Development of an Internet-based Robot Education System

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Abstract: Until now, many networked robots have been connected to the Internet for the various applications. With these networked robots, very long distance teleoperation can be possible through the Internet. However, the promising area of the Internet-based teleoperation may be distance learning because of several reasons such as the unpredictable characteristics of the Internet.

In robotics class, students learn many theories about robots, but it is hard to perform the actual experiments for all students due to the rack of the real robots and safety problems. Some classes may introduce the virtual robot simulator for students to program the virtual robot and upload their program to operate the real robot through the off-line programming method. However, the students may also visit the laboratory when they want to use the real robot for testing their program.

In this paper, we developed an Internet-based robot education system. The developed system was composed of two parts, the robotics class materials and the web-based Java3d robot simulator. That is, this system can provide two services for distance learning to the students through the Internet. The robotics class materials can be provided to the student as the multimedia contents on the web page. As well, the web-based robot simulator as the real experiment tool can help the students get good understanding about certain subject. So, the students can learn the required robotics theories and perform the real experiments from their web browser when they want to study themselves at any time.

Keywords: Internet-based robot education system, teleoperation, multimedia contents, Java3D, robot simulator

1. INTRODUCTION

Nowadays, with the growth of the Internet and advances in its related technologies, it has been highly demanded to employ the Internet as the way to access useful resources distributed over the public communication network for various applications in diverse fields. The robots may also be used as the useful resources on the network. So, the very long distance teleoperation in robotic application has been possible by using networked robots through the Internet, so-called the Internet-based teleoperation. Actually, many networked robots have been connected to the Internet for the various applications. However, the promising area of the Internet-based teleoperation may be distance learning because of several reasons such as the unpredictable characteristics of the Internet.

Distance learning means that lecture and learning are performed through the various communication methods between the lecturer and the students in difference places. Thus, lecture and learning does not restricted in time and space. However, most of distance learning system provides only the lecture materials as the multimedia form through the several methods such as NRT (Non-Realtime Teleteaching), BBS (Bulletin Board System), and VOD (Video On Demand) [1]. Thus, the students may study the required theories passively through the given materials without any realtime interaction. So, any tools for experiments for the distance learning system can help the student make good understanding of the lecture material.

In the case of Robotics lecture, the virtual simulator can provide these kinds of ways to the students for distance learning. As well, if the virtual simulator can be used as the operator interface to operate the remote real robot, then the student can get some kinds of telepresence as if he operates the real robot in place.

In this paper, we developed an Internet-based robot education system. In robotics class, students learn many theories about robots, but it is hard to perform the actual experiments for all students due to the rack of the real robots and safety problems. Some classes may introduce the virtual robot simulator for students to program the virtual robot and upload their program to operate the real robot through the off-line programming method. However, the students may also visit the laboratory when they want to use the real robot for testing their program.

Therefore, we intent to use the developed system for providing robotics class materials by using the multimedia contents and the web-based virtual robot simulator as the actual experiment tool through the Internet.

For the robotics class materials, the multimedia techniques have been used to publish the materials on the web. To make this, the dedicated multimedia authoring tool, Macromedia Authorware was used and the lecture materials can be provided as the form of web-based multimedia contents to utilize the benefits of current web-based multimedia techniques such as HTML for organizing different types of contents and the streaming service for publishing the multimedia contents effectively. With this, the students can learn the required robotics theories from their web browser when they want to study themselves at any time.

On the other hand, most of implementation effort was made to develop the web-based Java3d robot simulator in this system. The 3D graphical interface of the virtual simulator can give the some kinds of benefits in distance learning system for Robotics lecture and the general teleoperation systems with the remote robots.

A graphic simulator can be used to support easy interface for programming robots and can also be used to check a manufacturing system in advance. Strommer et al. [2] used the VR techniques to perform robot programming. In this system, programming is done with a virtual robot in the virtual environment, through the programmer interaction being mediated by VR I/O devices such as data glove, tracker, HMD, etc. Thus, the programmer feels immersed in the virtual work environment where he can navigate and look at the scene from any direction, and see objects closely. Specifying a trajectory is as simple as a hand gesture. The resulted code is automatically stored using a special-purpose toolkit called "VR4" [3].

In [4], a virtual simulator was developed to test the software in a manufacturing system. Since the virtual simulator can simulate various devices such as robots, the vision system, actuators, and sensors in its virtual mode, it can find any dangerous errors in the software that may occur.

