex environment there is a need for intuitive on-line training session with virtual reality simulation support. Such features should be facilitated through the user interface. The user interface should avoid using large introductory text pages.
6. Merging multiple mode of control and communication through one user interface.

The interface, command structure and the modular framework should simplify the way to enable connecting different devices and processes operating in various environments to the Internet.

3.3 Programming Development Environment

The programming environment facilitates and accelerates the creation of complex systems and architectures.

A selected programming environment should:

1. Offer greater interoperability.
2. Support asynchronous and synchronous communication.
3. Support wide range of application environment complexity.
4. Provide a simple and direct model for distributed computation.

3.4 Authentication

The Internet provides new opportunities for devices and processes to be remotely controlled using personal computers and low-cost Internet communications. However, the Internet is open to the public and provides little in the way of security. Therefore, in order for control systems to be safe and proprietary data protected, mechanisms must be in place to control access to systems and data.

For safety, monetary, and credibility reasons, data security must be provided for a teleoperations system, particularly when the system is to operate over open networks. The various things that a teleoperations service must do in order to be secure, in relation to operations over the Internet, can be grouped into two categories [31]:

1. Assuring the identity of the user; that the party accessing is known and authorized.
2. Protecting the transmission of data; ensuring that the data is not intercepted, corrupted, or substituted in transit.

The first serves the purpose of letting the system know who is actually using it. The second category is fairly obvious in purpose; it assures that data arrives intact, is not disclosed to unauthorized personnel, and that it arrives free from intentional corruption by malicious outside parties. There are two reasons for this' to keep secret data which should not be disclosed to the public, and to preserve the integrity of information which influences how a system operates or the actions of people in a system.

Assuring the identity of a user requires demanding some sort of verifiable identifier prior to granting access to services. Computer security scholars classify identifiers that can be used to authenticate the identity of a computer system user (or any person, for that matter) into three categories, or authentication factors. These are : (1) some object the user possesses (such as a key), (2) some secret the user knows (such as a password or combination), and (3) something that is characteristic of the user's person (such as a fingerprint).

As for protecting the transmission of data, many potential Internet teleoperations users would like to transfer data that they do not want to be accessible to the entire network. This ranges from proprietary data on advanced industrial processes, to public-safety related transmissions such as utilities operations data, to medical data in telemedicine applications which is required to be protected by privacy laws in most Western countries. Therefore, some form of encryption will be required to ensure that such data is accessible only to the intended party. Public-key methods would appear to be ideal for this use; the owner of the data can simply pass a public key to the teleoperations server operator, and the server encrypts the data using the specified key. The intended recipient decrypts the data using their private key, and no one else can do anything with it.

3.5 Intelligent Decision Making

The safety of teleoperated equipment/device should never be harmed or crash due to misuse, large time delay, communication malfunction, disconnection, and other types of uncertainty that may rise from the remote site, the network and the operator side.

This can be achieved by enhancing the capability of the teleoperated equipment with high level intelligent functions. Such functions will enable the device to have its own decision making capability, .e., it will have some level of autonomy.

Autonomy can help in reducing the bandwidth requirements for control, but introduces problems of its own, particularly in the area of interactivity. People seem to prefer "hands on" control, and do not get the same type of immediate feedback with an autonomous mobile robot that they would with a teleoperated one. This is exacerbated by the limited up-time of the robot, which reduces the chances for people to see it actually operating when they happen to come to the robot's web site [17].

Althougbh the robot/intelligent machine behaviors for teleoperated applications have its autonomy, the owner still has to worry about the safety of the robot/machine when it is working alone remotely. This kind of problems will lead to another research topic of intelligent remote control techniques.

To minimize such impact, there is a need,

1. for a remotely controlled system to decide when conditions are good enough by using observatory information that will enable it to act properly.
2. to have development environment that enable to design, simulate and test control algorithms for Internet based teleoperated systems before commanding the remote site. Web users may perform manipulation using a 3D graphics simulation contained in the Web browser. These interfaces follow the teleprogramming approach. Tasks are first tested on a simulator and the tested sequence of actions can afterwards be transmitted to the real robot.

for environment, safety and security sensors to enable remotely controlled system to operate in autonomous mode along with direct control mode (remote mode).

3.6 Other Important Factors

3.6.1 Interoperability

Interoperability and reusability are powerful and enabling capabilities that have helped improve effectiveness of computer-based environments in many domains. In the case of the Internet, interoperability is evident in the ability of network communication software and hardware from multiple suppliers to follow standardized protocols, and facilitate the reliable transfer of files across their interconnected networks.

