

Real-time Remote Robotics— Toward Networked Telexistence

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Many people have longed to project themselves to a remote environment—one where they have the sensation of existing in a different place—while actually remaining where they are. Another dream involves amplifying human muscle power and sensing capabilities with machines while reserving human dexterity through a sensation of direct operation.

In the late 1960s, General Electric proposed a research and development program to develop a powered exoskeleton that a person would wear like a garment, called Hardiman. The concept was to wear the Hardiman exoskeleton and command a set of mechanical muscles that would multiply human strength by a factor of 25. In this union of human and machine, the subject would feel objects and forces almost as if in direct contact with them. However, the project failed for a couple of reasons. First was the potentially dangerous effects of wearing a powered exoskeleton should it malfunction. Second, space inside the machine was needed to store computers, controllers, actuators, and the energy source, which eliminated the space for a human operator. Thus, the design proved impractical in its orig-

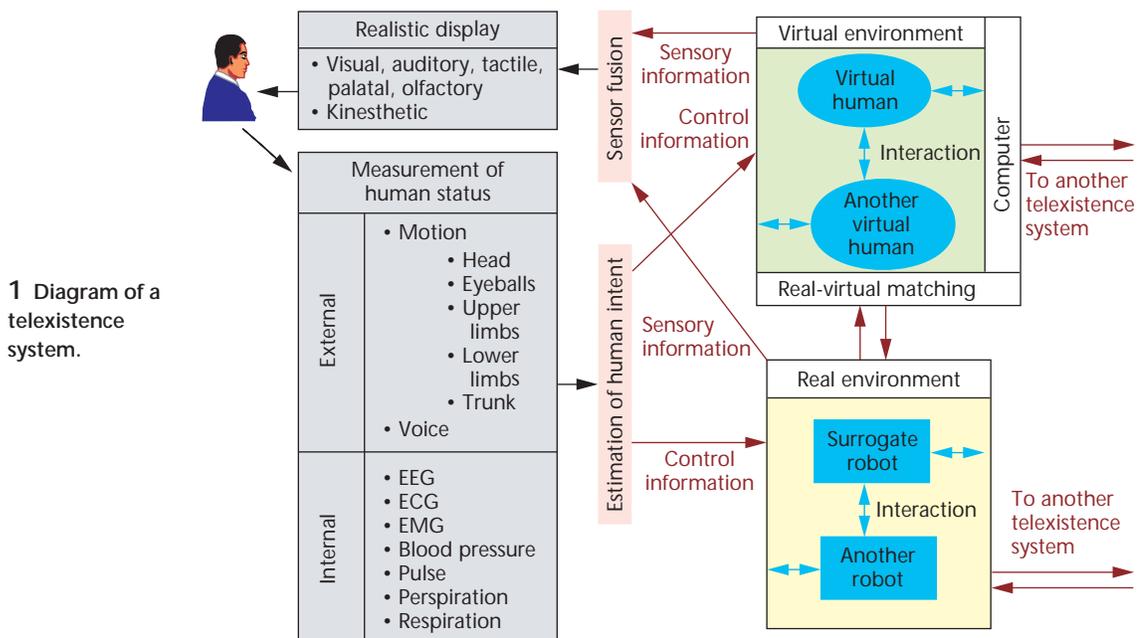
inal form. With the advent of science and technology, however, the realization of these dreams again becomes possible with a different concept.

Telexistence

The concept of projecting ourselves using robots, computers, and a cybernetic human interface is called telexistence (tele-existence). This concept expands to include projection in a remote real world or telexisting in a computer-generated virtual environment. Figure 1 illustrates the concept.

The telexistence concept I proposed in the 1980s played the principal role in the eight-year Japanese National Large-Scale Project “Advanced Robot Technology in a Hazardous Environment.” That project started in 1983, along with the concept of third-generation robotics, and ultimately established systematic design procedures for telexistence systems.

