Mechanism of an Anthropomorphic 7-DOF Slave Arm for Telexistence

Riichiro Tadakuma, Ichiro Kawabuchi, Hiroyuki Kajimoto, Naoki Kawakami, and Susumu Tachi
Graduate School of Information Science and Technology, The University of Tokyo
7-3-1 Hongo, Bunkyo-ku, Tokyo, 113-8656, Japan
Phone: +81-3-5841-6917 FAX: +81-3-5841-8601
E-mail: {tadakuma, kaji, kawakami, tachi}@star.t.u-tokyo.ac.jp

Abstract

We developed the robotic arm for a master-slave system to support "mutual telexistence," which realizes close physical communication with other people using gestures and remote dexterous manipulation tasks. In this paper, we describe the specifications of the experimental setup of the slave arm for demonstration of the feasibility of the mutual telexistence concept.

1 Introduction

We have been progressively moving towards the conclusion of a complete anthropomorphic seven degrees of freedom (7-DOF) redundant arm for a master-slave system to support "mutual telexistence," which is the concept of presenting the realistic sense of presence of a robot's operator to a remote location. This area of field robotics places special demands on the system because it must be endowed with human-like shape and movement, and is also safe for use in everyday environments with ongoing human contact. We describe here the mechanism design and feasibility evaluation.

2 Previous Work

Many anthropomorphic 7-DOF redundant arms of humanoid robots have already been designed and built to replicate human skills. One of the first was the "Extreme Condition Working Robot" of Mitsubishi Heavy Industries LTD. for the Japanese National Project on Advanced Robot Technology [1]. Another example was the MIA arm of Waseda University [2], designed to realize compliant motion.

Two of the full-size humanoid robot systems from Honda, called P2 and P3, have anthropomorphic 7-DOF arms [3]. H6 and ISAMU built by the University of Tokyo and Kawada Industries, Inc. also have 7-DOF redundant arms [4]. However, these arms' first vertical yaw joints in their shoulders have a large offset to enlarge the motion space, so they are a bit different from normal anthropomorphic robotic arms.

Another example was built by SARCOS Research Corp. [5] The robot's body was anchored at the waist and most of its joints were actuated by hydraulic pumps using oil pressure, so it is infeasible to be used in field robotics tasks such as moving around in everyday settings.

The most recent example is NASA's Robonaut [6]. It is a human-scale manipulator designed to fit within the exterior volume of an astronaut's suit and to realize thermal endurance to cope with eight hours of Extra-Vehicular Activity (EVA).

3 System Details and Experimental Setup

3.1 Design of the arm

The arm was designed to be as light as possible in order to move quickly and to be safe for human use. By uniting the housing parts of harmonic drive gear system with other parts such as the rotational axes of joints, we made the whole mechanism of the arm very light. Moreover, by this design, we succeeded in making the arm mechanism as slim as the outer human arm. The distribution of the joints of the arm replicates the human arm's structure in order to make it easy to be operated by telexistence using kinaesthetic sensation. This structure is also useful for interaction with people without a sense of incongruity. A complete view of the arm is shown in Figure 1.

In order to confirm the validity of our slave arm's functions, we compared it with other anthropomorphic 7-DOF arms. For comparison, we chose designs whose specification details were released in references, and the three axes of joints in their shoulders and wrists cross at one point, just like the structure of the human arm. The result is shown in Table 1 (human data was taken from Refs. [7-9]). The degree values of this table are displayed considering the posture of Figure 1 as a neutral point.

Through this comparison, we confirmed that our new slave arm supports sufficient payload and speed for mutual telexistence using gestures, and since it is much lighter than existent arms, the potential danger of injury due to malfunction is also greatly reduced. At the same time, our slave arm has a larger mobility range in the joints above the elbow.

