Force Simulation in Telerobotic System with Large Time Delay

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ABSTRACT
This paper introduces a telerobotic system. In this system, a distributed delay-compensating 3-D stereographic simulator is implemented in SGI ONYX/4 RE[2] with SPACEMOUSE, HMD devices, Sirius Video. Estimated Force Emulation can protect the real robot in time from being damaged in collision. A two hand six DOF master arm with force feedback interface is used in the controller. The simulation of free-floating manipulator is achieved in this system. The command sequences are generated at the same time with the movement of the simulating robot and are sent to the real robot after the simulating time delay. The images gotten from the camera are sent back to make overlapping to the simulating robot with time delay. Virtual reality technology and shared control are supported in this system. Some basic tasks are accomplished by controlling PUMA560 robot.

1. INTRODUCTION

For humans to expand permanently into space, teleoperated robots can function indefinitely in space environment. Teleoperation allows humans to participate intimately yet safely in taming the space environment. Technologies for ground-remote telerobotics have been developed to support ground-based control of space-based robots. Communicate time delay between the local site operator control station, where the operator resides, and the remote site robot control system is a significant factor for ground control telerobotics. A round-trip delay of several seconds or more is expected. The time delay precludes control mode which require closed loop control between the local and remote sites. The operator can not operate the remote site robot in time according to the video image. An alternative method is to generate command sequences through interaction in a local graphical environment. By simulating the real remote site robot and environment, we can control remote robot easily and efficiently. We introduce distributed system in Section 2.

The Estimated Force Emulation, which is used to protect the real robot in time from being damaged in collision, is introduced in Section 3.

In section 4, a simulation of free floating manipulator is presented.

To verify the control effect, a method is needed to resolve the mapping problem between the simulating robot and the real robot. And the graphical environment is connected to the PUMA560 robot. One camera are placed in front of the real robot to take the images and send them back to make overlapping with the graphical robot. This part will be described in Section 5.

In Section 6, a two hand six DOF master arm with force feedback interface is introduced, two robots can be controlled by this machine.

This system was used to control PUMA560 robot to perform some basic tasks, this will be introduced in Section 7.

2. Distributed Simulation System

As a trend, the calculation occupies more and more resources in emulation systems. In order to take full advantage of 3D Graphics Systems' preponderance on direct graphic interface, we designed the emulation system as distributed system. The functions that needs a lot of calculations include robot kernel emulation, collision detection and estimated force emulation. By assigning these functions into different high-end PCs, we can ensure the quality of 3D graphs. We chose TCP/IP as the network protocol because the system may be

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heterogeneous. We use a central computer to synchronize all the computers and I/O devices in the system.

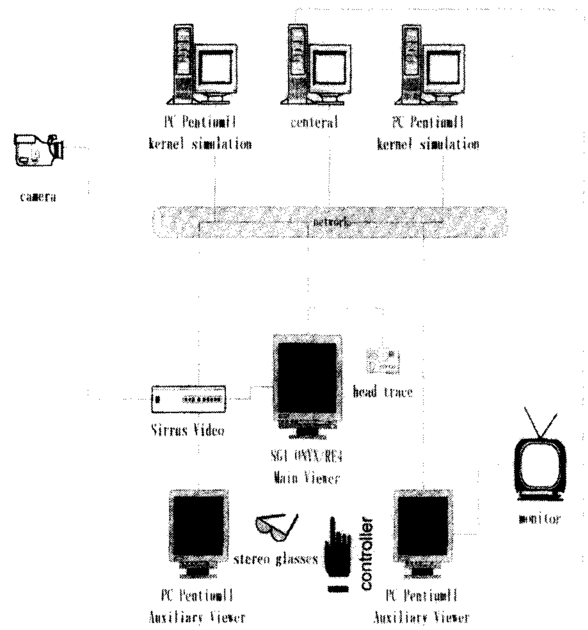

Fig. 1 System Framework

The centeral computer is in charge of following service:

1. Declaration Management. Allow members to specify the types of data they will send or receive by object class and attribute name.
2. Object Management. It supports creation, modification, and deletion of objects.
3. Time Management. It control advacement of system members along with centeral time.
4. Ownership Management. Allow system members to transfer ownership of object attributes.
5. Data Distribution Management. Allow system members to specify the distribution conditions for the specific data they send or expect to receive.

