Study on Telexistence LXX:
- Position estimation of head, body and hand in Telexistence with an anthropomorphic slave robot -

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Abstract: In Haptic Telexistence, posture of the operator body, head and hand should be closely mapped to the slave robot in order to transfer realistic haptic sensation. However, present Telexistence robots do provide position accuracy, but due to the limited DOF, it is difficult to keep the same posture of each joint close to the operator. We introduce a 3 DOF head, 6DOF torso, 7 DOF arms in TELESAR V so that the individual joints can be kept in a close posture to the operators' at all time. This structure enables us to maintain a synchronized posture w.r.t to the operator even when he is moving his entire body and maintain the position accuracy by compensating with the upper arm as it cannot be seen through the robot eyes via a HMD. With auto stereoscopic vision, binaural audio and haptic sensation, operator can feel robot's head, body and hand, as his own. Thus can perceive his bodily consciousness is with the robot's body boundaries.

Key Words: *Telexistence, Haptic Telexistence, Robotics, Dynamic Trajectory Generation*

1. INTRODUCTION

Telexistence is a concept that refers to the technology, which enables a human to have a real-time sensation of being somewhere else than where he actually exists and to interact remotely with real or virtual environments [1]. In 1988, an exoskeleton type master-slave system [2] called TELESAR I was developed for performing remote manipulation experiments. In 2005, a mutual telexistence master-slave system called TELESAR II [3][9] was developed with human-like arm and hand movements. The system had the functionality to perform conventional bi-directional verbal communication with a remote participant as well as nonverbal gestures such as handshaking. In 2007, a TORSO with a head [4] was developed which can transfer visual information in a more natural and comfortable manner by tracking the head motion of a person with 6-DOF accuracy.

In general, humans experience the conscious self as localized within their bodily borders. Due to high level of spatial unity perceived with multi sensory inputs makes human to think that the body they see, and can feel touch is their own body. Also, re

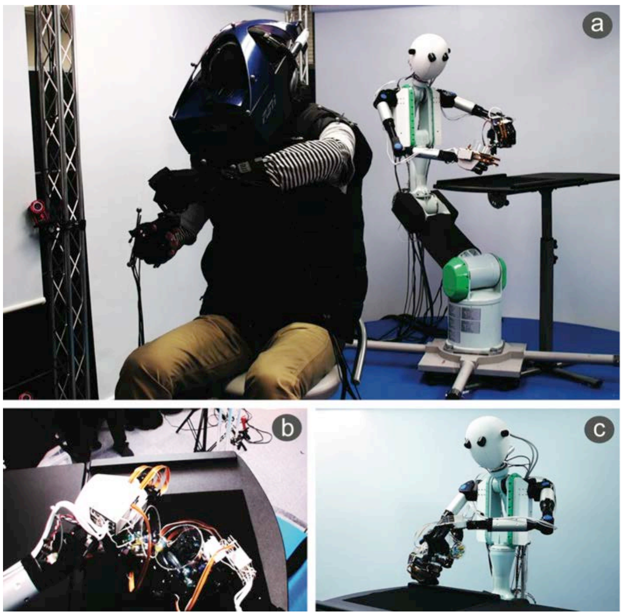

Fig.1. (a) Master-Slave configuration, (b) HD wide angle view, (c) Slave robot

searches have proved that if the same spatial unity is kept with a high level of multi sensory applied to a human, neurological conditions such as Rubber Hand Illusion (RHI) [5] and Body Transfer Illusion [6], [7] can be felt.

It has been evident from the previous telexistence research [2][3][4], if the operator can feel the slave robot as an expansion of his own body and ability to freely move and control the slave robot in a similar way to how his body moves, it will increase the throughput of the performed remote task. In addition with fingertip haptic and thermal sensation [10] synchronized with his kinematic model, operator can perceive a natural haptic sensation when touching objects remotely [12].

In order to achieve this requirement in telexistence, it is essential to have the following fundamental conditions satisfied.