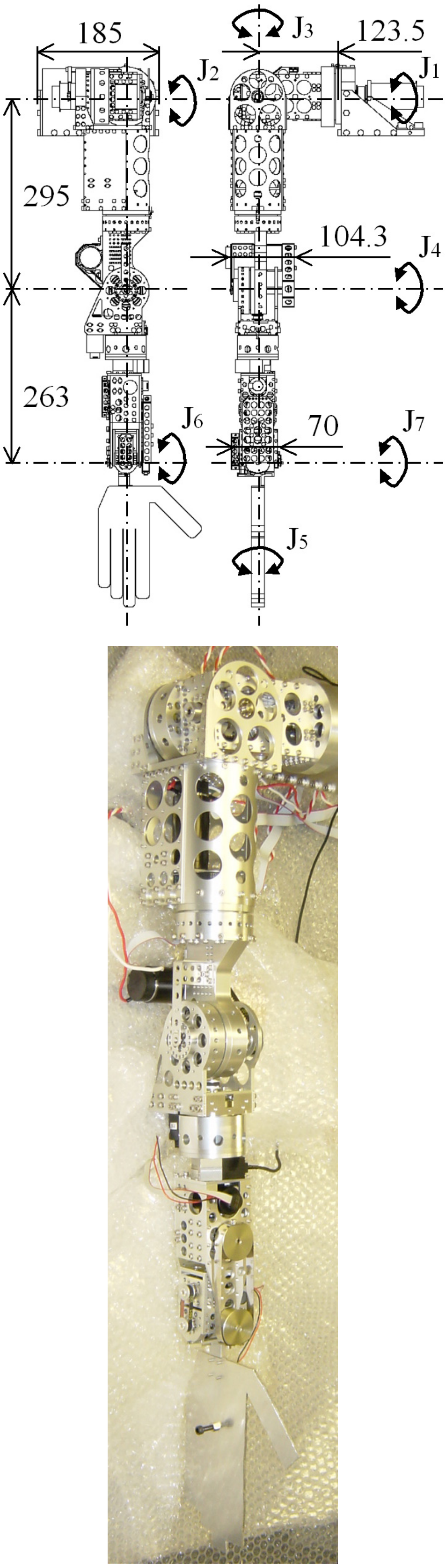

Figure 1 Complete view of the 7-DOF arm

Table 1 Comparing designs of the new slave arm

Robot			New slave arm (Human arm)	Mitsubishi Extreme Condition Robot	Waseda MIA arm
Weight [kg]			7.3	34.2	25
Mobility range [deg]	Shoulder	J1	-180/+180 (-60/+180)	-90/+180	-50/+180
		J2	0/+180 (0/+165)	-5/+165	-35/+90
		J3	-180/+180 (0/+100)	-100/+100	-90/+90
	Elbow	J4	0/+135 (0/+130)	0/+135	0/+125
	Wrist	J5	-180/+180 (0/+180)	-70/+220	-90/+90
		J6	-35/+35 (-35/+35)	-45/+85	-90/+75
		J7	-35/+35 (-35/+35)	-65/+65	-32/+32
Payload [kg]			0.5	5	0.5
Velocity [m/s]			1.2	2.8	1

3.2 Back-drivability of the joints of the arm

In the design sequence of the slave arm mechanism, a three-dimensional CAD system was used to measure the distribution of the moment of inertia and the position of the center of gravity of each arm component, in order to calculate precisely the torque needed to move each joint.

We also considered back-drivability of each joint, which is a critical aspect for a humanoid robot that has to interact with humans safely and to perform in everyday environments. To estimate the back-drivability, dynamics, power and endurance of each joint of the slave arms, we made an experimental joint with the same specifications as the shoulder of the slave arm. A complete view of the test joint is shown in Figure 2.