For the teleoperation, VR may serve as a predictor of motion commands, before they are actually sent to the remote robot. Blackmon et al. [5] developed a model based supervisory control approach using a "task sequence script" list of desired robot sub-goals. The experimental system consisted of a GUI on the operator's workstation displaying a graphical model of the remote environment. The operator could control a graphical model of the remote robot using a pair of two-DOF joysticks, in order to preview trajectories and detect potential collision spots. If the planned trajectory was not correct, the operator could edit it interactively by modifying the task sequence script.

In [6] and [7], the robot and the environment are modeled at the operator site and the operation information is continuously fed back from a simulator which indicates the interference force generated during the task: The so-called model-based bilateral teleoperation method has been developed to operate a remote manipulator with time delay, like as a space teleoperation system. The amount of information is reduced because only commands are transmitted to the robot, and the information about the remote robot and working environment are unnecessary.

In this paper, because our application is for the Internet-based teleoperation, the operator interface and the virtual simulator must be embedded as the web modules into the web browser. Thus, we made the virtual robot simulator by using Java and Java3D API to be executed in the web page.

By doing this, the developed system offers the several functionalities so that the student can learn the operating characteristics of the remote robot through the simulator.

2. INTERNET-BASED TELEOPERATION

In this paper, the developed system was designed for distance learning of Robotics including the real experiment tool with the remote robot. As the real experiment tool, the web-based Java3D robot simulator is for controlling the remote robot through the Internet. So, the student may perform the Internet-based teleoperation with the developed simulator as their experiments. Therefore, several considerations about the Internet-based teleoperation must be made to construct the desired system for this purpose.

A telerobotic operation involves some kinds of interactions between a human operator and a remote robotic system via communication channels. So, the performance of the communication channel is crucial factor in the teleoperation system.

To be successful in the Internet-based teleoperation, several effective schemes to deal with the restricted bandwidth and arbitrary transmission delay of the Internet should be established. One of possible solutions may be in the high degree of autonomy and local intelligence at the remote robotic system. However, the intelligence needed for fully autonomous operation of the remote robots may not possible in the near future due to the high costs, technical limitations and high levels of operational uncertainty. And also, the autonomy levels of the remote robotic systems may vary depending on the working environment, size, and tasks.

Due to these limitations on the Internet-based teleoperation, the set of requirements to achieve the high reliability and performance cannot be addressed easily. Therefore, the objective of this research is to identify, implement, and evaluate techniques for controlling the robotic devices on the Internet.

Therefore, the related techniques for controlling the robotic devices on the Internet should be identified, implemented, and evaluated to find the reasonable set of requirements for Internet-based teleoperation.

In teleoperation system, which uses robots, the generic automated robot system is demanded to be controlled by the operator remotely. This system can consist of complex subsystems at both the remote site and the operator site. The outline view of these subsystems can be showed as several components of needed underlying techniques for two sites: sensing, control and AI (Artificial Intelligence) for robot work site, and data exchange, visualization, HMI (Human Machine Interface), and operation schemes for the operator site. As well, the networking technologies are very important for connecting two sites which reside in distinct regions, and for exchanging the required information and managing the coupled subsystems closely in both sites.

With these underlying techniques of teleoperation, there were remarkable experiments that utilized the open public network, the Internet as the communication medium during 1994-1995, they are Goldberg's Mercury project [8] and Taylor's Australia's Telerobot project [9]. Unlike the conventional teleoperation system which uses the dedicated communication line to allow the access in the restricted region or between the fixed nodes, above two experiments have many meanings in that they made the open accessibility to the public, and give the possibility to overcome the short operation distance. Afterward, these robots that can be controlled through the Internet were called as the 'Internet robot' or ' Internet-based robot', and the terms, 'Web robot', 'Web-based robot' were used for the case of using the Web browser as the operator interface.

However, the Internet as the communication medium in the teleoperation system has the inevitable problems that of the network transmission delay, which cannot be predictable because the Internet is the open public network environment. For reliable control of the remote robot, the continuous and reliable data exchange should be guaranteed for operator's commands and the feedback information from the remote work site. In the conventional way that uses the dedicated communication lines, the reasonable control schemes can be established with the considerations of the characteristics of underlying network in designing the systems. However, the network behaviors of the Internet can be often changeable according to the traffic loads in time varying, so the reliable data exchange cannot be expected and the given time constraints of the system cannot be achievable without any consideration. Thus, appropriate schemes for data exchange should be established by specifying these problems and identifying the requirements for solving them in the Internet-based teleoperation system.

