Virtual Reality Tools for Internet-Based Robotic Teleoperation

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Abstract

This paper describes the general system and software architecture for the Internet-based robotic teleoperation system using virtual reality tools. The existing technology and application are discussed in this paper. An example is also presented based on the general architecture. Finally, the conclusion and future research direction are given.

1. Introduction

Robots play a more and more important role in our daily lives today. They are now being used in different fields including industry, research, education and entertainment. Different robots have different degrees of intelligence and can be used for different purposes. Some robots can only perform simple and repetitive work such as pick and place. To do this work, robots are set to a particular position and angle at the beginning. For every fixed time interval, they pick the object of the same size and same shape, change the position and angle, and place it to another specified place. This kind of robots has very limited intelligence since it only repeats the same task and doesn't have many interactions with operators. They are often used in industrial assembly lines. With the rapid development of research work, more and more advanced robots with high intelligence have been developed. They can perform some work which is hard for human beings to access or handle the situations where high intelligence is required. With the use of different sensors installed on them, robots can get many feedbacks from the field where they are working. For example, the feedback from the force sensors of the robot can tell the operator how much pressure the robot is currently loaded, and the control system can automatically stop the robot implementing more movements if the pressure is above the limit so that the robot cannot be damaged. The infrared sensors can detect the objects around the robot and direct it to avoid or follow them. The temperature sensors can tell the surrounding temperature of the robot to guarantee the appropriate working temperature.

Since robots have more and more applications, how to control them is becoming an essential research topic in the robot development. Today, the Internet has become an inseparable part of our daily life. Therefore, to combine the robot control with the Internet technology becomes an interesting and promising research direction. This is called the Internet-based robotic teleoperation. It provides a convenient channel to control robots remotely.

Many robotic teleoperation systems exist today. One active system providing free access through the Internet is NASA space telerobotics [1]. The system is designed to develop telerobotic capabilities for remote mobility and manipulation by merging robotics and teleoperations and creating new telerobotics technologies. This Space Telerobotics Program consists of a wide range of tasks from basic scientific research to applications developed to solve specific problems. Except the professional use of telerobotics, some educational and recreational-oriented experiments have also been conducted. For example, a web-based telerobotic system has been developed for research and teaching in Essex university, U.K. [2]. Using a Web browser, a remote operator can control and program a mobile robot to navigate in a laboratory by receiving visual feedback and a simulated local perceptual map via the Internet. MINERVA is a museum tour-guide robot, which is successfully exhibited in Smithsonian museum [3]. The approach of this system specifically addresses issues such as safe navigation in unmodified and dynamic environments, and short-term human-robot interaction. PumaPaint Project is a remote painting system which is built for the user to control surplus Puma 560 to paint on the wall [4, 5]. In Mercury Project, a system was developed which consists of a robot arm fitted with a CCD camera and a pneumatic system [6]. Located over a dry-earth surface, the robot allows users to direct short bursts of compressed air onto the surface using the pneumatic system. Therefore, operators can "excavate" regions within the environment by positioning the arm, delivering a burst of air, and viewing the image of the newly cleared region [6]. Another example is the teleoperated industrial robot in Australia which allows users to implement tasks such as demolishing and stacking wooden blocks [7].

In most existing teleoperation systems, 3D virtual environments are used to get better control of robots. Different systems employ different techniques to implement Internet-based robotic teleoperation system using 3D virtual reality tools. In this paper, we will specify the general system and software architecture of the typical Internet-based robotic teleoperation system. An example will be presented following the general architecture design. The future research directions of robotic teleopertion systems will be given at the end.

2. System and software architecture

2.1 System description and architecture

The Internet is an essential part in robotic teleoperation system. However, the slow rate and instability of the Internet connection restrict the real-time control and feedback of teleoperation tasks. For example, the operator cannot observe the real-time change of the robot and the existing environment through the transmission of video images due to the network delays. To efficiently implement the teleoperation of robots, most systems apply 3D virtual environment to simulate the environment. The main advantage is the achievement of fast response to the operator's actions because smaller data package is required to update the virtual robot and it's environment. It provides the operator with a "live" virtual representation of the scene instead of the delayed video images [8]. It can also increase the efficiency of the operator performance because the operator can choose appropriate points of view, zoom the scenes and make some objects transparent or semitransparent, etc. The augmented reality can also be used in the system to get a better visualization and help the operator get more immersion of the virtual environment.

In the architecture design, a teleoperation system generally includes three major parts: client, server and robot [9]. The general teleoperation system architecture is shown in Figure 1.

