Proceedings of the 11th
KACC, October 1996

A STUDY ON THE NEW METHOD OF FORCE REFLECTION CONTROL FOR THE TELEOPERATED MOBILE ROBOT

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Abstract This paper presents a new method of force reflection in the teleoperated mobile robot control: artificial force feedback. Generally it is well known that force feedback from slave to master increases the reality with which the operator interacts with the environment. In the applications of the teleoperated mobile robot, however, such a force feedback control algorithm has rarely appeared in the literature because the contact force between the environment and the mobile robot is not available. In this paper, a method of artificially generating the feedback force for the teleoperated mobile robot is presented in order to improve the task performance. The computed artificial force feeds into the new designed joystick so as to increase the telepresence of the environment. Through simulations, we confirm the validity and effectiveness of our algorithm.

Keywords Force Reflection, Teleoperated Mobile Robot, Telepresence

1. INTRODUCTION

Teleoperation has the potential to play a significant role in the hostile environment operations, such as the nuclear power plant, undersea, and space operations. In teleoperation, a human operator conducts a task in a remote environment via master (or joystick) and slave robots. In tele-manipulator cases, providing contact force information to the human operator can improve the task performance. Although the information can be obtained from visual displays, it is more useful when provided directly, by reflecting the measured force to motors on the master. When this is done, the contact force is said to be "reflected" to the human operator, and the teleoperator is said to be controlled bilaterally [1]. There has been a great deal of activity to present the force feedback: contact sensation for finger [2], kinesthetic sensation for hand [3], and so on.

On the other hand, in teleoperated mobile robot cases, such a force feedback control algorithm has rarely appeared in the literature because the contact force between the objects and the robot is not available. Really the contact force can be generated only when mobile robot collides with obstacles and this means the failure of teleoperation. In order to improve the task performance, it is also preferable to increae the sense of telepresence in the teleoperated mobile robot case, using the feedback information of environment. To utilize such a feedback information of environment, we present a new method called "artificial force feedback" as an alternative of the contact force feedback that is used for the bilateral control of tele-manipulator.

To generate the force feedback information for mobile robot, we bring the idea from the potential field approach [4]. Introducing the idea of artificial repulsive force, we can easily generate the feedback information of environment. Of course, another methods are available for generating the artificial force feedback data, for example, vector field histogram [5] and so on. The orginality of our work lies in the fact that we apply the force reflection algorithm to the teleoperated mobile robot at first using the artificial force feedback concept. In addition, we design a joystick with two motors newly, and the computed force value feeds into this joystick through the motors.

This paper is organized as follows: The Section 2 gives a main design procedure for our algorithm and shows a structure diagram of the newly designed joystick. In the Section 3, the experimental results confirm the effectiveness and validity of our algorithm. In the experiment, we use the visual display system instead of the real mobile robot. Finally we draw some conclusions in the Section 4.

2. MAIN ALGORITHM FOR VIRTUAL FORCE FEEDBACK

A teleoperator system can be represented by the block diagram of Fig. 1 and consists of five subsystems: the human operator, the master, the communication block, the slave, and the environment. In this paper, we focus on the development of the master that has the proper structure for the force feedback and the feedback method from environment. Now we consider the design of master at first.

2.1. Design of Joystick with Two Motors

The joystick can have the control actions with three degree of freedom: translation (2 d.o.f.) and rotation (1 d.o.f.). Since the translational motion plays a key role during the mobile robot operations, it is desirable for the feedback information to be used for improving this motion. Fig. 2. shows the picture of the designed joystick which contains the potentiometer and two DC motors. Note that the potentiometer returns the velocity control value of joystick and each motor is attached to the x and y axis of the joystick frame respectively.

Since each motor drives x and y axis motion respectively, we require to compute each x and y component of the feedback torque τ_r. In the following section, we will propose one way to generate the feedback torque.

2.2. Force Reflection Control Scheme

As stated earlier, providing the force information to the human operator can improve the task performance, although, such a force reflection algorithm has rarely appeared in the field of teleoperated mobile robot. This is due to the fact that the contact force cannot be obtained during the normal operation of mobile robot and the occurrence of contact is regarded as the collision with objects in the mobile robot operation. Anyway, it is clear that in order to improve the task performance, it is desirable to increase the sense of telepresence also in the teleoperated mobile robot case. Since, as the alternative of the contact force feedback, we present a new method of force reflection such that the distance value between robot and objects is used to generate the corresponding force. In this paper, we bring this idea from the potential field method [4].