In teleoperation system using the Internet, the data exchange schemes for the operator's commands and the feedback information should be established. To get the appropriate requirements for these schemes, the overall system configuration, the communication medium, and the operator modalities should be considered significantly. However, for the aspect of the communication medium, the established schemes can be devised only for diminishing or compensating the network delay rather than improving any properties of the underlying network technologies because the Internet-based teleoperation employs the open web standard techniques as is.

The overall structures and the required subsystems for teleoperation can have various configurations according to the given purpose and the target system. However, the Internet introduces the inevitable problems that make it difficult to achieve the high interaction between the operator site and the robot work site. The continuous excessive data cannot be transmitted to make the closely coupled teleoperation over the Internet. For the operator's commands, discrete robot commands are better suitable rather than the continuous commands. Thus, the remote robot system should have required autonomy to perform the given operation without the operator's intervention. For this reason, the remote robot system should have the abilities for sensing, generating the required information and recovering the errors while it is working. In the conventional teleoperation system, these requirements are also important for reliable control of the robot. But, in the case of using the Internet, these come more strict requirements.

On the other hand, the system for the operator site usually employs only a generic PC system that uses the mouse to make the commands, and the feedback information is represented in the operator interface. Especially, the operator interface consists of several portable software modules like as Java applet or COM in the case of using the web browser. So, no additional software or hardware is required, and the operator can control the remote robot almost immediately without any setup or installation.

The data exchange schemes cannot be considered without relation to the operator's control modalities. The main interests of this scheme are how to control the remote robot and how to display the feedback information. The high autonomy of the remote robot makes the operator's commands simple. This is why the early Internet-based robot system introduced the web-based operator interface and the industrial robot manipulator that can be controlled by the dedicated robot controller. However, the sufficient information about the work environment should be provided to the operator although the operations can be made in that simple way. Generally, the feedback information can be generated from the various sensors installed in the remote robot system. And this feedback information is displayed in the form of result images or the graphical scenes in the operator interface. In transmitting the multimedia data such as the real images over the Internet, the result images cannot be reached to the operator site at the right time. So, the good synchronization of executing the operations and receiving the correct feedback information is hard to achieved. For this reason, such schemes that can compensate the delayed feedback information for the operator are necessary.

Therefore, several reasonable considerations for the above mentioned problems should be made in the aspects of the overall system configurations, data exchange schemes, operation methodologies, and the operator interfaces for the Internet-based teleoperation.

3. SYSTEM OVERVIEW

The developed Internet-based robot education system was composed as shown in Figure 1. The overall contents consist of Robotics lecture materials, complement materials, and the experiment tool, the developed simulator. All these contents are two types: multimedia contents for lecture materials and complement materials, the web-based Java3D robot simulator for experiment tool. The multimedia contents were authorized by using the dedicated authoring tool, Macromedia Authorware, and the web-based Java3D robot simulator was developed by using the Java and Java3D APIs. Each contents are made as the plain HTML web page. So, the student can use these contents simply with his web browser.

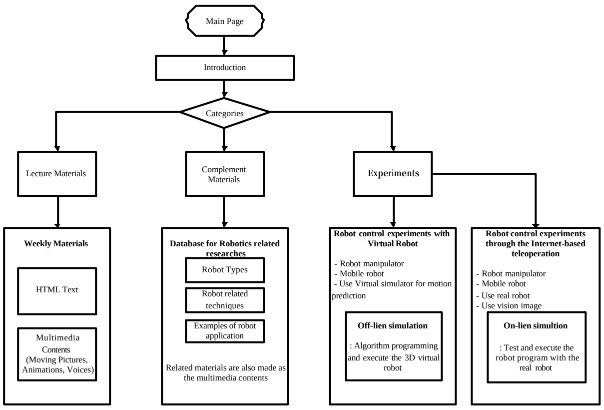

Fig. 1Diagram for overall contents

The web-based Java3D robot simulator was developed as the web-based operator interface. So, the required functions for the simulator were implemented as a web module that can be embedded into the web browser. The developed simulator was designed to be connectable to the web server system that may accept the multiple accesses from several users. And the overall system has the general client/server communication architecture.