3.6.2 Controllability

The separation between the operator and the device/process at the remote site diminishes much sensory information at the operator interface that would be available if the operator were actually present at the remote site. The sensory information may include, force, torque, visual, environmental, audio, tactile, etc.

There is a need to create feeling and to convince users that what they have been requested, what they see and what they are interfacing with is happening and is due to their actions. What the user has intended to do has been accomplished.

Accordingly, to enhance the controllability of a teleoperation system and to improve its performance, it is important to develop an effective haptic interface. A good haptic interface will try to integrate and reproduce the sensory information that are needed to create a realistic and comfortable feeling to the operator while interacting with the device/process at the remote site.

Even if such information is sensed using suitable sensors the following point need to be addressed:

1. Loss of information may occur during transmitting, and displaying the sensed information. Also, noise and uncertainty

associated with sensors are another parameters that need to be considered.

2. Loss due to representing and reproducing the sensory information at the operator site.
3. Physical sensing limitation. Such as the case of visual sensors, where the camera viewpoint is displaying inappropriate image, the narrow view of vision, the depth information mat be insufficient, etc.

3.6.3 Multi level control modes

For real time control over the Web, an authorized Web user (teleoperator) should be given the right to choose between several modes of control. Different levels of control modes will provides a teleoperator with suitable capability that enable him to monitor and accomplish a task while interacting with a remote system/equipment by using different levels of control modes. There is a need for general-purpose command structure with subcommand list under each category to enable a teleoperator to perform his work properly under each level of control.

The teleoperation interface should provide the user with a command window that allows him to go through the available control modes and select one that match the need for each situation. There are several levels of control modes that need to be considered:

1. Continuous manual control mode
   The continuous manual control of remote site requires sufficient training before the operator becomes familiar with the dynamics of the system. This control mode enables the teleoperator to take full control responsibility by sending direct primitive commands to the device/process at the remote site. The device/process will follow the commands and execute it. But, for safe operation, the device/process at the remote site should have the capability to recognize and notify the operator if the value of the parameters associated with a primitive command is abnormal. Continuous manual control mode through the network with the inherent latency and low bandwidth has its own bottlenecks.
   The advantage of having this level of control is giving the user the ability to see the results of his actions directly. The drawback is that the control is difficult under important time delay.
2. Supervisory control mode
   To overcome the disadvantages of direct manual control for teleoperation tasks, various control schemes using supervisory control have been used, where lower level tasks are executed autonomously at the remote site, while the operator provides higher level instructions from the local site.
   This mode provides the operator with the ability to supervise an autonomously executed task without direct intervention into the process. Different levels of interaction can specified under this mode including the right to intervene at any time to interrupt the execution.
3. Observation mode
   This mode will enable a teleoperator only to monitor the situation of a device/process at a remote site without issuing any commands that affect the operation of the device/process. This will enable many users to access the same remote site at the same time. But, we will have always one user with the right to control.
4. Collaborated control mode
   Such control mode is required when more than one user is collaborating in the setup and the operation of an experimental work/research or an integrated process. The user interface should reflect the situation of each teleoperator and their control mode in order to the facilitate the awareness among the users participating in the control session.

3.6.4 Accuracy and Reliability

One of the biggest concerns during teleoperation is that the teleoperated device/process should not crash or misused. Also, there should be co collision with other objects within the work space. It is important to minimize teleoperation errors, such as, mispositioning, mistrial while achieving a proper contact, slipping of an object while being manipulated, etc.

For some of the mentioned cases, to enhance and increase the performance of real time teleoperation there is a need to guide the target operation by providing it with localizing reference, and reducing the mental processing required to perform a task. To achieve this, a virtual fixtures have been introduced[10]. Virtual fixtures that are computer generated percepts, overlaid onto workspace that can provide similar benefits to the tools and fixture in real world. Virtual fixtures can be diverse in modality, abstract in form, and custom tailored to individual task to user needs. The Virtual fixtures can be defined using Virtual Reality modeling Language (VRML) tools linked to web browsers. Using this web related technology, remotely distributed users can quickly convene in a virtual space to manage complex teleoperations by jointly designing virtual fixtures.

In the field of telemedicine, after safety, no single factor has been more important in the clinical field trails than reliability. There is a need to make sure that teleoperated equipment/processes are functioning properly.

3.6.6 Human Factor

There is a continuous need to develop and evaluate human-computer interaction designs, methods and technology for networked computers that support real-time monitoring and anomaly detection, diagnosis, failure impact assessment and malfunction procedure evaluation.

Human factors usually have an impact on how the user interface structures the user's task and on the design of the user interface itself. In teleoperation human factors can be an even more critical technology because the design of the controlled system should make use of human performance data.

