A Teleoperating System For Underwater Manipulator To Practice A Time Limit Task

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***Abstract*--This paper explores the use of virtual reality technology to help visualize the remote environment and control the remote underwater robot indirectly. Also an online parameter prediction system is developed to cope with the time delay. The paper consists of two parts: (I) the development of improved virtual model based teleoperating system, and (II) an investigation into the feasibility of the predictor performance. The experimental system is an Internet-based teleoperating system for an underwater 7-axis manipulator. The task of this project is a time-limited task. That is to retrieve and catch a moving target in the water through the tele-operating system.**

***Index terms*—Time delay, virtual model, teleoperation**

I. Introduction

Tele-operation is hindered by time delays due to transmissions over large distances. In time delayed teleoportation, it may take place a few seconds for the remote robot to receive operator' command and for visual feedback to reach the operator. To overcome the effects of time delay in visual feedback, the operator must adopt a move-and-wait strategy whereby a small movement is made and the operator waits to observe the results of the movement before committing to further action [1]. A solution to this kind problem had been proposed by Bejczy and his colleges at Jet Propulsion Laboratory [2]. It is called the "phantom robot". The phantom robot is a graphical representation of the remote robot that is overlaid to the video image of the real robot. The virtual robot is properly registered with the position of his real counter part and responds instantaneously to the operator's input. Thus the phantom manipulator servers as a predictor of the remote motion, and allow faster and safer teleoperation.

For other methods such as predictive displays and supervisory control have been developed to address these efforts [3,4]. Predictor displays extrapolate the last known state of the slave forward in time, thus providing the operator with a predicted current state. In recent years, the development of virtual reality is attracting a great deal of attention. A general definition of virtual reality is that it is a simulation, in which computer graphics are used to create a realistic looking world. Usually the simulation is three dimensional, dynamic, and interactive. Further bring in multi-media techniques enables virtual reality to go beyond pure graphics in emulating reality [5].

However for Internet based tele-operation, time delays become more complexly than using such those private communication line. Because the network transmitting is generally based a low bandwidth network in current. Not only is the volume of transmitting data limited, but also the transmitting speed is fluctuant with time changing. As well as a data packet loss problem could not be overlooked. Although the delay is not so much longer than the private line connection, it is non-deterministic. This makes the teleoperation via Internet become extremely difficulty.

In this paper, an approach toward overcoming the Internet time delay implements a real time control to an underwater robot manipulator to achieve a time limited task. A virtual model based graphically user interface has been utilized in this teleoperating system. Interaction between the human operator and the remote robot is facilitated through the virtual model of the real robot environment. The operator can command the simulated robot, to test the feasibility of the tasks or to define a sequence of the goal positions for real robot. Not only the virtual model can server as a monitor for monitoring the remote environment, but also may server as a simulator of motion commands, before they are actually sent to the real robot. The operator can also preview the planned path using a virtual model for acceptance or modification prior to execution. As a solution to the time delay, an online parameter prediction method is explored. For the selected task, it was shown that the predictor has worked well in coping with the time delay under 2 seconds.

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II. MODEL BASED TELEOPERATING SYSTEM DEVELOPMENT

A. System Overview

Based the developed technology and researches by now, a tele-operating environment for underwater robot manipulator is constructed and developed. The teleporting system is showed in Figure1.

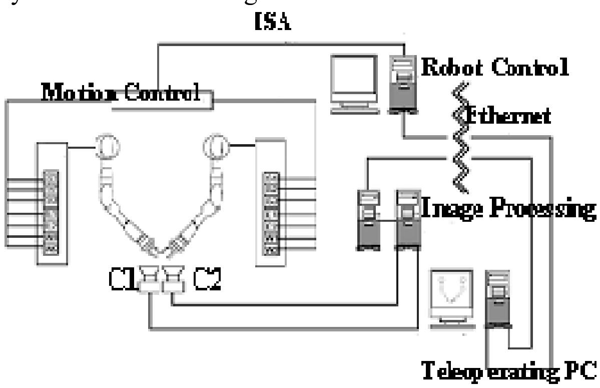

Fig. 1. Teleoperaing System Configuration

This is a system view of the teleoperating system. It consists of four hardware components: a robot control system, a tele-operating console, a vision process system, and an underwater robot manipulator. The underwater robot manipulator has two arms with 7 links. The vision processing system consists of two CCD cameras, a PC for processing images and another one for transmitting position data to the operator. A template matching vision system is employed to perform all the off board processing and extract the target information. The tele-operating console applies 3D computer graphics to simulate the underwater robot, its task environment, and the location of the object to be retrieved. The robot control part sends operating orders to and receives feedback data from the control system through a TCP/IP based network.