As part of the project, experimental hardware telexistence systems have developed and their conceptual feasibility demonstrated. I participated in the project at the Mechanical Engineering Laboratory (MEL) in Tsukuba



City, Japan that designed and developed a prototype of a telexistence master-slave system for remote manipulation experiments. Our group also conducted preliminary evaluation experiments with Telesar (Telexistence Slave Anthropomorphic Robot), one of the first telexistence systems (Figure 2). Later, I worked on design and development for an experimental telexistence system in a virtual environment (Figure 3). In these studies, we conducted quantitative evaluation of the telexistence manipulation system by tracking tasks. (See “Further Reading” sidebar for details.)

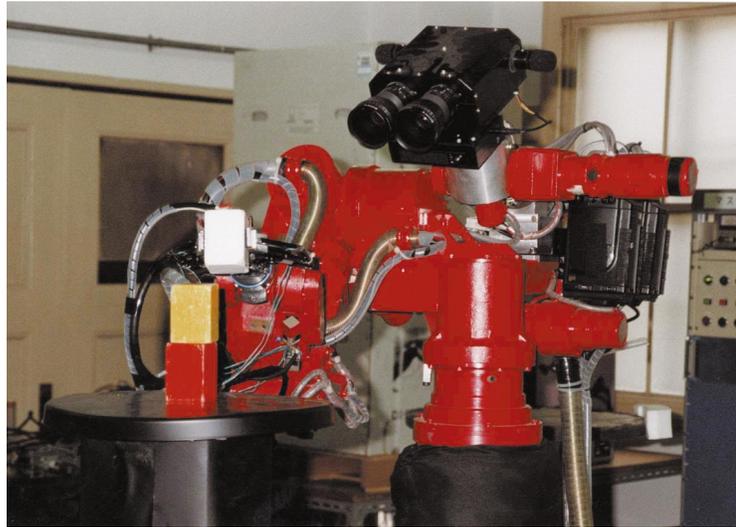
These experimental studies demonstrated that a human being can telexist in both a remote and a computer-generated environment by using the dedicated telexistence system. However, it’s difficult for everyone to telexist freely through commercial networks like the Internet or next-generation worldwide networks.

Real-time remote robotics (R^3)

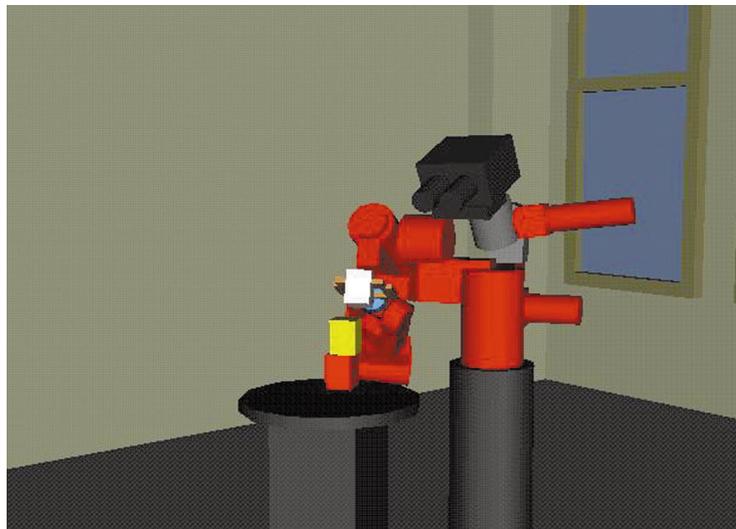
In 1995, the Japanese Ministry of International Trade and Industry (MITI) proposed a long-range national research and development scheme to realize a society where anyone can freely telexist through a network. This scheme is called Real-time Remote Robotics (R^3). As the first step toward R^3 , MITI conducted a two-year feasibility study from April 1996 to March 1998 called Friendly Network Robotics (FNR). This study resulted in the launch of the National Applied Science and Technology Project “Humanoid and Human Friendly Robotics.” This five-year project targets the realization of a so-called R^3 society by providing humanoids, control cockpits, and remote control protocols.

