Paper

Direct Mobile Robot Teleoperation via Internet

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As networks such as the Internet go global, they become an important tool for everyone from engineers to the general public. This makes network-related technology an up-and-coming field. Conventional techniques should be applied for teleservice and teleoperation in global and general-purpose networks. Robots are a promising example of physical agent potentially useful via such networks in the near future. We describe direct teleoperation of a mobile robot via the Internet and experiments involving a real system and network.

Keywords: Teleoperation, Internet, Mobile Robot

1. Introduction

Attention is being increasingly focused on services that use network environments such as the Internet thanks to the constantly improved network environment and the teleoperation technology. From this viewpoint, robots are expected to play an important role as physical agents (media) via general-purpose networks.

Many studies have focused on robot teleoperation and effective findings have been made. Some of these studies discuss human-machine cooperation via networks.[2,3,5-9] Suzuki et al. proposed teleoperation of robots using the World Wide Web (WWW), setting three command levels:

1. Task
2. Motion
3. Direct Operation

A system using the task command level gives only abstract commands to robots via an operator, and the robot automatically executes planning and motion generation required for a task. A system using the motion command level has the operator plan the task and instruct motion to the robot, executes the required motion control. A system using the direct manipulation command level has the operator interfere with control of the robot executing a task.

Figure 1 shows a group robot operation interface using the WWW browser. An experiment remotely operating group robots using this interface was done. Use of command levels 1 or 2 is desirable if robots are autonomous enough. Use of command level 3 is practical if a task is actually executed in a general-purpose network. Detailed reviews on the direct operation command level have not yet been done in Refs.2) and 3). Problems depending on general-purpose networks are stated in these references as subjects of future study. We constructed direct teleoperation of autonomous mobile robots using the Internet and discuss results. We also discuss solutions of problems in experiments. The network-based human-machine-coordinated system merges robot autonomy and human judgment.

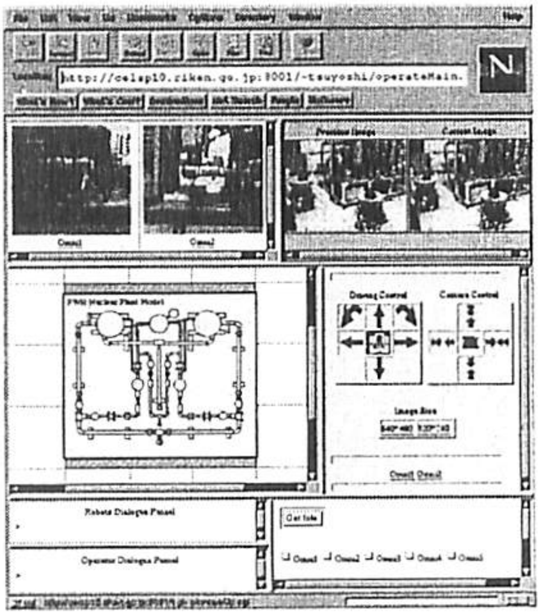

Fig. 1. Home page for controlling robots via Internet

2. Teleoperation

This section gives the basic teleoperation configuration of mobile robot and details target robot.

2.1. System configuration

Figure 2 shows the teleoperation system configuration for omnidirectional mobile robots operated via the Internet. The system consists of input, communication, and operation target units. The input unit consists of a PC with LinuxOS installed and a game joystick connected to the PC. Images