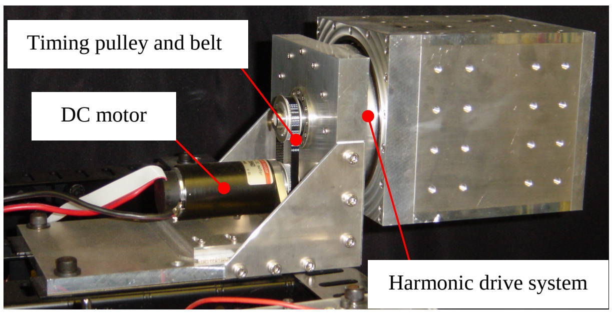

Figure 2 Experimental joint with harmonic drive system and DC motor

This joint has the same harmonic drive system and DC motor in each joint of the slave arm. The reduction ratio of the harmonic drive is 50. Through a test measuring the electric current of the motor and the power output by the joint model, we confirmed that the model has enough back-drivability to ensure safety for a communication robot and enough power to move the arm in the same way as a human arm. The test joint can provide 20.6 Nm of load moment and starts back-drive at 3.46 Nm with no backlash.

Thus, the reduction ratio of the harmonic drive of each joint of the slave arm was set to 50 to maintain back-drivability. The torque needed to back-drive the harmonic drive of each joint is estimated with the specifications table in the catalogue of the component and the result of the joint model test described above. Because of this back-drivability, we can measure the torque of each joint of the slave arm by monitoring the current that flows to the DC motor of the joint without any additional force sensors. After the calculations and experiments described above, we decided the power of the motor for each joint of the arm. The actuators for the arm are shown in Table 2.

Table 2 Actuators of the slave arm

Shoulder Motor	J1, J2	150 [W]
	J3	90 [W]
Elbow Motor	J4	90 [W]
Wrist Motor	J5, J6, J7	17.5 [W]
Reduction Ratio		50

The drive mechanism used for the pitch axis of the wrist is shown in Figure 3. The output shaft of the DC motor is input into the harmonic drive gear system through the timing belt and pulley. Because the output shaft of the harmonic drive system with a high reduction ratio is connected to the joint directly, the elasticity of the timing belt can be neglected. The same mechanism is adopted in all joints of the arm.

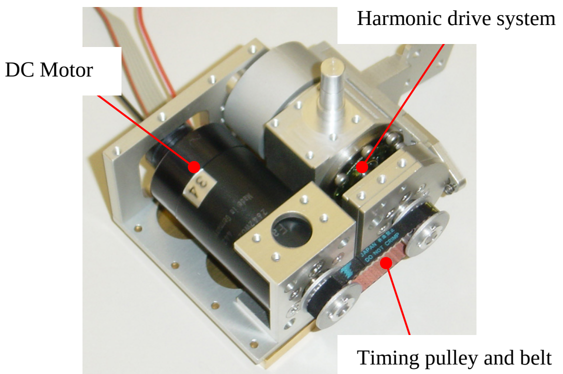

Figure 3 Drive mechanism used for pitch axis of the wrist

3.3 Mechanism of the wrist joints

A steel belt and pulley were used for the last rotational axis of the Roll joint of the wrist mechanism of the arm as shown in Figure 4, because the Roll joint has a large offset from the output shaft of the harmonic drive system that drives the joint, and a smaller backlash and higher rigidity and back-drivability than a timing belt is required for a mechanism after the output shaft of the harmonic drive system. This mechanism realizes all three axes of the wrist crossing at one point, just like a human wrist.