In a well-developed teleoperated systems human operators may carry out some varying mix of five tasks:

1. programming,
2. teaching,
3. controlling (primitive level)
4. commanding, (high level)

5. monitoring,

4. SYSTEM ARCHITECTURE

The objective of this section is to present a concept for a general-purpose teleoperation system with monitoring and control capabilities. The goal is to create simple, easy, reliable Internet based framework that can support wide range of applications that are distributed in terms of time and space.

The developed concept enables any number of remote hosts that represent service stations, manufacturing processes, home appliances and utilities, research facilities, laboratories, inspection processes, security, etc. to be monitored and controlled over the Internet via WWW browser by geographically distributed users (stationary or mobile).

4.1 Requirements and Considerations

A successful teleoperation system with functions of monitoring and control should be highly reliable, provide a fast response and present an informative and intuitive interface. For systems providing services, response time and initial impression are very important.

The followings are the design requirements and considerations that have been focused on while developing the concept of teleoperation framework within the scope of this papers.

1. The ability to integrate distributed heterogeneous teleoperation systems and communication protocols.
2. The system should be independent on computer platform and operating system both the remote and local sites.
3. A modular based software system that enables new module and feature to be plugged in directly and easily. Also, it is necessary to establish a modular framework for the process/device (robot/mobile robots) on the web
4. Scalable, to be easily modified and extended system.
5. Innovative and interactive Web site that contains platform independent software to support user interactions with real world. The visibility of the equipment/process and the environment.
6. The framework should allow multiple agents/users to cooperate and to produce a fully functional, flexible, reliable and executable teleoperation system.
7. Flexible command structure to support wide range of applications.
8. To deploy one or more monitoring/control sitess that can send sensory information and receive instructions (commands) from local PC node. The remote site may have some level of intelligence and decision making according certain circumstances.

4.2 System Architecture

4.2.1 The Developed Concept

There are wide ranges of applications that are geographically distributed and can be teleoperated. These applications may be categorized in different groups based on the type of services (medical, manufacturing, research, school, home, etc.). While each of these systems is performing its own functions, a need may arise to have interactions among systems within the same category or with other categories. Also, there is a need to manage the operation of different teleoperated systems by tracking operation, logging records

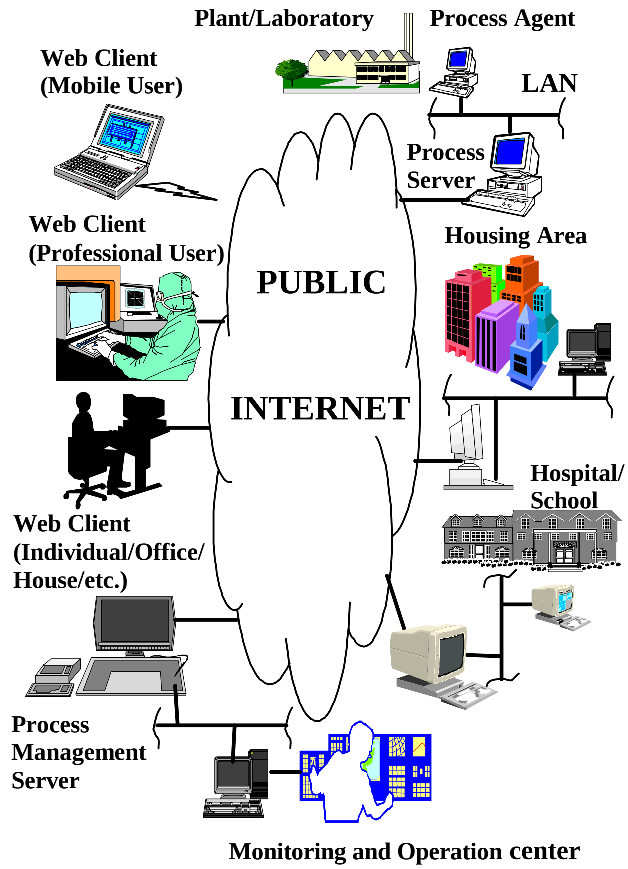

Fig. 1 The developed concept

related to specific components (such as, sensors, actuators), status of equipment and access for different purposes. A design of a teleoperated system and a new concept to manage and administrate distributed teleoperation systems has been developed. The developed concept is shown in Fig. 1.

The architecture of the developed concept may include one or more teleoperation system without having any constraints on their geographical location. Any of the teleoperated systems may work to monitor and control an individual process or an integrated set of processes. In order to track the technical operational information related to each of the targeted processes, to keep record for any access to these systems, to manage the interaction between them, one or more Process Management Server and a monitoring and operation center are allocated for such a purpose.