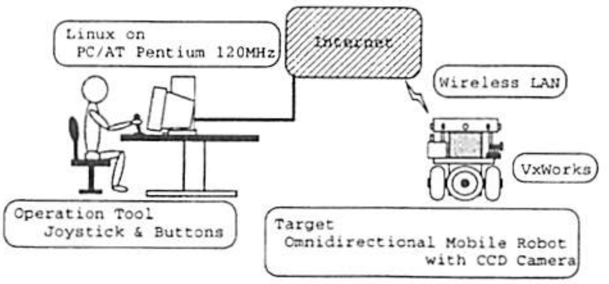

Fig. 2. Teleoperation for omnidirectional mobile robot

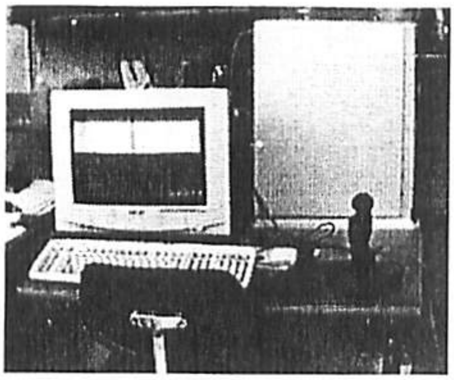

Fig. 3. Input devices

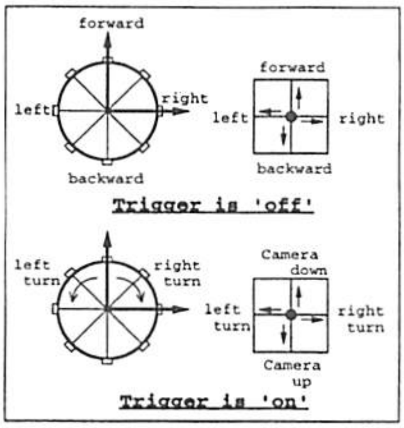

Fig. 4. Joystick assignment

are fed from the remote site and displayed on a TV monitor. The communication unit consists of TCP/IP and a wireless LAN using the same communication as the Internet. The input unit and robot are connected by a network. Commands are given to robot as velocity values. Robot is detailed in the next section.

The operator inputs commands via the joystick and a button (**Fig.3**). Input commands are transmitted to robot via the Internet and radio LAN. The joystick has two degrees of freedom (DOF) – forward-backward and right-left – and the combined joystick and button (**Fig.4**) gives robot motion commands. Command modes are switched by the trigger button on the joystick. Wit the trigger off, the joystick executes commands of robot motion in translation; with the trigger on, it executes commands of robot motion in orientation angle and camera tilting. Camera panning was integrated with robot motion in the orientation angle. Omnidirectional mobile robot is directly operated using image information only.

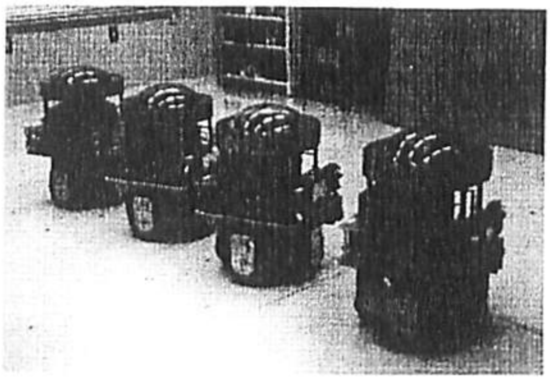

Fig. 5. Omnidirectional mobile robot

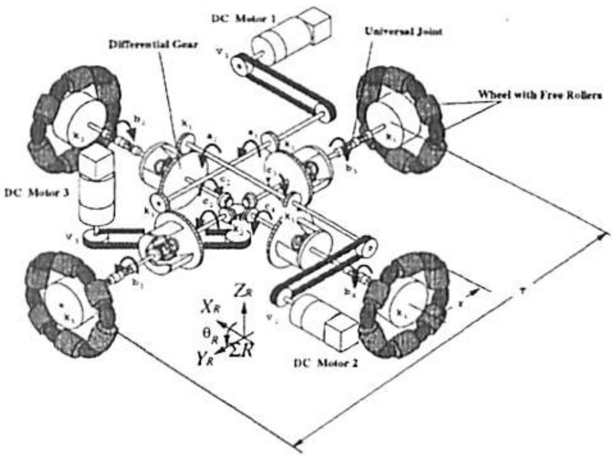

Fig. 6. Omnidirectional mobile mechanism

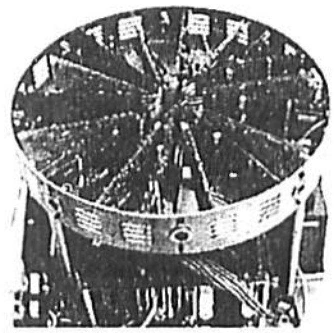

Fig. 7. Sensor on omnidirectional mobile robot

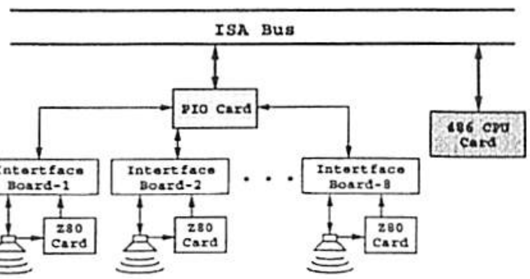

Fig. 8. Connection of robot and sensor controllers

2.2. Omnidirectional mobile robots: ZEN

The omnidirectional mobile robot we operated (**Fig.5**) has special wheels and drives (**Fig.6**) that move omnidirectionally by driving four wheels with three drive motors.[4] A