Figure 4 shows the concept of an R^3 system. Each robot site includes its local robot’s server. The robot type varies from a humanoid (high end) to a movable camera (low end). A virtual robot can also be a locally controlled system.

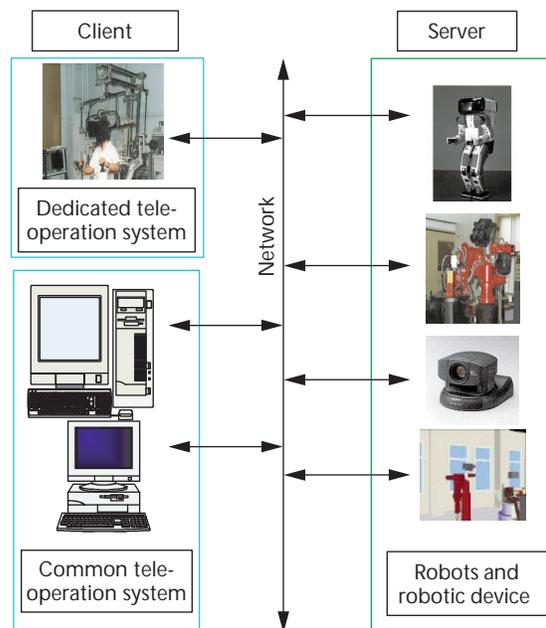
Each client has a teleoperation system, ranging from a control cockpit with master manipulators and a head-mounted display (HMD) and a Cave Automatic Virtual Environment (CAVE) on the high end to an ordinary personal computer system on the low end. RCML/RCTP (R-Cubed Manipulation Language/R-Cubed Transfer Protocol) is now under development to support the low-end users’ ability to control remote robots through a network.