B. Robot Control System

The robot we use is composed of dual arm 7-axis underwater manipulator developed by Mitsubishi Heavy Industries, Ltd. The model is PA-10.The robot control system has four functional layers: the controlled object (the arm robot itself), the servo driver unit, the motion control unit, and the operation control unit (See figure 1). The operation control unit is performed by a control PC, which can accept commands like arm status, arm joint angle coming from distanced operator. And then sent these information to the motion control unit via an ISA BUS I/O port. Off cause the status and position of the robot can also be obtained from the control PC directly. The velocity of axis is calculated in the motion control unit and sent to the servo unit via ARCNET. The servo driver controls the AC motor of each joint to generate the motion of the robot. On the other hand, the result of motion is sent at an inverse route as feedback data.

C. Vision Processing System

The vision system physically consists of two CCD monochrome cameras, several I/O boards, a MS-DOS based computer and a Windows NT 4.0 workstation based computer. The two cameras collect images of the robot workspace from same viewpoints. The image-processing program runs in DOS shell. The object image can be extracted from the environment image using a template-matching method and the position of the object can be calculated using the stereovision algorithms. The NT workstation acts as a user interface to the vision system and sent the object position data to the remote operator. The image processing system is functionally consists of extracting the target position from the images and sending the target position information to the operator site. The method for target recognizing is paten reorganization. First, the target's search paten is registered. Then based the registered paten, using the paten-matching algorithm, the edge of the search target can be extracted from the image and the target position is searched. By considering recognizing the moving target, the rolling and scale changing also be used in the algorithm.

D. Teleoperating System

The tele-operating unit consists of a Windows 2000 PC. It uses a 3D computer graphics to model the remote real environment. That real-timely displays the robot status, the water tank that is known as the invariable parameters and the target position that is coming from the image processing system. This virtual model is shown in figure 3. By graphically user interface, the operator can interact with the remote robot. Firstly using the feedback data sent by vision system and robot control system, the target's current position and robot status can be modeled in the display. By this information, the operator can make decisions and sent commands to the robot of the virtual environment via the input device. Simultaneously these command are also sent to the remote robot control.

III. VIRTUAL MODEL BASED TELEOPERATING SYSTEM IMPLANTATION

Classical teleoperation requires one operator controlling a robot end effector directly. This approach elevates the operator to the role of a supervisor who controls the robot indirectly through a graphic abstraction.

A. System Configurations

In this research, an approach towards developing a virtual model to implement operator' supervising control. This experimental system consists of a GUI on the operator' workstation displaying a graphical model of the remote environment. The operator could control a graphical model of the remote robot by sent the control command through the virtual model input panel.

The interacting computer models residing at the operator allow the specification of task goals by the human operator and the interpretation and execution by the real robot. This model is dynamically updated by position feedback from the remote site. Communication between the workstations at the two sites is via Internet through TCP/IP protocol.

The monitor is using a 3D computer graphics to model the remote real environment. That real-timely displays the robot status, the water tank that is known as the invariable parameters and the target position that is coming from the image processing system. An input panel with virtual push buttons and sliders allows operator to switch control mode and issue control command. The software was written in JAVA programming language, and is running on Microsoft' windows 2000 environment. Java 3D API is an application-programming interface used for writing three-dimensional graphics applications. It gives high-level constructs for creating and manipulating 3D geometry and for constructing the structures used in rendering that geometry. The real liked virtual worlds can be described using these constructs, which provide enough information to render these worlds efficiently. The operator can use the virtual model as both a visual aid and as a tool for outlining tasks for the robots to perform autonomously under human supervision.