CCD camera on the robot captures images in front. The camera is 2DOF and varies the view in panning and tilting. The camera field angle is 20 degrees both right and left of the lens center, i.e., 40 degrees total, when the camera is standing still. The robot is equipped with 8 external infrared and ultrasonic sensors (**Fig.7**). Paired infrared and ultrasonic sensors constitutes each sensor, and each unit is driven by a microprocessor (**Fig.8**). The microprocessor reshows a physical agent on the network because the microprocessor OS is VxWorks, which operates in real time, and the microprocessor has an IP address.

3. Experiment

3.1. Basic experiment

Mobile robot teleoperation was in an environment (**Fig.9**) unknown to the operator. The only information the operator had was the environment image in front of the robot.

Problems found in the experiment include:

1. Information about the environment in front of the robot alone is not sufficient for optimizing omnidirectional movement.
2. Image information invokes incompatibility.
3. Command use involves random time-delay.

Problems 1 and 2 arise from differences in the image recognized by human visual sense and the image presented by the CCD camera on the robot. Ref.12) and others report that wide-angle lens use extends the visual field and enables comfortable maneuvering. The visual field size greatly affects maneuverability. If a robot has omnidirectional mobility, effective use of information about dead angle area more greatly affects maneuverability – a point that must be fully studied even if a wide-angle lens is used. Problem 3 involves a communication load that varies with time because the system uses a general-purpose network with time delay (**Fig.10**).

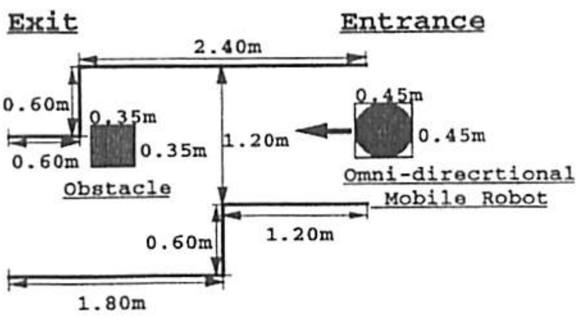

Fig. 9. Experimental environment

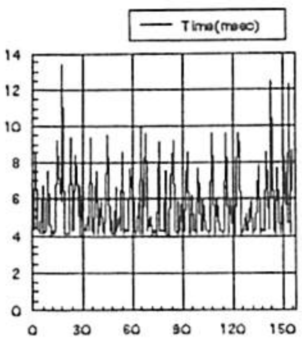

Fig. 10. Example of time delay on network

Problem 1 is solved by providing the operator with more sensor information without burdening the network with problem 3 or letting the robot solve it locally based on autonomous judgment. Work efficiency is also improved by effectively using robot autonomy. Problem 2 is solved by separating robot and camera motion by linking robot motion to the joystick and camera motion to the image on the head-mounted display (HMD) by projecting camera information onto the HMD, which has an orientation sensor. Problem 3 is also solved by keeping time lag constant by reserving communication resources on communication lines and compensating. Another solution is an interface that interpolates the time lag.

3.2. Review of solutions

This section devises ways to solve the above problems, discussing techniques enabling the system to function efficiently via feedback with relatively little information, i.e., image information only.