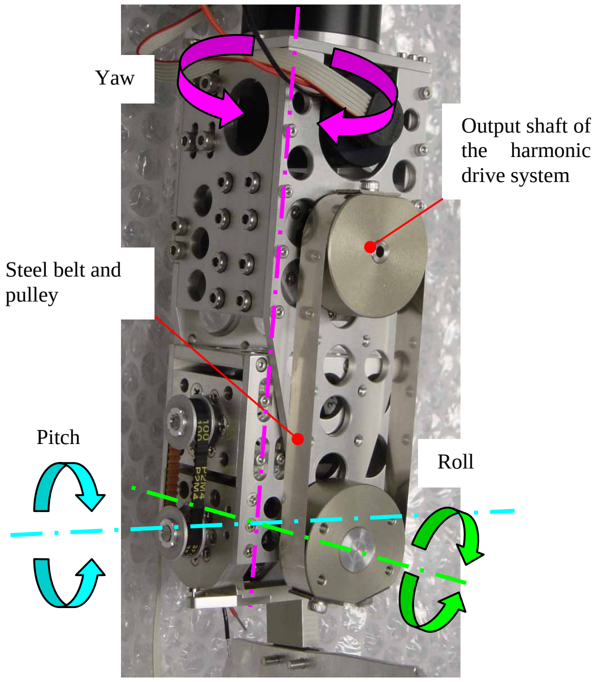

Figure 4 Mechanism of the wrist joints

3.4 Mechanism of the Pitch axis of the shoulder

Since the Pitch axis of the shoulder is a cantilever structure, we adopted angular contact ball bearings with pressurization at both ends of the rotational axis, in order to receive the thrust forces that work on the base of the Pitch axis as shown in Figure 5.

These thrust forces work at the base of the shoulder by decomposing the bending moment from the weight of the mechanism below the shoulder into a pair of forces, as shown in Figure 6.

This support mechanism realized the stabilized rotation of the Pitch axis of the shoulder.

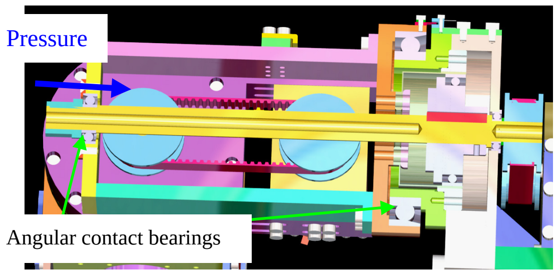

Figure 5 Position of angular contact bearings

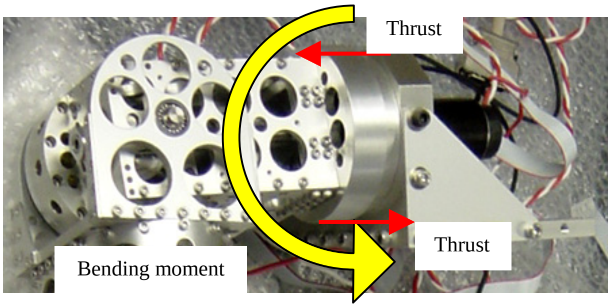

Figure 6 Forces on the Pitch axis of the shoulder

4 Control System

Figure 7 shows an overview of the control system for the arm. HPtec μSB-4A is adopted as a motor driver for each wrist actuator. μSB-10A is adopted for the actuator above the elbow joint, because 90W and 150W motors require more current than the motors in the wrist joints.

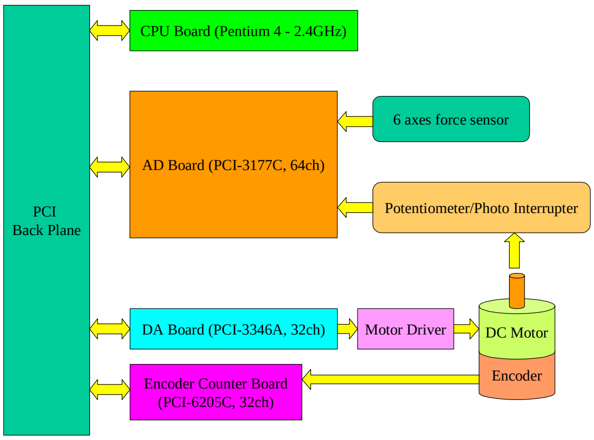

Figure 7 Control system for the arm

5 Conclusions

This paper described the mechanical design and development of the new anthropomorphic 7-DOF slave arm for Telexistence. It has enough degrees of freedom, joint angle range and torque to satisfy dynamic gestures for daily conversation and remote dexterous manipulation tasks. Further, the back-drivability of each joint ensures safe operation for human contact. In the near future, the robot will move and match its mechanical impedance according to the dynamic model of its operator's body. With this system, the operator will be able to move the robot in the remote place very smoothly, and "mutual telexistence" with a high sense of presence will become possible for both the operator and the remote observers.

6 Acknowledgments

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7 References

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