B. Model Based Operator Manual Control

Under the model based manual control (M Mode), the operator can interact with the virtual model of the real environment for on line path planning for the robot on the remote site. The operator commands a simulation to define model control sequence, or input desired goal positions for

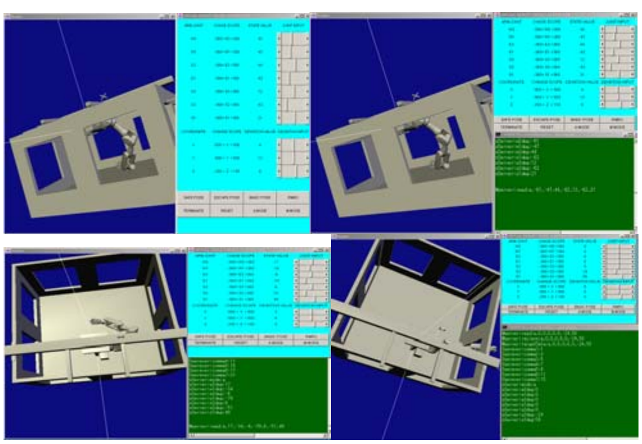

Fig. 2. Model Based Operator Manual Control

the robot. If requested, the operator can also preview the planned robot trajectories for approval and possible modification. Also an inexperienced operator can get enough training to gain the valuable experience about the real robot environments before he could operator the real robot. Another characteristic is that the virtual model has more flexibility than the real robot. For example, in defining a model control sequence, the operator can arbitrarily command the virtual robot unconstrained by the actual robot environments, and try various robot positions without possible implications of the damage from directly manual control error.

C. Model Based Automatic Control

Under the model based automatic control (A Mode), the robot moves automatically by the visual position feedback. Figure4 shows a scene when robot is given the task to retrieve and catch a moving target. The target position data is initially extracted by the CCD cameras, which are installed in the real environment. To compensating the time delay in whole system including the network operation and hardware operation. A on line parameter prediction system is employed. The system real timely processing the parameter coming from the real environment and returns the prediction result back to the real robot. After received the target data, the robot can compute the coordinator data to the motor's toque by reverse kinematics' algorithm, and move the each link to retrieve the target. Because all the system is running automatically, the operator just behavior as an observer for monitoring the abnormalities or terminate the system in emergency.

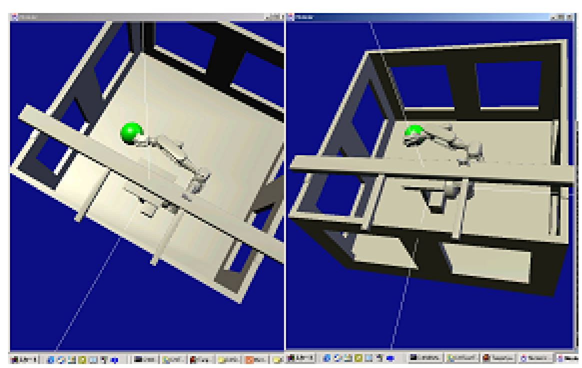

Fig. 3. Model Based Automatic Control

D. On-Line Parameter Estimation

Because the network transmitting is based a low bandwidth network, there exist some problems to prevent the task implementing from operating. One of the problems is the limitation of network communication speed that will decrease the task-achieving rate. Another one is a data packet loss problem .The side effect of this problem is losing transmitted ball position data and operating commands. As a compensation for such these problems, an online parameter prediction system is adopted.

The prediction system needs two kinds of data to update the virtual environment in the master side. The whole environment data are divided into time dependent data and constant data. The environment data that changes with time, such as ball position data and robot position and status data, are considered as the time dependent data. Other environment data such as field scale, water tank are considered as the constant environment data. The virtual environment is presented on the monitor by renew these data. When the ball is starting to fall, the time dependent data are sent from the slave side.

On-line determination of parameters is critical for time-limited task. If the structure of the dynamics is known with confidence, then the system identification problem is reduced to optimization of the estimated parameter. The least squares algorithm is the most basic technique for on-line parameter estimation. According to the least squares principle, the unknown parameters of a mathematical model should be chosen in a manner which minimizes the sum of the squares of the differences between the observed and computed values. When the observations are obtained sequentially in real time, it is desirable to perform the computations in order to minimize computational time. The computations can be arranged in such a way that the results obtained at time k-1 can be used in order to get the estimates at time k. By investigating various simulated ball-tracking patterns in this research, a linear prediction is enough to approximate the ball track. That is employed initially for the prediction system. A ball track is approximated to a following equation. Let A and B represents the unknown constants.