The client part is the interface for the operation. It includes computers. Some client parts also include the augmented reality devices, such as a dataglove or a stereo head-mounted display. The software in the client part includes the User Interface, 3D virtual robot, virtual environments model, and operation model. Some systems also include video images and other feedbacks transferred from the server.

The server part contains a server computer which is connected to the real robot controller. Some systems also include an on-site camera with an image acquisition board, and different sensors for different purposes. The server software includes different models of data processing such as sensor data acquisition and processing, image acquisition and processing. It also has the connection and control model of the robot.

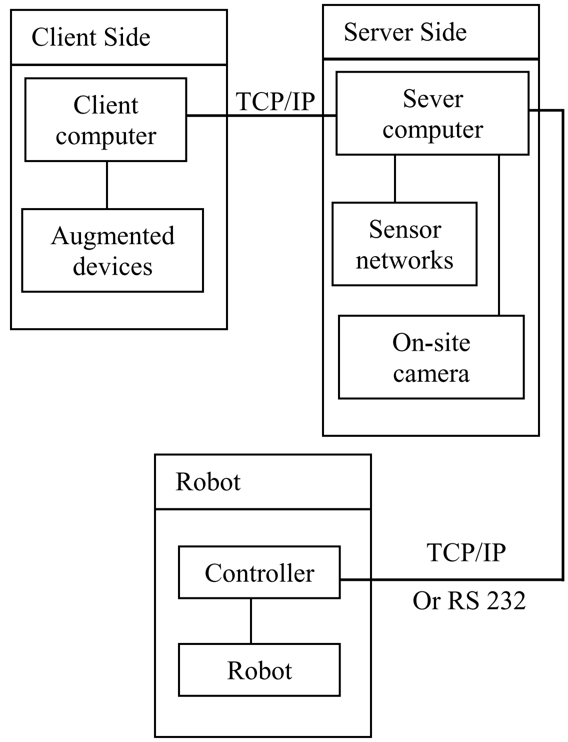

Figure1. System architecture

The robot part includes the robot itself and the robot controller. Different systems choose different robots, such as PUMA 560, CRS A465, etc.

2.2 Software architecture

The general software architecture of the robotic teleoperation system is shown in Figure 2.

The operator needs to interact with the remote robot through the user interface. Because the robotic teleoperation systems are Internet-based ones, the user interface is an applet in a web browser or a stand-alone Internet application [10]. The interface can either be created by use of HTML and CGI, or JAVA. There are several models for the user interface: virtual robot and virtual environment model, video images model, sensor feedbacks model, augmented reality device feedback model and teleoperation model.

The virtual robot and virtual environment model simulate the real robot and real environment. The operator can control the real robot by operating the virtual robot in the user interface. The other models can also be combined together to provide feedbacks of different formats including image or video. The image and video data can also be referred to update the virtual robot and environment in the process of control. The sensor feedback model can also provide other information