When a client is connecting to the web server, a small program that can be executed in client's web browser is transmitted. This small program is implemented as a form of Java Applet that contains several functions and specification of the programs. The downloaded virtual simulator as the form of Java Applet has the functionalities of complete operator interface which has the simulation features within the web browser so that the operator can use it to predict the robot motions through the simulation and to control the real robot. To control the remote robot, the operator's commands should be transmitted the web server. Then, the web server is communicating with the robot control server to pass the operator's commands.

Then, the robot is controlled by the robot control server through the local control loop. Figure 2 shows the system configuration to perform Internet-based teleoperation by using the developed web-based Java3D robot simulator.

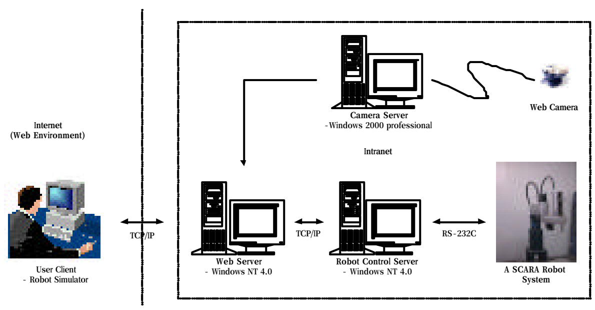

Fig. 2 System configuration.

As shown in the figure 2, the operator needs only his computer system and the input device is a generic mouse and keyboard. Before commanding the remote robot, the operator can use the virtual robot simulator to predict the real robot motion and plan the successive operations to perform a certain task.

In the remote system, there are several subsystems such as web server, robot control server, robot servo system, and the robot manipulator. The feedback images are captured by vision camera connected in the web server, and the captured images are provided to the client through the web server continuously. Then, these feedback images can be displayed in the operator's web browser.

In this system, the target robot was the SAMSUNG SCARA robot, FARA SM3. The counterpart models of the simulator and the work environment were built in Java applet program by using the Java3D APIs.

4. INTERNET-BASED ROBOT EDUCATION SYSTEM

4. 1 Robotics lecture material

For the robotics lecture materials, the multimedia techniques have been used to publish the materials on the web. So, the students can learn the required robotics theories from their web browser when they want to study themselves at any time. Previously, the materials for the distance learning were made by using the static contents including text, some illustrations, and human voice, etc. Unlike these, we used the dynamic contents like as moving pictures, and computer-generated synthetic human voice by using TTS (Text-To-Speech). The moving pictures may be useful to demonstrate the real robot motions in 3D-coordinates space. For examples, the demonstration for the robot moving which varies according to the motion types and robot types was made by synchronizing the robot moving in the moving pictures and the voice demonstration. Figure 3 shows the introduction part of the Robotics lecture material for 1st week.

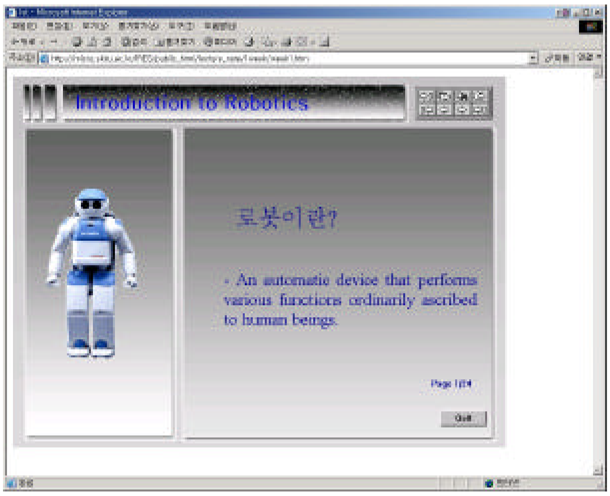

Fig. 3 Robotics lecture material on the web page.

Each weekly lecture material was made as the separate HTML page and the overall lecture materials composed of 16 weekly lecture materials. With these materials, the student can learns about the main subjects from the basic vector-matrix theories to the robot kinematics and dynamics theories of Robotics textbook [10].

