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TELE-EXISTENCE MASTER SLAVE SYSTEM FOR REMOTE MANIPULATION

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ABSTRACT: A tele-existence master slave system for remote manipulation experiments is designed and developed, and an evaluation experiment of a tele-existence master slave system is conducted. By making a comparison of a tele-existence master slave system with a conventional master-slave system, efficacy of the tele-existence master slave system is verified and the superiority of the tele-existence method is demonstrated quantitatively.

INTRODUCTION

Tele-existence aims at a natural and efficient remote control of robots by providing the operator with a real time sensation of presence. It is an advanced type of teleoperation system which enables a human operator at the controls to perform remote manipulation tasks dexterously with the feeling that he or she exists in one of the remote anthropomorphic robots in the remote environment, e.g., in a hostile environment such as those of nuclear radiation, high temperature, and deep space. Much effort has been made for the development of tele-existence [1-5] or telepresence [6-8] through the feedback of rich sensory information which the remote robot has acquired to provide the operator with a real-time sensation of presence.

In the previous reports [1, 2], the principle of the tele-existence sensory display was proposed. Its design procedure was explicitly defined. Experimental visual display hardware was built, and the feasibility of the visual display with the sensation of presence was demonstrated by psychophysical experiments using the test hardware. A method was also proposed to develop a mobile tele-existence system, which can be remotely driven with the auditory and visual sensation of presence. A prototype mobile tele-vehicle system was constructed and the feasibility of the method was evaluated [2]. The principle of active power assistance was applied for controlling the visual display with two degrees of freedom [3, 4]. In order to study the use of the tele-existence system in the artificially constructed environment, the visual tele-existence simulator was designed, a quasi-real-time binocular solid model robot simulator was made, and its feasibility was experimentally evaluated [5].

In this paper, a tele-existence master slave system for remote manipulation experiments is designed and developed, and an evaluation experiment of tele-existence is conducted. By conducting an experiment comparing a tele-existence master slave system with a conventional master-slave system, efficacy of the tele-existence master slave system and the superiority of the tele-existence method is demonstrated quantitatively.

TELE-EXISTENCE MASTER SLAVE SYSTEM

The tele-existence master slave system consists of a master system with a visual and auditory sensation of presence, computer control system and an anthropomorphic slave robot mechanism with an arm having seven degrees of freedom. The operator's head movement and right arm movement are measured by the master motion measurement system in real time without constraint. The measured head motion signal and arm motion signal are sent to the two computers, respectively. Each computer generates the command position of the slave head movement or the arm movement of the slave robot. The servo controller controls the movement of the slave anthropomorphic robot. A specially designed stereo visual and auditory input system mounted on the neck mechanism of the slave robot gathers visual and auditory information of the remote environment. These pieces of information are sent back to the master system, which are applied to the stereo display system to evoke sensation of presence of the operator.

Slave System

Figure 1 shows a general view of the anthropomorphic slave robot designed and developed. The slave robot has a three degree of freedom neck mechanism on which a stereo camera is mounted. It has an arm with seven degrees of freedom, and a torso mechanism with one degree of freedom (waist twist). The robot's structural dimensions are set very close to those of a human [4]. The weight of the robot is 60 kg. and the arm can carry a 1 kg load at the maximum speed of 3 m/s. The precision of position control of the wrist is ± 1 mm. The dimensions and arrangement of the degree of freedom of the robot are designed to mimic those of the human being. All three axes of the neck rotations meet at one point 50 mm above and 245 mm apart from the point where all three axes of the shoulder rotations meet. The two axes of the wrist and the two axes of the elbow are also designed to meet at one point, respectively. The motion range of each degree of freedom is set so that it will cover the movements of a human, while the speed is set to match the moderate speed of human motion (3 m/s at the wrist position).

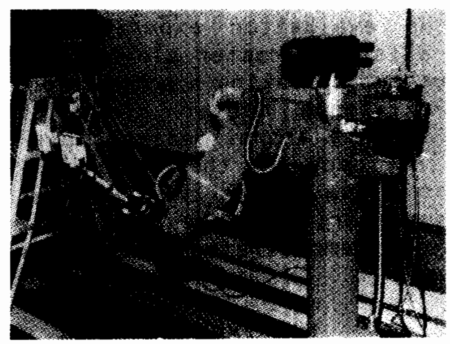

Fig. 1 General view of the anthropomorphic slave robot.

A combination of a D.C. servo motor and a harmonic drive reduction mechanism is used as an actuator for each joint except the elbow extension/flexion, which includes conventional gears. The location of the motors is designed so that the appearance of the arm resembles a human arm as closely as possible, and the range and the speed of the manipulator satisfy the necessary specifications.