2 Telesar (Telexistence Slave Anthropomorphic Robot).

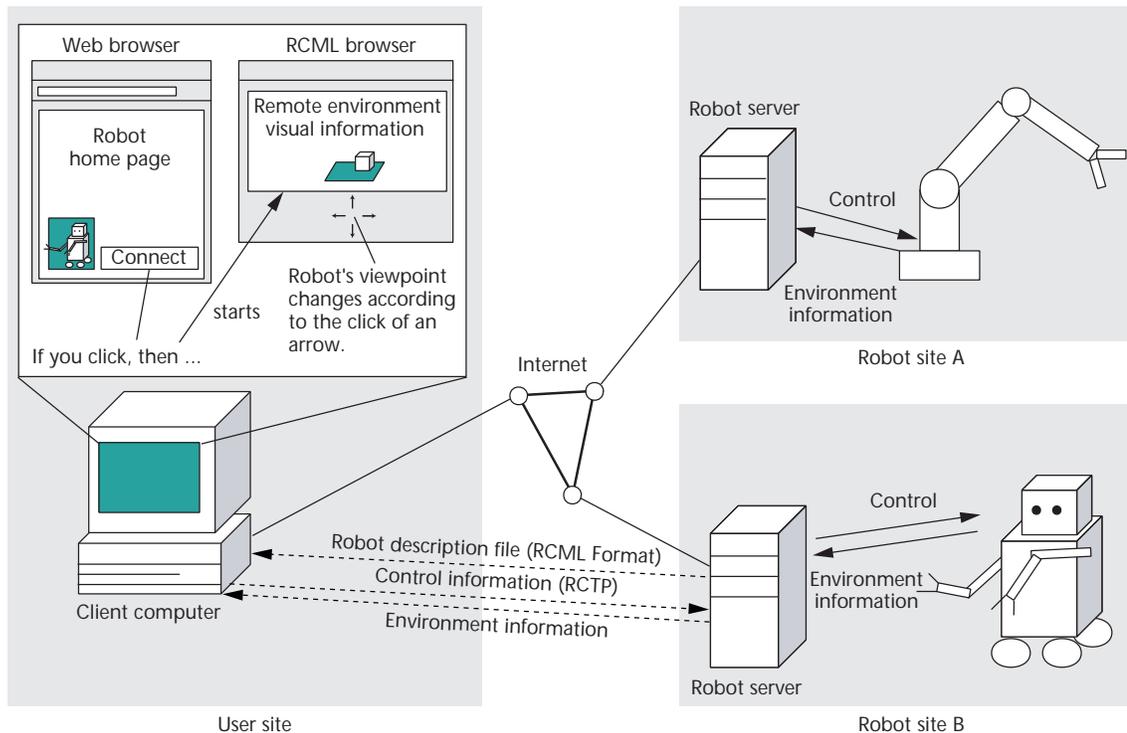


3 Virtual Telesar at work.



4 R^3 concept.

5 Diagram for RCML and RCTP process.



RCML

To standardize the following control scheme, my working group proposed a language dubbed RCML, which describes a remote robot's features and its working environment. We also developed a communication protocol called RCTP, designed to exchange control commands, status data, and sensory information between the robot and the user.

With a Web browser a user accesses a Web site describing a robot's information in the form of hypertext and icon graphics. Clicking on an icon downloads the description file—written in RCML format—to the user's computer and launches the RCML browser. The RCML browser parses the downloaded file to process the geometry information, including the arrangement of the robot's degrees of freedom, controllable parameters, available motion ranges, sensor information, and other pertinent information. The browser decides what kind and how many devices are required to control the remote robot. It then generates a graphical user interface (GUI) panel to control the robot, plus a video window that displays the images "seen" by the robot and a monitor window that lets users observe the robot's status from outside the robot. If the user has a device such as a 6-degrees-of-freedom (DOF) position/orientation sensor to indicate the robot-manipulator's endpoint, the user can employ that instead of the conventional GUI panel. See Figure 5.

RCML, an extension of VRML, uses nodes to allow either an RCML browser or a VRML browser to handle the RCML files. When using a VRML browser, the RCML-related part of the description will be neglected.

RCML describes the following information about a robot and its environment:

- Geometry of the robot and its configuration (degrees

of freedom, workspace, control variables, and other output devices such as speakers and laser pointers on board the robot)

- Specification of available sensory information (video signals from robot cameras, sound from microphones, and range data from ultrasonic sensors)
- Remote environment geometry and its specifications

This information is described in the form of VRML node extensions, and VRML fully describes the geometry.