Virtual Reality technology is supported. WTK is used to deal with the VR programming. Three-dimensional stereo glasses are used to get 3-D stereograph. The SPACE MOUSE is used to control the simulating robot in the environment.

3.Estimated Force Emulation

The main purpose of Estimated force emulation is to protect the real robot when collision occurs. When the robot collides with some obstacles, operator should be able to detect the right direction of this collision from the hand controller with force feedback so the further damage to the robot can be avoided. When the system detects collision, it calculates the mutual force between these two objects. Then the system will calculate the equivalent force on the tip of the robot from the forces we just got, and finally, it will reflect the size and direction of the force to the hand controller with force feedback.

According to the robot's DH parameters, the transformation matrix form the coordinate which fixed on the joint i-1 to the coordinate which fixed on the joint i is:

$$^{i-1}A_i = \begin{bmatrix} \cos(\theta) & -\cos(\alpha)*\sin(\theta) & \sin(\alpha)*\sin(\theta) & a*\cos(\theta) \\ \sin(\theta) & \cos(\alpha)*\cos(\theta) & -\sin(\alpha)*\cos(\theta) & a*\sin(\theta) \\ 0 & \sin(\alpha) & \cos(\alpha) & d \\ 0 & 0 & 0 & 1 \end{bmatrix}$$

Because of these matrixes, the accurate position of every point in every joint can be calculated. To improve the effect of simulation, the columns which are embodied to the joint are used for collision detect. Only if the column hits the obstacle, the accuracy plane collision detection is used to get the collision information and the load node. A ball obstacle is put into the test system.

We assume the manipulator is rigid, and the obstacles are linear elasticity.

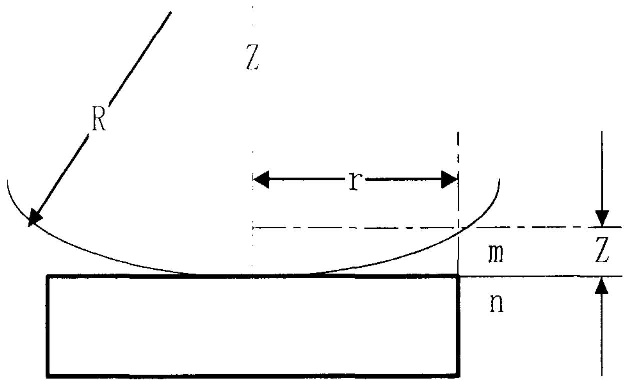

Fig 2 Mutual Force Analysis

$$z = \frac{r^2}{2R}$$

z is very small。

When the plane move toward the ball, the distance between plane and point M will become closer and closer. W is the displacement of the point M, which is caused by the distortion of the ball. The max displacement of the peak point in ball is d,

$$d - w = \frac{1}{2R} r^2$$

$$w = d - \frac{1}{2R} r^2$$

The interface between the plane and the ball is circle. The pressure density of the interface q is symmetry to the center point O of the interface。

$$w = \frac{(1-\upsilon^2)}{\pi E}\iint q\,ds\,d\psi$$

$$k_1 = \frac{1-\upsilon^2}{\pi E}$$

The radius of interface between plane and ball is a, and the press density in the center of the interface is q_0

$$q_0 = ka$$

The distribution of the press density is according to the hemisphere. The radius of the hemisphere is a.

$$k\iint q\,ds\,d\psi$$

$$= k\int \frac{q_0\pi}{2a}(a^2 - r^2\sin^2\psi)d\psi$$

$$\frac{kq_0\pi}{2a}\int_0^{\pi}(a^2 - r^2\sin^2\psi)d\psi = d - \frac{1}{2R}r^2$$

$$\frac{kq_0\pi^2}{4a}(2a^2 - r^2) = d - \frac{1}{2R}r^2$$

For every r, the equations are true. Then a and d must suit for following equations.

$$\begin{cases} d = \dfrac{kq_0\pi^2 a}{2} \\ a = \dfrac{kq_0\pi^2 R}{2} \end{cases}$$

$$a = \sqrt{dR}$$

$$q_0 = \frac{2\sqrt{d}}{k\pi^2\sqrt{R}}$$

$\frac{q_0}{a} = \frac{2}{kR\pi^2}$ is the scale constant of the press density distribution.