The model-based control method of the type in which the model-based portion of the control law is outside the servo loop is used in this experiment. The actual servo system is shown in Fig. 2. The computer generates a pulse sequence to assign the desired position, and the position control is conducted by counting the difference between the computer generated pulse and the measured pulse from an encoder. Angular velocity is estimated by using a frequency-voltage converter. Feedforward compensation is conducted by a compensation filter as shown in Fig. 2.

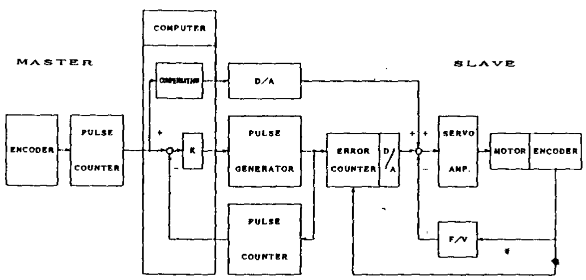

Fig. 2 Block diagram of the control system.

The vision system of the slave robot consists of two color CCD video heads of the TV cameras. Each CCD has 420,000 pixcells and has its optical system with a focal length of f=15 mm and an aperture of F 1.6. Focus is automatically controlled by the TTL AF method. The separation of two cameras are set at the distance of 65 mm, and the two cameras are aligned parallel. As for the auditory system, two microphones are placed 243 mm apart from each other, and the same locational relation is used for the auditory display of the master system.

Master System

Figure 3 shows a general view of the tele-existence master system and Fig. 4 shows the schematic diagram of the mechanism of the system developed. A human operator wears a stereo audio visual display with a sensation of presence. The audio visual display is carried by a link mechanism with six degrees of freedom. The link mechanism cancels all gravitational force through a counter balancing mechanism with a relatively wide range of operation (up/down: -500 ~ 400 mm; right/ left: -300 ~ 300 mm; forward/ backward: -300 ~ 800 mm). It also enables the display to follow the operator's head movement precisely enough to ensure his/her ordinary head movement. Maximum measured inertial force is within 5 kgf. The master arm consists of ten degrees of freedom. Seven degrees of freedom are allocated for the arm itself, and an additional three are used to comply with the body movement.

Fig. 3 General view of the tele-existence master system.

Figure 5 shows the principle of the gravitational cancellation mechanism. In the parallel link mechanism of Fig. 5, balance weights m_2 and m_3 and lever lengths d_1, d_2, d_3 and d_4 are

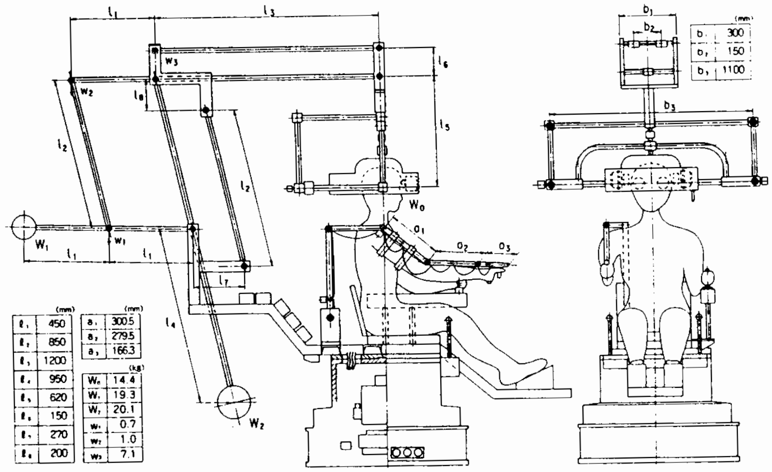

Fig. 4 Schematic diagram of the tele-existence master system.

suitably chosen so that the center of gravity always remains at the pivot position P regardless of the movement of the load m_1.

The direction of A-A' is always kept perpendicular to the floor regardless of the movement of the load m_1 by using other parallel link mechanisms shown in Fig. 3 (AA'-BB' and BP-QR). In the parallel mechanism of AA'-BB', AA' = BB' and AB = A'B', while in BP-QR, QR = BP and Figure BXQ ≡ Figure PYR.

The above consideration is for the two dimensional movement in sagittal plane (i. e., up/down and forward/ backward). As for the horizontal movement (left/right), another parallel link mechanism with three bars and a universal joint mechanism shown in Fig. 4 are introduced, which resolve the motions constrained in the sagittal plane and the motion of the sagittal plane per se. As for the former motion, the aforementioned mechanism realizes the stable orientation of A-A', while the two upper links of the three link mechanism ensure the stable orientation regardless of the movement of the sagittal plane.