4. 2 Web-based Java3D Robot Simulator

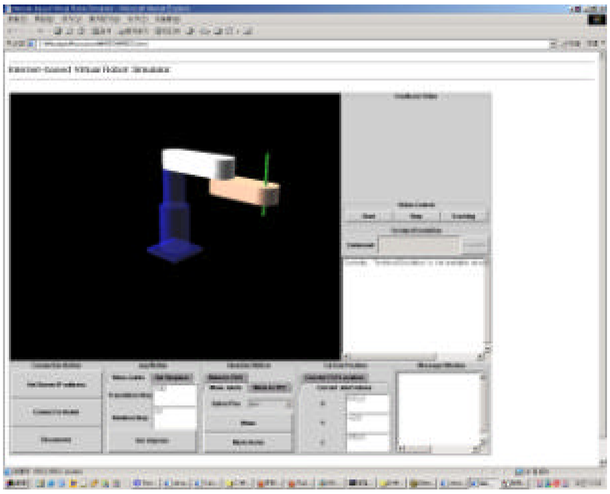

Fig. 4 Web-based Java3D Robot Simulator.

Figure 4 shows the appearance of the developed web-based robot simulator.

As the web-based operator interface, the developed simulator was designed with considerations in the aspects of easy-of-use and the versatile functionalities. The developed operator interface gives 3 dimensional visual information to the operator unlike the previous 2 dimensional operator interfaces. Some Web-based operator interfaces employed the VRML(Virtual Reality Modeling Language) or Java3D to build 3 dimensional graphic application that can be executed within web browser [11-13].

These systems have some benefits from the aspect of platform independence, but VRML needs specific VRML browser to visualize and the Java3D shows relatively lower rendering speed. And VRML should be used with other languages, C++ or JAVA through the external authoring interfaces such as EAI (External Authoring Interface), JNI (Java Native Interface) [14].

Although VRML and Java3D have been used widely, OpenGL and Microsoft's COM (Component Object Model) may be selected for reusing the developed software components.

To navigate the virtual work environment, the operator can use the simple interface with the mouse. For acquiring the feedback images, the web camera was used to check the operation results in the operator interface. By using the web camera, the operator can check the operation results and verify the robot motion while the robot is moving. In this system, one USB camera and the JMF toolkit was used to capture and transmit the feedback images to the client systems.

In figure 4, the received robot image was displayed in the operator's web browser.

Because the developed simulator and the received robot image can be displayed in one web browser, the operator can check whether simulated operation is performed properly through the simulation preview and the displayed real images simultaneously.

With 3D viewing functions such as 'Rotate', 'Translate', and 'Zoom', the operator can investigate the virtual work environment more closely. Practically, the real images are captured from the fixed camera and the viewpoint cannot be changed. But the viewpoints of virtual camera can be easily changed by the user inputs through these world control buttons.

The buttons on the botton of the operator interface are for the simulation related functions such as set locations, execute commands, and simulation. Then, the operator can get the several information such as the robot type, joint information, and working area. Based on this information, the operator can issue the suitable commands to the remote robot without mistakes.

Also, there is text information panel for displaying helpful information. The operator can get several interactive messages for his action with simulator and the real robot. For example, the current joint values and the location of real robot can be displayed at the end of each operation.

Additionally, the command line input panel is to provide the same functions of the real robot. The operator can use the real robot languages to control the virtual robot by single command or programmed tasks. The command line input makes the operator exercise with the real robot commands. In the real robot programming, the stored location data or specified location from the user inputs can be used for certain tasks.

For example, simple command such as 'move to t1' can be used to make the robot move where 't1' is the stored location in the robot controller program. By using these features of simulator, the operator can control the virtual robot as doing with the real robot.

5. EXPERIMENTS

Prior to make the on-line operations, several off-line simulations were performed for verifying the required functions of the developed simulator. Through the off-line simulation, the operator can get the required information such as the characteristics of robot operations and perform previewing of the planned operations prior to make the real robot move by using the simulation features. Figure 5 shows the off-line simulation results in the web browser.

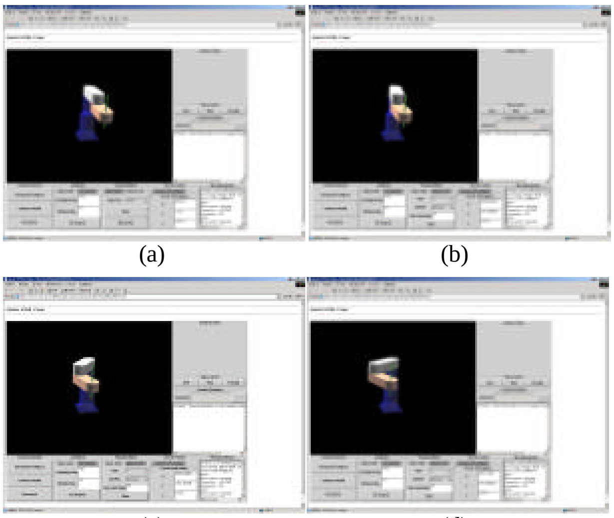
(a) (b) (c) (d)

Fig. 5 Offline simulation.