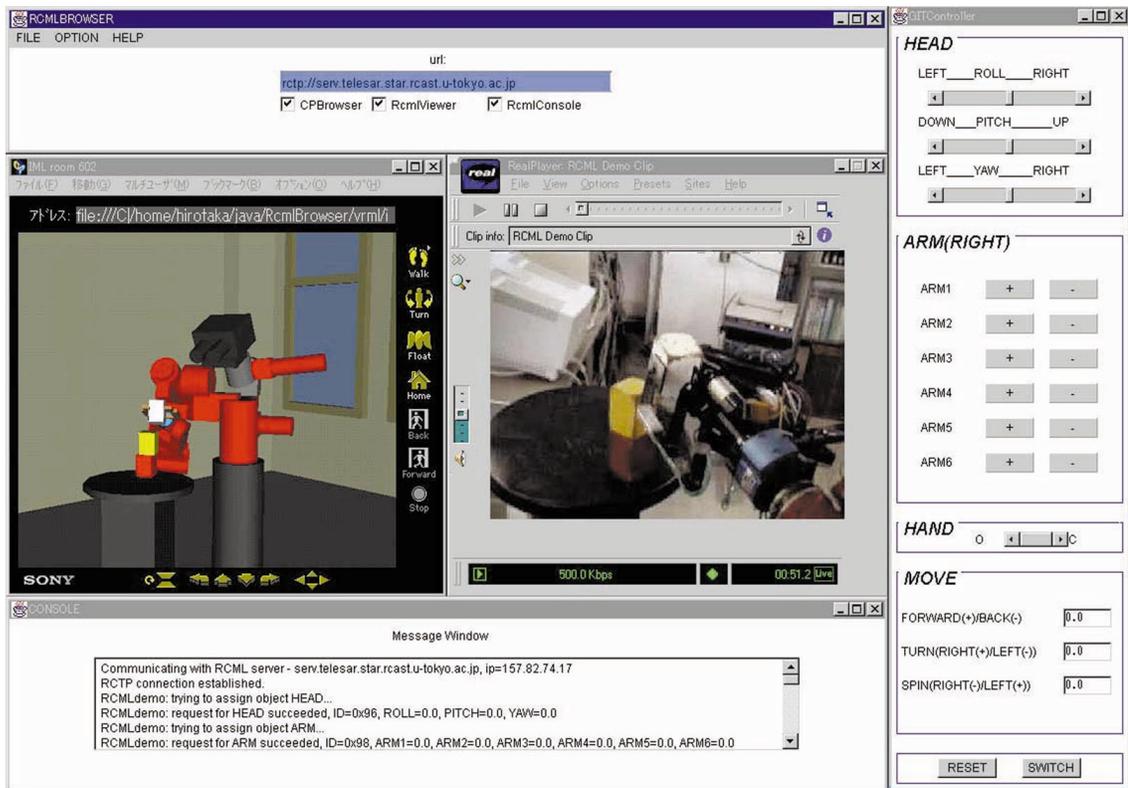
RCTP

RCTP is defined and used to communicate between a server site (robot) and a client site (user). The kinds of information transmitted through this protocol are

- System: connect/disconnect request, error status
- Control: values obtained from the user's input devices, such as 6-DOF position/orientation sensors, and GUI via keyboard or mouse
- Sensory: data obtained by the robot's sensors, such as position and orientation of the manipulator, and video signals from the robot cameras (information transmittable via a separate channel)

In the initial step, the authorization phase, the client requests connection with a server, which checks to see if another client is occupying the robot. If so, the client software rejects the request to control the robot and assigns "onlooker" mode. Otherwise, the client receives permission to control the robot.

Next, the system enters the negotiation phase. Here, the client assigns controllable objects at the remote site with their available devices. It also assigns a remote, sensory-information channel with local output devices.



6 An example of an RCML browser displaying the VRML image of the robot (left), the TV image (right), and the optional text communicator (bottom).

After finishing the negotiation phase, the system enters the actual data communication phase. The communication takes place in an object-oriented manner. While the connection holds, the control data is transferred over the network in a generic form independent of specific devices. This lets the system control any kind of robot, regardless of various DOF and geometry.

Figure 6 shows an RCML browser controlling Telesar using a GUI. The left graphic window displays the VRML presentation of the remote robot, whose motion reflects that of the real remote robot. The user can select any arbitrary point of view. The right picture window displays the TV image taken by the camera mounted on the robot's head. By using the GUI (right box), a user can control the motion of the camera, the robot manipulator, and the robot. Text communication is also possible using the text box. If the client has special devices for control, they can be assigned for use instead of the GUI. The same is true for display devices such as an HMD.

Conclusion

Virtual reality must have the computer-generated environment or transmitted remote environment's essence of reality to effectively become reality for the user. One of the most promising technologies today is the integration of virtual reality and robotics on the network. The general concept is called networked robotics; in particular, we call it R^3 . This Japanese national R&D scheme is moving toward the realization of mutual telexistence through various kinds of networks, including the Internet. The launch of the five-year MITI "Humanoid and Human Friendly Robotics" project in April 1998 takes the first step toward the realization of R^3 . We eagerly await the results. ■

Acknowledgments

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Further Reading

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