$y = Ax + B$ (x, y are observed ball position in X,Y axis) ……………………………………………………………………(1)

We can find values of A and B that make equation (2) minimize. In order to obtain A and B, N sets of ball position (x_i, y_i) are used.

$$E(A,B) = \sum_{i=1}^{N} (y_i - Ax_i - B)^2$$

……………………………………………………………………(2)

A and B have to satisfy the following equations.

$$\frac{\partial E}{\partial A} = 2\{A\sum_{i=1}^{N} x_i^2 + B\sum_{i=1}^{N} x_i - \sum_{i=1}^{N} x_i y_i\} = 0$$

……………………………………………………………………..(3)

$$\frac{\partial E}{\partial B} = 2\{A\sum_{i=1}^{N} x_i + BN - \sum_{i=1}^{N} y_i\} = 0$$

……………………………………………………………………..(4)

Equation (3), (4) are liner simultaneous equations. By solving these equations, optimum A and B can be acquired from equation (5), (6).

$$A = \{N\sum_{i=1}^{N} x_i\, y_i - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} y_i\} / \{N\sum_{i=1}^{N} x_i^2 - (\sum_{i=1}^{N} x_i)^2\}$$

……………………………………………………………………..(5)

$$B = \{\sum_{i=1}^{N} x_i^2 \sum_{i=1}^{N} y_i - \sum_{i=1}^{N} x_i \sum_{i=1}^{N} x_i y_i\} / \{N\sum_{i=1}^{N} x_i^2 - (\sum_{i=1}^{N} x_i)^2\}$$

…………………………………………………………………….(6)

Applying A and B obtained from equation (5) and (6) to equation (1), a ball track is approximated.

IV. EXPERIMENT INVESTIGATIONS AND RESULT

We have implement the teleoperating system described above for experiments. Through these experiments, the feasibility of the system in overcoming the time delay is investigated.

A. *Investigation of Time delay's influence*

To demonstrate the maximum permissibility of the teleoperating system, a time-limited task is selected. The operating subject for is to retrieve and catch a moving target in the water. The real robot and his environment are in the water. For excluding the excessive disturbances, the water is static water. In real robot environment, when the target ball is moving in

30-50mm per second in the water, the ball position data is extracted by the vision processing system. Then the data is sent to the teleoperating system for prediction continually. Based those parameter, an online parameter predicting is performed in the remote site. After the prediction is carried out, the processed parameter will be sent back to the real environment. The real robot's control system receives the predicted parameter and moves the real robot to retrieve and catch the target.

Figure 5 shows the effect of time delay to the task achievement.

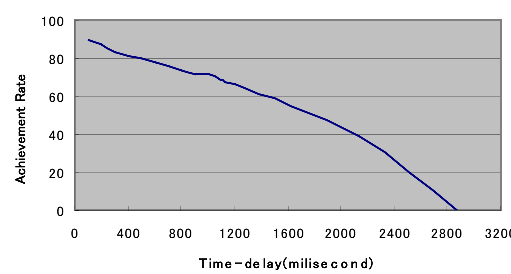

Fig. 4. Time delay Influence In Task

B. *Prediction performance measurement*

We measure 100 sets of actual target positions and predicted target positions. Comparing two kinds of data, the predictive errors are shown in Figure 5.

The prediction errors are from -20 [mm] to 20 [mm]. It is considered the prediction performance is feasible to catch the target. From the result of the measurement, it is confirmed that the prediction system is effective.

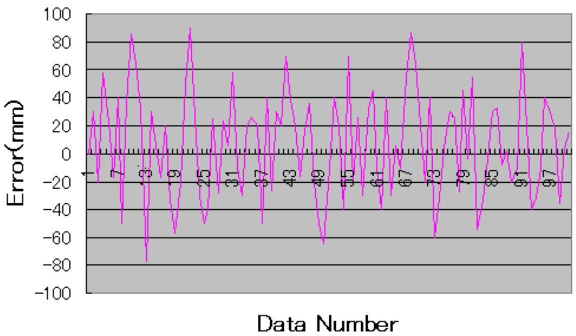

Fig. 5. Prediction Error

V. CONCLUSION

In this research, an virtual model based teleoperating system is developed for an underwater robot environment. The experiment results show this system is workable in performing a time-limited task under 2000 milliseconds time delay.

A virtual model based graphically user interface has been utilized in this teleoperating system. The emphasis of such a system is the incorporation of a virtual model of the real robot and environment to assist the operator in controlling the underwater robot through Internet. Not only does the virtual model GUI allows the operator interact with the virtual model by an intelligent mean, but also provide an effective visual display for the real environment.

An on-line Parameter estimated method is explored in this research. It is an effort to overcome the unavoidable time delay happened in the system. The investigation result shows that the algorithm is successfully used to characterize the behavior of predictor.

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