To achieve such a force feedback, it is essential for a robot system to have an understanding of its surroundings, by acquiring and manipulating a rich model for its environment of operation. This model is based on assertions composed from the various sensors, and reflects the data obtained and the hypotheses proposed so far. In this paper, we assume that the range data of robot's surroundings are available in the form of the proximity measure for the simplicity. Now the proposed method of forming the force feedback data can be given as follows:

$$\begin{aligned}\mathbf{f}_r &= \begin{pmatrix} f_x \\ f_y \end{pmatrix} \\ &= \begin{pmatrix} sat(k_f \sum_i^{n_s} f_i \cos\varphi_i) \\ sat(k_f \sum_i^{n_s} f_i \sin\varphi_i) \end{pmatrix}\end{aligned} \tag{1}$$

where

$\mathbf{f}_r$	the artificial force feedback vector
f_x	the x component of $\mathbf{f}_r$ in the joystick frame
f_y	the y component of $\mathbf{f}_r$ in the joystick frame
n_s	the number of sensor beams
k_f	the force feedback gain
φ_i	the angle between x axis of joystick and the sensor beam of i th sensor.

And

$$f_i = \begin{cases} \frac{1}{d_i^2} & \text{if} \quad d_i \le \rho_0 \\ 0 & \text{otherwise} \end{cases} \tag{2}$$

$$sat(x) = \begin{cases} x & \text{if} \quad |x| \le x_{max} \\ sgn(x) \cdot x_{max} & \text{otherwise} \end{cases} \tag{3}$$

where

d_i	the proximity measure in the direction of φ_i
ρ_0	the radius of active window
$sgn(\cdot)$	the function of returning the sign value
x_{max}	the maximum bound of saturation.

Fig. 3 will be helpful for the comprehensive understanding of the above equations. Note that the saturation function is used so as to prevent the resulted feedback force from exceeding the driving power of motor. And any other methods can be used for generating the feedback data. The following equation gives the real value of feedback torque for each motor attached to the joystick.

$$\tau_r = k_r \mathbf{f}_r \tag{4}$$

where k_r is a constant value and without loss of generality, we can set k_r equal to 1.

3. EXPERIMENTAL RESULTS

To confirm the effectiveness of the mentioned algorithm, we develop a force-reflecting simulation system and perform some simple experiments.

3.1. Setup for Experiment

The total system for experiments is composed of three parts: a visual display system, a joystick with motors, and a communication block. Before applying our algorithm to the real robot system directly, we need to acquire the credit for the validation of the proposed method. And so, we employ the visual display system as a simulator of real robot. Note that we have developed the omnidirectional mobile robot called KAEROT [7] for the purpose of nuclear facility operation, as shown in Fig. 4 and we are now preparing for the real experiments.

A visual display system performs three key functions: the graphical representation for environment of operation, the generation of the proximity measure data between robot and objects, and the computation of the feedback force. These functions are implemented under the UNIX workstation environment.

The real-time OS called VxWorks is employed for controlling the DC motors and acquiring the control input value from the joystick.

The communication block is realized by LAN between the visual display system and the control system for joystick. The overview of the system configuration is shown in Fig. 5.