Addition of robot autonomous judgment

For problem 1, we determined that commands from the operator be adjusted by introducing local judgment by the robot made using sensors. The robot uses the following functions to locally adjust the operator's commands:

$$v_{comx} = v_{opx} - k(s)\, \mathcal{G}(\|v_{opx}\|, l_s) p_s \quad \cdots\cdots (1)$$

$$v_{comy} = v_{opy} - k(s)\, \mathcal{G}(\|v_{opy}\|, l_s) q_s \quad \cdots\cdots (2)$$

$$\omega_{com} = \omega_{op} \quad \cdots\cdots (3)$$

$$\mathcal{G}(v,h) = \begin{cases} 0 & \ldots\ \alpha < h \\ \dfrac{v}{\alpha - \beta}(\alpha - h) & \ldots\ 0 \le h \le \alpha \end{cases} \quad \cdots\cdots (4)$$

where

n: Number of sensors
v_{comx}: Velocity command in the direction of the x axis
v_{comy}: Velocity command in the direction of the y axis
w_{com}: Velocity command in the direction of the orientation angle
v_{opx}: Velocity command in the direction of the x axis given by the operator
v_{opy}: Velocity command in the direction of the y axis given by the operator
w_{op}: Velocity command in the direction of orientation angle given by the operator
l_i: Sensing result of sensor i
s: Number of the sensor detecting the shortest distance
p_i, q_i: Unit vector in the directions of the x and y axes unique to each sensor
α, β: Thresholds ($\alpha > \beta$)

Subscript i denotes the number specifies one of the eight robot sensors. $\mathcal{G}(.,.)$ reshows a function with a nonlinear spring that repulses the force compressing the spring beyond