4.2.2 Design Structure of the developed Teleoperated System

The hardware structure that constitute the designed teleopration system within the scope of this paper includes, Web Client, Process Server, Process Agent, I/O Interface, and the process itself that needs to be monitored and controlled. The Internet is used as a medium to enable any of Web Clients to access a requested teleoperation system site according to an authorized procedure.

Fig. 2 shows the design layout of the developed reference structure of a teleoperated system. It illustrates the main components of the system, the relation between them and the flow of information in terms of requests and responses (commands and feedback).

The control interface has been decided to be served through a Web browser. A targeted process has been connected to a Process Server that services each incoming network request to it. Accordingly, information about the remote environment/process is sent to the Web Clients (users) and commands from the users are sent to any of the selected processes via the Process Server and through it to the Process Agent connected to the target process.

Web Clients (users)

It is user computer that must have the ability of connecting to the Internet. It is a modest personal computer (laptop or desktop) with Network Interface Card (NIC), Internet access and a generic Web browser. With such a configuration, the browser will enable authorized users to link to the Process Server.

Process Server

The term 'Process Server' is used to refer to the computer (Unix Sun Workstation) where the Web Server is. It is connected to the Internet where an Internet address is assigned. This will enable it to accept incoming HyperText Transfer Protocol (HTTP) requests that are to be serviced by the Web Server or to accept incoming network connections. The Web Server responds to Universal Resource Locator (URL) requests for any file on the raider/directory by sending back to the Web client the requested files that are used to construct the Web pages that serve the control interface through a Web browser. When a user request is initiated, the related Web pages will be downloaded and the client applets will be executed on the user's computer. This will serve the control interface and enable the user to interact and perform monitoring and control operations via the Internet. Then, the downloaded client applet connects back to the Web Server through a selected port. When a Web Client sends a request for connection to log-in, the Control Server who is always listening might accept or reject the request according to the existing connections, authorizations, and the available system resources. The Process Server caches through the Process Agent the most recent status images and sensory information concerning a target process. It sends such information whenever a Web client request comes in.

Process Agent

This term is used to refer to the computer that needs to be available at the process site. It acts as a special type of client, which connects the Process Server with the controlled process. The connection to the Process Server can be done through a modem or through Local Area Network (LAN). It communicates with the process through the process controller. A Process Agent needs to have a proper type of interfacing capability with the process in order to handle the transfer of data and commands in both directions.

A Process Agent maintains a periodic connection with the Process Server by sending the most recent status images and sensory information concerning the target process. It also receives and answers on demand instructions coming from the Web client via Process Server.

A process can be a production line in a plant, home appliances and utilities, laboratory equipment, clinical equipment, etc. A suitable hardware interface (control interface) is a must in order to enable the process and the Process Server to interact with each other.

4.3 The Developed Software

Three types of software modules and three protocols have been developed. These modules are: User Client, Control