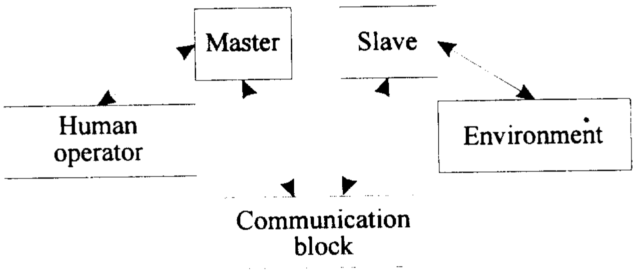

Fig. 1. Block diagram of the teleoperator system

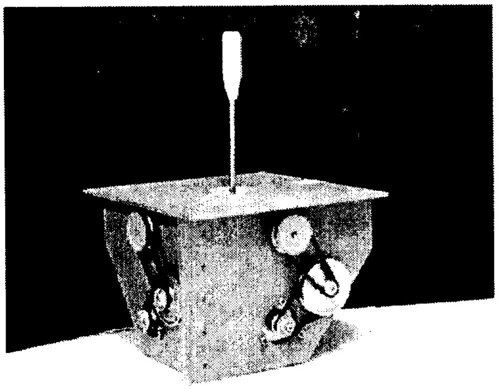

Fig. 2. Picture of joystick

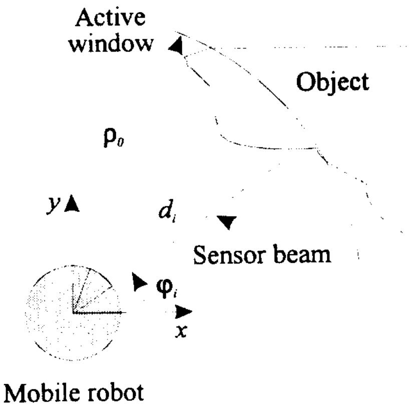

Fig. 3. Illustrated view for the proposed algorithm

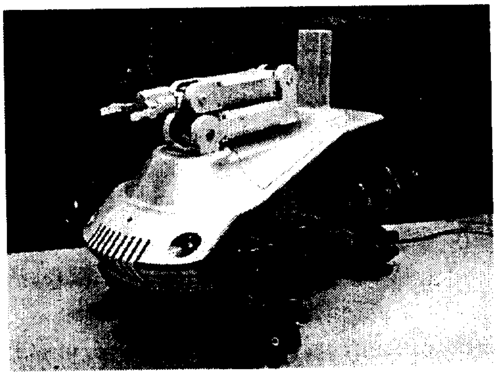

Fig. 4. Picture of KAEROT

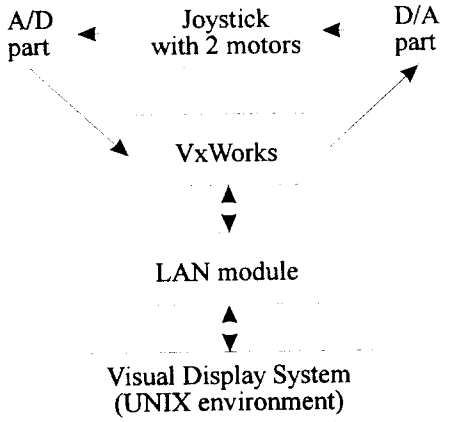

Fig. 5. Overview of experimental setup

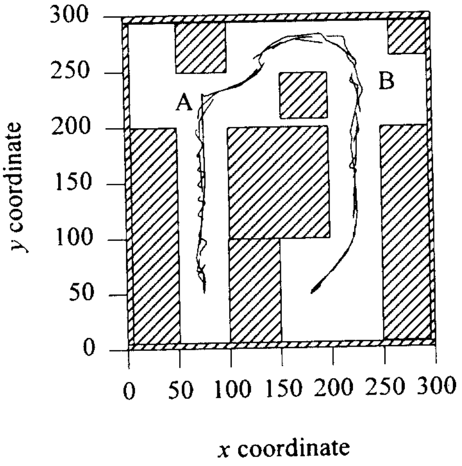

Fig. 6. Experimental result
− : $k_f = 250$ ·· : $k_f = 350$ -· : $k_f = 450$

3.2. Feedback Gain Tuning and Experiment

In the conventional force reflection theory of telemanipulator, it is well known that stability can be improved by reducing the force feedback gain, but at the cost of reduced sensitivity [6]. This statement is also correct in our case so that larger feedback gain k_f would make the joystick oscillatory in interaction with environment and smaller gain would reduce the chance of improving a task performance.

We perform the experiment as depicted in Fig. 6. As we can see, there are abrupt changes of the feedback force on the part marked by "A" and "B" and they correspond to the corners respectively. And the gain $k_f = 350$ provides a nice feedback to the human operator and the smooth and good path is obtained as a result. This experimental result shows us that the proposed algorithm for force feedback is useful to understand the robot's surroundings and helps the human operator drive well. Of course, the operator can control the mobile robot without the force feedback data, however, it is preferable to utilize the information of environment as possible. Some other experiments are also performed and we can obtain the satisfactory results. Through experiment, the validity and effectiveness of our algorithm is confirmed and the future works direct to the real experiments applying our algorithm to KAEROT [7].

4. CONCLUSIONS

This paper has introduced a new method of force feedback for controlling a teleoperated mobile robot. Since this pioneering work, little has been reported in the field of teleoperated mobile robot because the contact between environment and robot is not allowed during the mobile robot operation and thus the contact force is not available for feedback any more. We have proposed a new method called *"artificial force feedback"* which artificially generates the feedback force information of environment, using the proximity measure between objects and robot. This generated feedback force can correspond to the contact force in the tele-manipulator control.

In order to feed the generated force into the human operator, we have newly designed the joystick with two DC motors which are attached x and y axis of joystick frame respectively. By adjusting the current value of the motor, we can generate the desired feedback torque and this torque has an effect on the translational motion of mobile robot directly.

Through the experiments, we use the visual display system instead of the real robot because we just want to confirm the validity and effectiveness of our pioneering approach. Since we have verified that such a feedback method be helpful to improve the motion of mobile robot through experiments, future works include the application of our algorithm to the real robot. Now we are preparing the experiments, using the omnidirectional mobile robot called KAEROT [7] which has been developed for the nuclear facility operation.

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