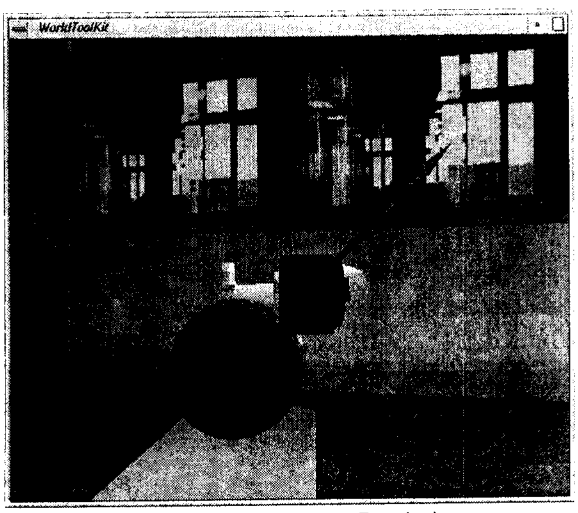

Fig3 Estimated Force Emulation

According to those formulas, the direction and the value of the mutual force can be determined. It shows in Fig 3. The arrow in the fig 3, identifies the direction, value of the mutual force and the load node.

4. FREE FLOATING MANIPULATOR SIMULATION

When the quality of base is close to the quality of manipulator, the movement of manipulator will cause the movement of base in aerospace. According to the convert from free-floating manipulator to manipulator with fixed base, the coupling between base and joint can be resolved. The convert method is standard model transition method, which is called as dynamics equal manipulator (DEM). The kinematics of free-floating manipulator can be achieved. The simulation images are followed.

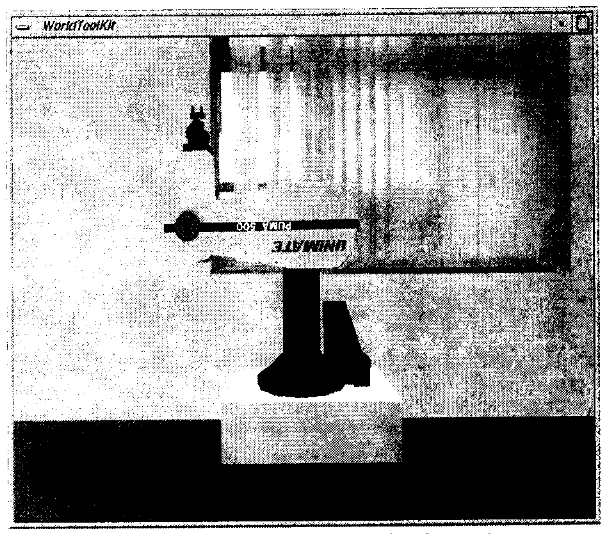

Fig4 Free Floating Manipulator 1

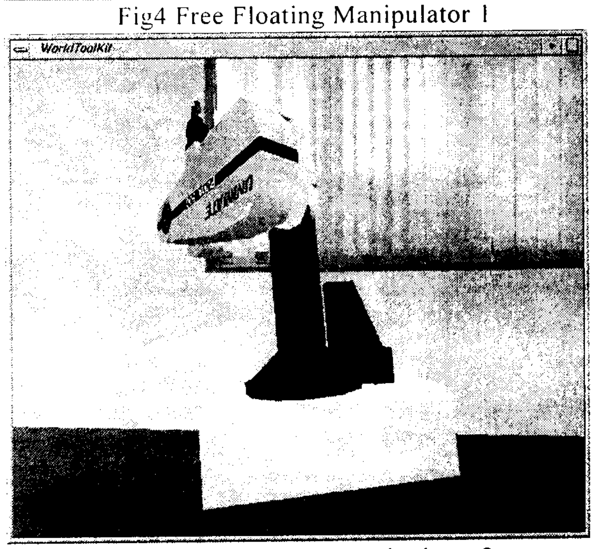

Fig5 Free Floating Manipulator 2

5. TO VERIFY THE CONTROL EFFECT

In Space Remote Operating Robot System, the transmission delays between space robot and ground station are always changing according to the variation of the environment. This inconsistency forbids us from using a constant to make the one-to-one mapping between emulated robot data and actual robot data. To solve this problem we attached a timestamp T to both upper-bound and lower-bound data. In upper-bound data, this parameter indicates in T seconds after the space robot received the first operating code, its position and attitude must fulfill the requirement that is contained in the code. In lower-bound data, this parameter means in T seconds after the space robot received the first operating code, its position and attitude is kept in this group of data. We now can get the one-to-one mapping of emulated robot data and actual robot data by this parameter T.