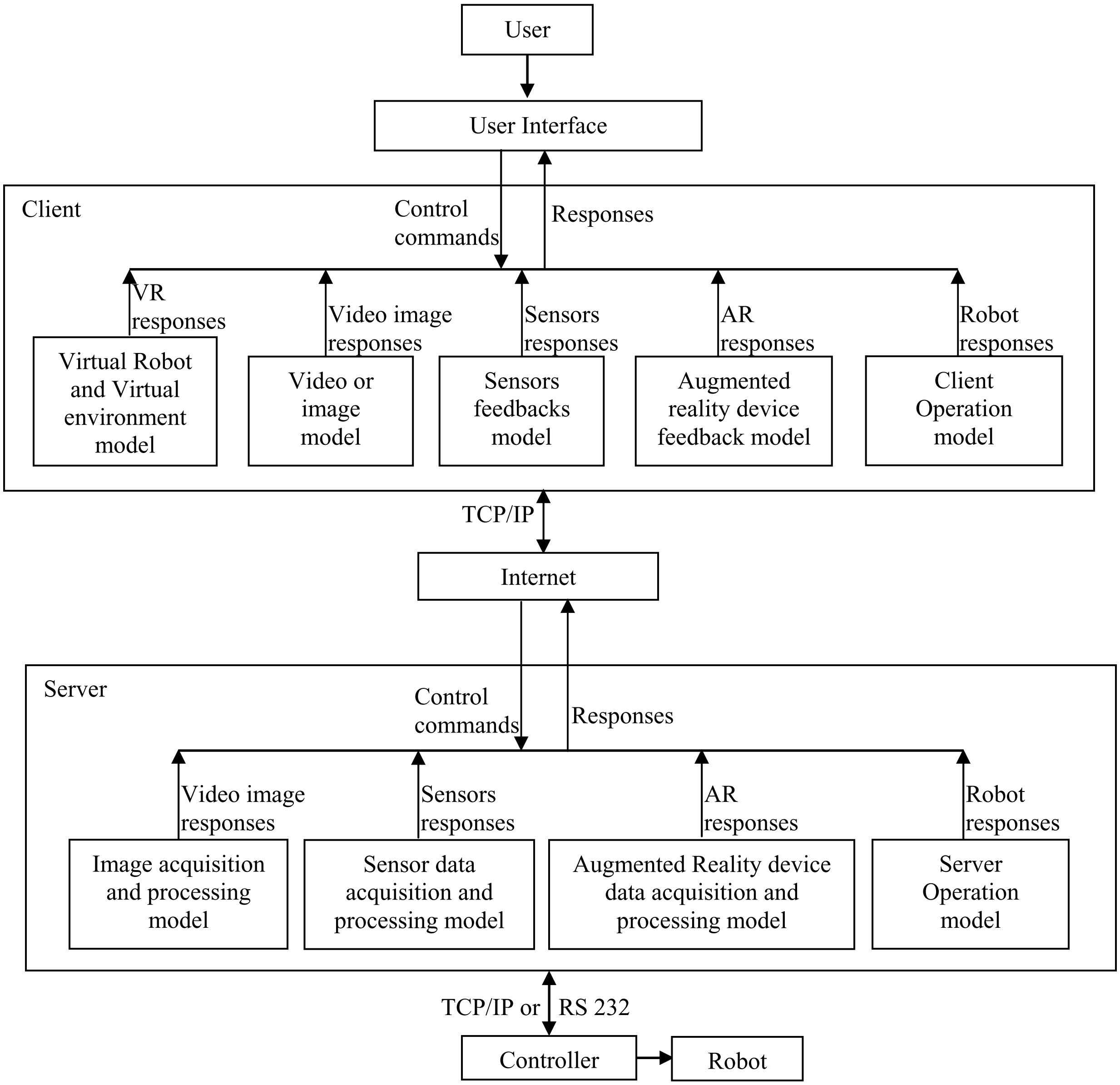

Figure 2. Software architecture

including pressure, tactility, temperature, taste etc. The feedbacks from augmented reality devices can help the user get more immersion of controlling the virtual environment.

All of commands and requirements from the client side can be sent to the server side through the Internet.

On the server side, the server computer can send commands to the controller of the real robot to do different data acquisition and processing for sensors, cameras or augmented reality devices. After the process, the server will send processed data back to the client through the Internet.

The robot controller controls the real robot to do whatever the client requires.

3. Example

The following example is a project on space robotics [11]. Its practical goal is to develop a system for the control of robot manipulator PUMA 560 via the Internet. The methods used in this system are to overcome the main problem of the Internet unpredictable time delays. The same approach is also used for CRS A465, and mobile robot Nomadic XR4000 "Diligent".

In this system, a 3D virtual environment of the robot's working environment is produced on the client side. The robot, and the objects with which the robot interacts, are placed into it. Through the user interface, the operator sends control commands to the robot. On the server side, the server computer can control the robot to implement operations from the client side. Then the data packages containing the current coordinates of the robot and objects are transmitted to the visualization module at the operator's site. These data are then rendered in real time.

Figure 3 shows the 3D model of the robot, the user interface on the client side; the real robot and environment on the server side.

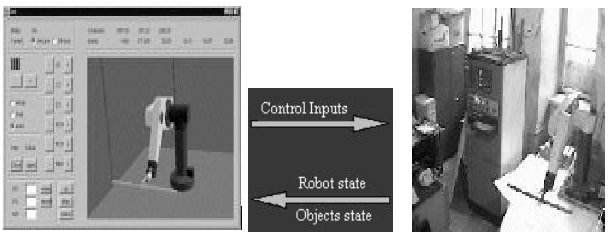

Figure 3. An example of teleoperation system

This method considerably reduces system traffic as compared to video image transmission. It allows the robots to be successfully controlled, even when communication rates are slow (0.1-0.5 KB/sec). All systems have been tested under real Internet conditions at different locations in Russia, England, France and Korea.

4. Conclusions and future work

In this paper, we address the general system and software architecture with virtual reality tools for the Internet-based robotic teloperation. An example based on this architecture is also given.

The robotic teleoperation system can be applied to remote manipulation and navigation in hazardous environments, remote manufacturing, entertainment, education and training.

In the future work, the following research directions should be carried out, such as accurate updating the virtual robot and environment in real-time; using more augmented reality devices to achieve more immersion for the operator in controlling the virtual 3D environment; adopting more different sensors to get more information from the surrounding environment of the robot and resolving the problem of sensor fusion; and finally providing the multi-user service environment.

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