As for the rotational movement, the three directional rotational mechanism whose three axes meet at one point is used. Parallel link mechanisms are also used to attain the twist movement and also for the load bearing. The arrangement of the degrees of freedom is made so that the most important part movement can be attained at any orientation.

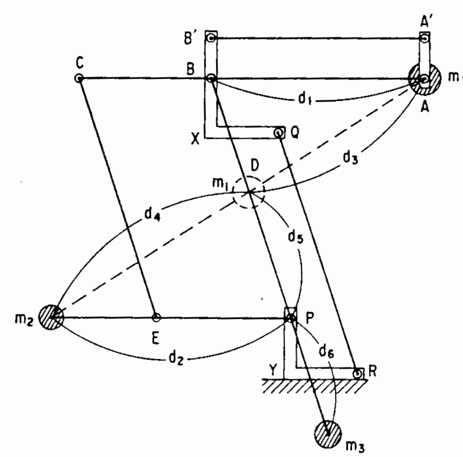

Fig. 5 Parallel link mechanism.

Stereo visual display is designed according to the developed procedure which assures that the three dimensional view will maintain the same spatial relation as by direct observation [1, 2]. Adding to the fundamental design procedure, an optical system using polarizers and analyzers was introduced to eliminate the unnecessary reflected image by the internal mirror. This made possible the compact arrangement of the display system (See Fig. 6 and Fig. 7).

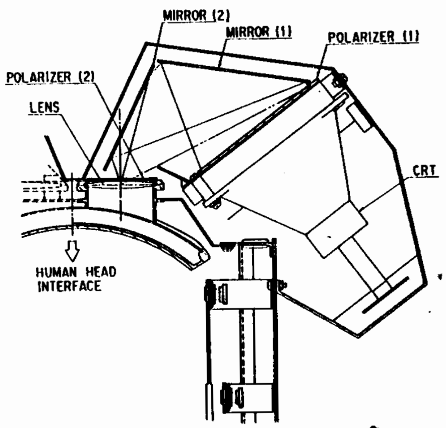

Fig. 6 Visual display design (right eye side).

Fig. 7 General view of the display.

EXPERIMENTS

Two main characteristics of tele-existence master-slave system are:

(1) Natural three dimensional vision (close to direct observation), which follows an operator's head movement in real time,

(2) Natural correspondence of visual information and kinesthetic information, i.e., an operator observes the slave's anthropomorphic arm at the position where his/her arm is supposed to be.

In order to evaluate the effect of the above features on teleoperations quantitatively, the following three operation schemes were compared.

(a) Operation using the tele-existence master slave system,

(b) Operation using the tele-existence master slave system without stereo effect.

(c) Operation using a conventional color TV display.

The operation task is to insert a bar into four torus targets placed randomly in the work space. Their distances from the operator and orientations are set randomly. The comparison was made for the time elapsed to insert the bar into four tori sequentially (see Fig. 1).

Figure 8 shows the result for four subjects. In spite of the differences between the subjects, common tendency is quite clear. For all subjects (b) is about 30 percent better than (c). This is due to the effect of the feature (2) of the tele-existence. Scheme (a) is about 20 percent better than (b), which indicate the effect of the feature (1).

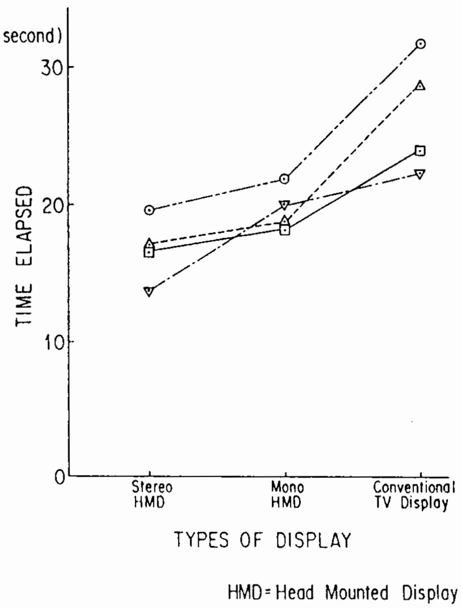

Fig. 8 The experimental results.

By conducting this experiment comparing the tele-existence master slave system with the conventional master-slave system, efficacy of the tele-existence master slave system was verified and the superiority of the tele-existence method was demonstrated quantitatively.

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