The PUMA560 robot was connected to the graphical environment. The graphical robot and the real robot have the same structure, so the joint-to-joint control is used to control the real robot. When the simulating robot move, the command was sent to the real robot after the simulating time delay to control the real robot to move as the simulating robot.

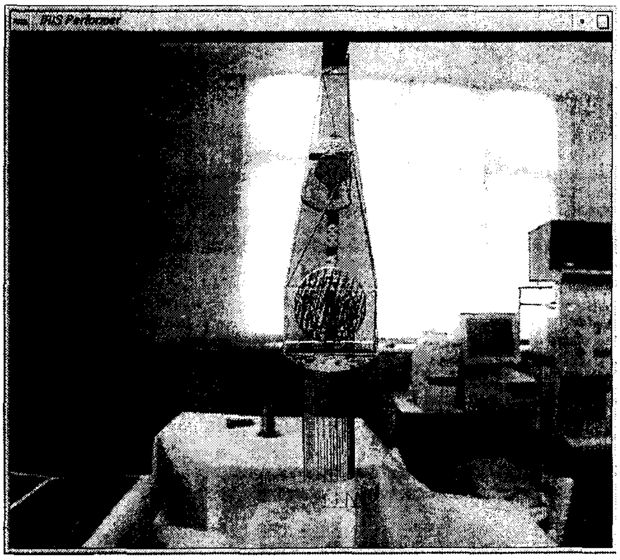

Fig. 6 Overlapping between image and graph

To do overlapping between the image and the graph, we should first calibrate the camera and demarcate the viewpoint and then to overlap the graphical robot on the image. In the Fig. 6, the background is the image gotten from the camera in real time. The frame drawn by line is the graph of the simulating robot created by the computer. If the frame can overlap the image of the real robot all the time, we can say the control is successful.

6. SIX DOF MASTER ARM WITH FORCE FEEDBACK INTERFACE

The structure of the master arm is STANFORD structure, and the type is RRPRRR. It is universal hand controller. To compare with PPPRRR master arm, its structure is quite simple, but the control system must calculate kinematics. Because the structure of the master arm is different to the structure of PUMA 560, then we control the end of the PUMA 560 to trace the movement of the master arm. And it can accept the Estimated Force Emulation information through force feedback interface.

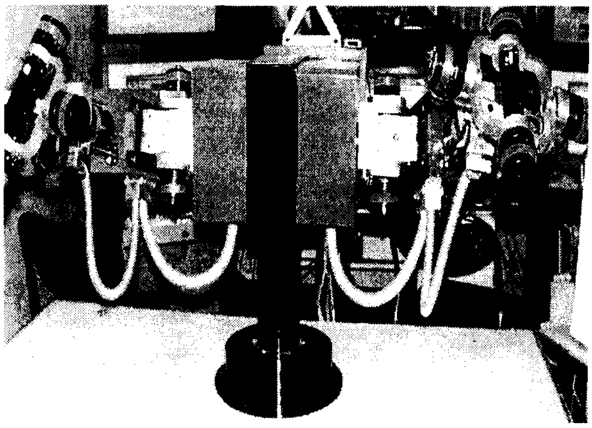

Fig 7 Six DOF Master Arm

7. THE BASIC TASKS

The system was used to perform the following tasks:

1. plug a pole into a hole
2. assemble a structure from several identical cube parts
3. two arms grasp an object together
4. two arms to do plugging operation coordinately

In the tasks, the real robot could repeat the graphical robot's movement after the simulating time delay. The frame of the graphical robot can cover the image of the real robot all the time. The result is successful.

8. CONCLUSION

Many aspects of robotics were integrated into the system. Key technologies of the system have been:

1. High quality graphical simulation, the model was displayed with texture.
2. Distributed Simulation System.
3. Estimated Force Emulation.
4. Free Floating Manipulator Simulation
5. Six DOF master arm with force feedback interface
6. By adjusting and overlapping of the camera images and the computer graphs, the effect of the control can be judged.

To improve the performance of the system, many technologies and methods will also be used into this system such as share control, etc.

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