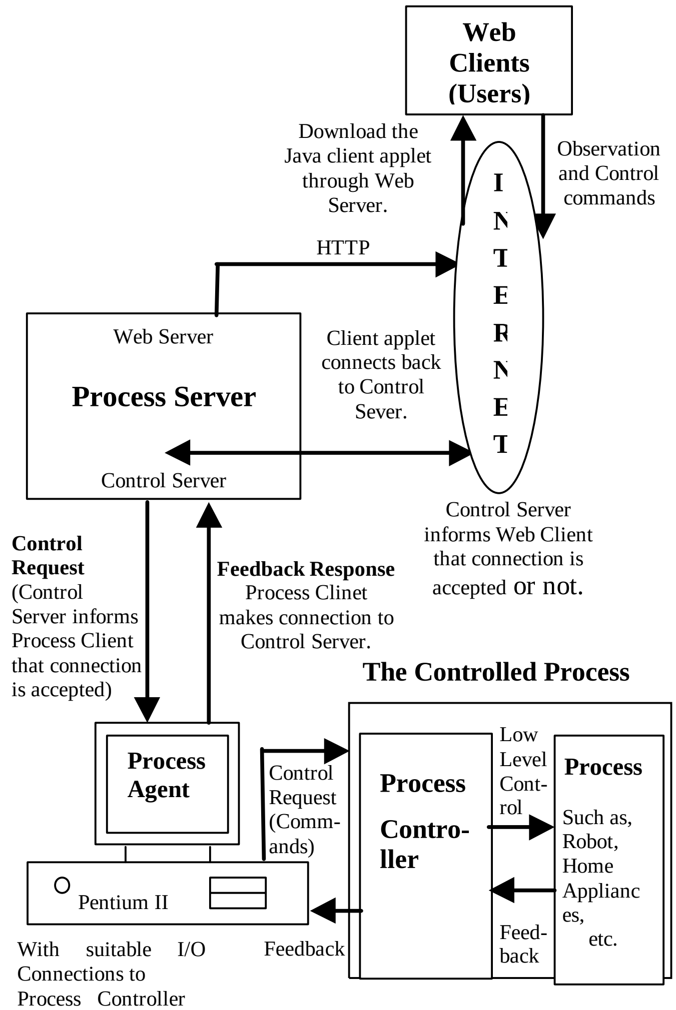

Fig. 2 System Layout for the developed Internet-Based Monitoring and Control System.

Server, and Process Client.

The **User Client** is designed in Java applet and is embedded in Web pages for the Web users to download from the Web

Server. It enables the users to monitor and control a device/process. Users can be anyone who has Internet access.

A protocol to manage the follow for requests and responses between the Control Server and the User Client has been developed and implemented.

The **Control Server** runs from the Web Server and is always ready to accept connections from clients. It should be the first one to be activated and be continuously ready to accept connection requests from Web clients through a Web browser. Using the Java ServerSocket, the control Server always listen for connection request. When a client socket attempts to connect. It throws a thread to negotiate the connection. Once the Control Server has setup the connection, the server uses a regular socket to communicate with the client. Then, a client identifies himself and asks for permission to control. The user who is granted permission to control is called the Controller. There is only one controller allowed. When a Controller has been assigned, other users that are accessing the system at the same time will be given the status of Observer to enable them monitor the process without controlling it.

The **Process Client** designed as standalone application that transfer commands from the Control Server to the process through a suitable I/O interface. It should started after the Control Server and before any log-in from any clients. The way the Process Client is connected to the Control Server is similar to that of User Client. The user does not control this program. It is receiving commands from the Control Server and sending responses to it. The Process Client sends instructions to the process through the available I/O and receives back responses. A protocol has been developed to manage this operation. This protocol does not involve networking, and the communication is done using a proper I/O interface.

5. APPLICATIONS DEVELOPMENT

The best way to prove the usefulness, adaptability and robustness of a system is by implementing and testing it. For this two applications have been selected to demonstrate our developed concept.

5.1 Remote Monitoring and Control of House Appliances and Utilities

Remote control and monitoring system that allows users to change the settings of house appliances and other utilities available at a house. A Web user can remotely access, monitor and control the integrated components to the system using browser based user interface. The design of the teleopearated system is based on the described design at section 4.2. The system has been demonstrated successfully.

5.2 Remote Monitoring and Control and of a Robot Manipulator

Controlling and monitoring a robot manipulator via the Internet represents an interesting challenge for demonstrating a real application. The implemented system is designed to control and monitor the activity of a robot manipulator named MoveMaster-II. The developed system enables a user to control and program the robot in a real time situation through Internet. Three types of control levels has been implemented. The system has been demonstrated successfully.

6. CONCLUSIONS AND FUTURE DIRECTIONS

6.1 Conclusions

In this paper issues that are important to the development of teleoperation systems and affecting their performance have been discussed. Solutions and comments were presented.

A design of a teleoperated system and a new concept to manage and administrate distributed teleoperation systems has been developed. The architecture of the developed concept may include one or more teleoperation system without having any constraints on their geographical location.

Two individual applications were selected, implemented and demonstrated successfully. The developed system was entirely written in Java language and is accessible via a Web browser.

Among the most critical issues that affect the use of teleoperation systems in complex real time applications were identified as; user interface, time delay and controllability. The controller in the operator interface has to be designed such that the operator can effectively control the remote system.

6.2 Future directions

1. Enable teleoperated intelligent robot/machine/process to interact with other teleoperated system by exchanging information, data, and commands related to specific events. This means to have a teleoperated system that can as an autonomous teleoperated Web client in addition to its normal function.
2. Develop technique that allows for smooth and reliable real time visualization of the events related to the target process even when large transmission delays occur. A predictive display approach can be considered for this purpose.
3. Integrating different technologies of communication standards to meet the needs of users creating distributed application and computing solutions.
4. Adopt Web-based open source library approach to support the development of distributed applications in the filed of teleoperation.
5. Facilitate sharing information worldwide or across distributed teleoperation systems or among distributed users accessing the same teleoperation system. Additional feature can be to enable read, write and share data between applications and/or different data sources and targets.
6. Develop user interface that facilitates the access of distributed scientific and manufacturing equipment and facilities.

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