As simple task for verifying the simulation features, the pick-and-place operation was performed by using the developed web-based robot simulator. For this, the PTP (Point-To-Point) motion commands was used with the two fingered gripper at the end-effector of the virtual robot. The simulation sequences follows to the a-b-c-d-c-b-a path, and each movement to the via-point is a PTP motion.

After operations were verified through the off-line simulation, the simulated results as the operator's commands can be transmitted to the real robot to perform the real operations. Before transmitting the operator's commands to the robot server, the status of the real robot should be checked through the communication sequences shown in figure 4.10.

If the robot is available, then the operator can send the operator's commands by performing the simulation. While simulation progresses in the operator's web browser, the intermediate simulation results as the operator's commands are sent to the remote robot. So, the real operations and the virtual operations are performed simultaneously. The actual operation of the remote robot can be showed by the feedback images from the web camera. Several real robot images for the on-line simulation are showed in figure 6.

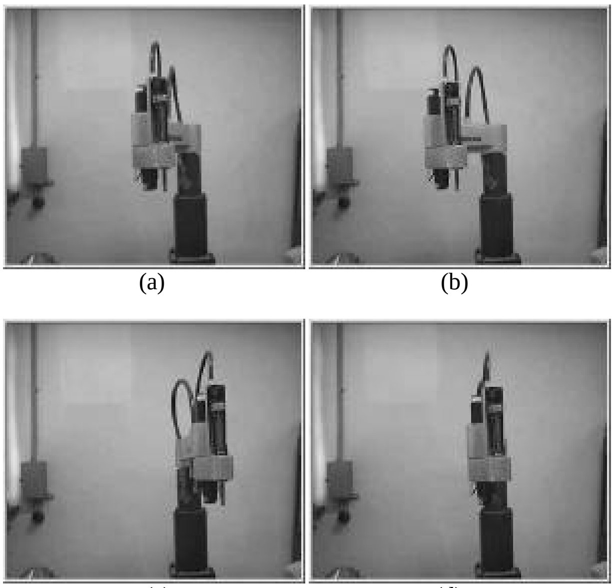
(a) (b) (c) (d)

Fig. 6 Online simulation verification by camera information window.

6. CONCLUSION

In this paper, we developed the Internet-based robot education system for providing robotics class materials by using the multimedia contents and the web-based virtual robot simulator as the actual experiment tool.

For the robotics class materials, the multimedia techniques have been used to publish the materials on the web. So, the students can learn the required robotics theories from their web browser when they want to study themselves at any time.

For providing the actual experiment, we used the web-based virtual robot simulator that can be used to operate the remote actual robot through the Internet. The developed simulator can be embedded into the web page, because it was made as the Java applet and the 3D virtual scene was made by using the Java3D API.

Unlike the existing standalone robot simulators, the developed robot simulator can be executed in the operator's web browser because it is implemented as the web-enabled program. And also, the previous web-based robot system employed the simple operator interface based on the 2D graphics and static feedback information. This resulted in the lack of required information for the operator's decision making and restricted the possible operations over the Internet into simple operations, so the 3D graphic robot simulation features were implemented for web-based operator interface.

With the web-enabled program, the operator can control the remote robot in any place where the Internet is available.

Due to the characteristics of the Internet as the public communication network, the web-based robot system could not expect close connection between the remote worksite and the operator site. Therefore, the operator could not perceive the remote work environment with only static robot images as feedback information. To compensate the lack of required information, the 3D graphic simulation features of the developed operator interface for the web-based operator interface were very helpful to the operator.

For the feedback information, the real robot image was provided to the operator to check the operation result in his web browser. In this system, feedback images were captured by the web camera and the captured images are transmitted to the clients through the Internet. In the operator's web browser, these feedback images could be displayed.

With the developed Internet-based robot education system, the students can use the multimedia contents for self-studying on their web browser at any time they want, and the multimedia contents which contain the dynamic media can make the good understanding of required robotics theories. And also, the web-based virtual robot simulator can be useful to exercise their robot programming by operating the 3D virtual robot and its intuitive 3D interface can be helpful to understand the real robot motion.

ACKNOWLEDGEMENT

This work was supported by Korean Research Foundation Grant. (KRF-2002-048-D00020)

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