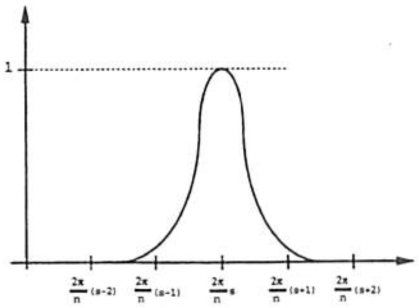

Fig. 11. Gain for sensing result

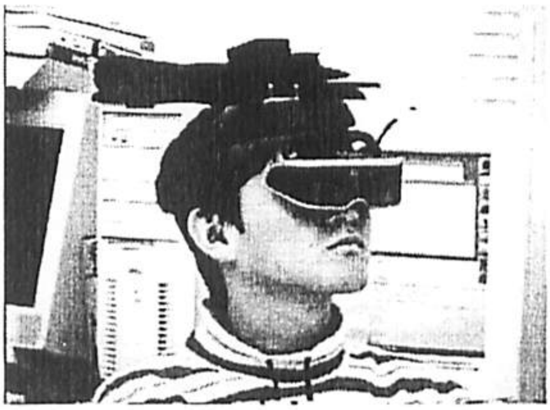

Fig. 12. HMD with gyroscope

Fig. 13. Experiment with HMD

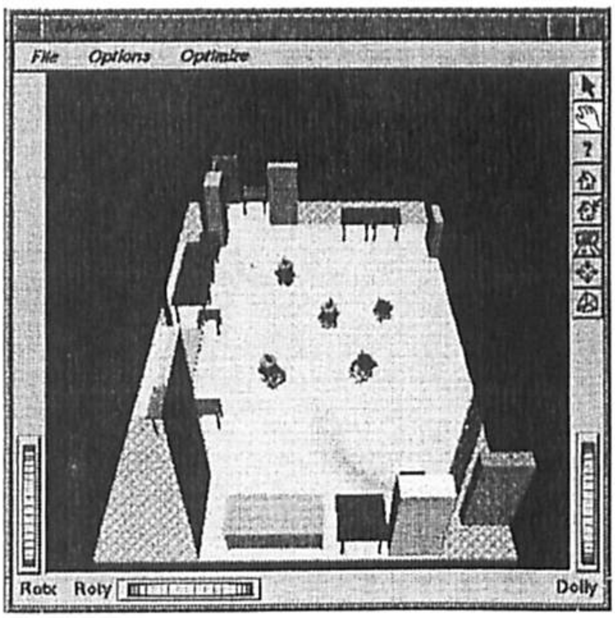

Fig. 14. Virtual environment as a human interface

α, the natural length of the spring represented by the function, whereas it demonstrates no reaction against pulling. This function provides the basic rule for determining the magnitude and direction of the effects that sensing results have on command values. Coefficient $k(.)$ as an example reshows the gain applied to sensing results, reflected in drive commands to robot (**Fig.11**). α and β denote constants determining the degree of local adjustment, and setting them to any value is permitted. Specifically, α denotes the value selected from sensor information as the most desirable distance to obstacles where the robot starts to recognize objects, and β the value selected as the most desirable nearest distance to objects. Since the robot we control in our research determines the location independently from orientation, the orientation angle was determined exactly as instructed by the operator, without reflecting it in robot judgment. The robot adjusts operator commands based on these functions to avoid obstacles it approaches. Mobile robot thereby avoid obstacles by coordination with commands by the operator via autonomous use of local sensing information. This system realizes teleoperation relatively easily by making robot autonomously avoid obstacles at both sides and the back, despite relatively little information, i.e., the front image only, fed back. Command values not updated due to communication time lag could cause problems in driving robot. Nonupdated commands are processed because data in robots are processed in parallel in communication, driving, and sensor systems. Robots avoid collision even using sensor information by the functions above, which produce satisfactory results even if exact commands are not sent due to communication errors or other problems.

HMD Introduction

Introduction of HMD was studied to solve problems of incompatibility in image information and information deficiency. The commercially available HMD uses a gyrosensor added to the system (**Fig.12**). Panning of the CCD camera was geared to the motion of the operator's head (**Fig.13**). Camera motion input was permitted only when no motion commands are given to the robot, because complete separation of motion adversely affects information about the direction in which the robot proceeds. The operator's motion was linked to camera motion, improving the sense of manipulation compared to images simply fed back.

Interpolation interface

The interpolation interface used against time delay is a virtual environment on a computer (**Fig.14**) that reproduces remote site status by building a virtual world on the operator's side, unaffected by traffic. It attempts to realize real-time teleoperation by interpolating virtual information and the time lag and deficient information from the real world.

The virtual environment consists of environment and robot models and a virtual robot process. The environment model reproduces the environment at a remote site using a 3D model, although reproduction is possible when required information about the operating environment is made available in advance. The robot model reproduces in the virtual

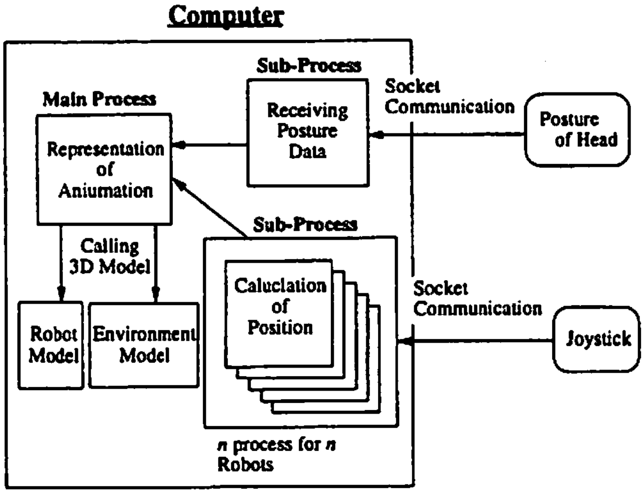

Fig. 15. Information processing on operator site

environment the robot status in the real environment based on information via the network. The process (**Fig.15**) consists of a single parent process and multiple child processes. The parent process draws animated images including 3D models. Child processes handle camera orientation information and compute the robot location from data input via the joystick. Parallel execution of these processes displays the virtual world modeling the real world on a computer. Mobile robot teleoperation via animated images in the virtual world enables interpolation of images deficient or lacking information. This interpolation interface copes capably with dynamic variation in visual angle information caused by movement in the environment, if environmental information is available in advance, satisfying interpolation requirements even with several other robots. The interface will be fully capable of coping with dynamic environmental changes, such as variation in the environment itself, if technology becomes available for generating a 3-dimensional model using multiple cameras in the environment. A child process executes modeling in parallel with parent process processing.

This interface is still under development, and has not yet been introduced into the actual system. We are sure that the interface will be an effective tool in teleoperation as further developments are made.

4. Conclusions

This paper presented a system for teleoperating robots via the Internet and a teleoperation experiment. Accomplishing tasks via robot teleoperation will come to be applied in various fields as network environments improve. In such teleoperation, robots play important roles as physical agents on an existing network, such as the Internet. We proposed several solutions based on findings after building a basic system that used omnidirectional mobile robot as a control target, and reviewed the solutions via an experiment in which robots accomplished simple tasks, such as passing a bottleneck. Future discussions will target higher-level tasks.

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