1. Operator should be able to freely and independently move his head, upper body, arms and hands. In contrast, slave robot's hands should follow similar movements while maintaining 6 DOF accuracy of arm and head endpoint.
2. Robot trajectories should seamlessly maintain the exact vector from eye-to-hand to be same with operators'.
3. Operator should clearly see a wide-angle stereo view of the remote site and feel the robot vision is same as his own vision in a dynamic trajectory.

In order to address the above points, a slave robot with higher level of dexterity is necessary. We developed "TELESAR V", a telexistence master-slave robot system with a conjunction of 53 DOF to perform full body movements.

2. DESIGN CONSIDERATIONS

Conventional tele-operation system sometimes uses exoskeleton based master system [2][8] to capture the movements of operator. These systems limits the operator's movements to the exoskeleton system's mechanical constrains. Thus in order to satisfy the first condition, a non-mechanical, not direct attachable measurement system is necessary. This also gives full flexibility to move head, body and arms independently as desired.

In order to map the point-of-view and arm endpoint 6 DOF and to maintain the eye-to-hand vector, a higher DOF robot is necessary. Conventional dexterous robots [8] are not capable of achieving this due to not having enough DOF in the torso. A robot that can mimic similar spinal movements (extension, flexion, lateral flexion, and axial rotation) similar to a human is required as robot's torso. In order to address the above point both torso and an anthropomorphic robot arm should have minimum of 6 DOF. Furthermore robot's eye coordinates should be exactly following the operator's eye coordinates in order to feel that the robot vision is exactly a replicate of his [11].

We developed a system called "TELESAR V" that satisfies the above mentioned 3 conditions. As shown in Fig. 1(a) operator can freely move in his space while able to mimic the spinal movements and perform human-like body assisted stroke motion. As shown in Fig. 1(b) robot can maintain a 6 DOF point of view and arm endpoint accuracy so that the vector between the two points of vision and arm endpoint is seamlessly mapped to the operators same points.

3. IMPLEMENTATION

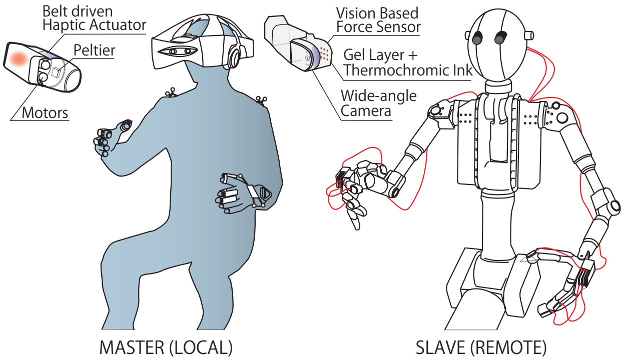

Fig. 2. TELESAR V: System Overview

As shown in Fig. 2, TELESAR V system consists of a Master (Local) and Slave (Remote) system. A 53 DOF dexterous robot is developed with 6 DOF torso, 3 DOF head, 7 DOF arms and 15 DOF hands. Robot also has Full HD (1920 × 1080 pixels) cameras for capturing wide-angle stereovision and stereo microphones situated on robots ears for capturing audio from the remote site. Voice from operator is transferred to the remote site and output through a small speaker installed on robots mouth area for conventional verbal bi-directional communication.

3.1 Development of 53 DOF human sized anthropomorphic robot

As shown in Fig. 3, TELESAR V slave robot consists of 4 main systems. (torso, head, arms and hands). Torso is developed based on a modified "Mitsubishi PA 10-7C Industrial Robot Manipulator" placed upright. First 6 joints of the manipulator arm is used as torso and last joint with a separately attached 2 DC motors are used as the 3 DOF (roll, pitch, yaw) head.

A custom designed 7 DOF human sized anthropomorphic robot arm is fixed between the Torso joints 5 and 6 to make it similar to human sized dexterous robot. In order to increase the level of dexterity of the slave robot arm, it is designed with similar limiting angles of each joints compared with ordinary human arm. However we have included a position based electrical limit overriding the mechanical limit to provide extra safety in case of a joint angle overshoot. Table. 1 shows the mechanical and electrical joint angle limitations in positive and negative direction.

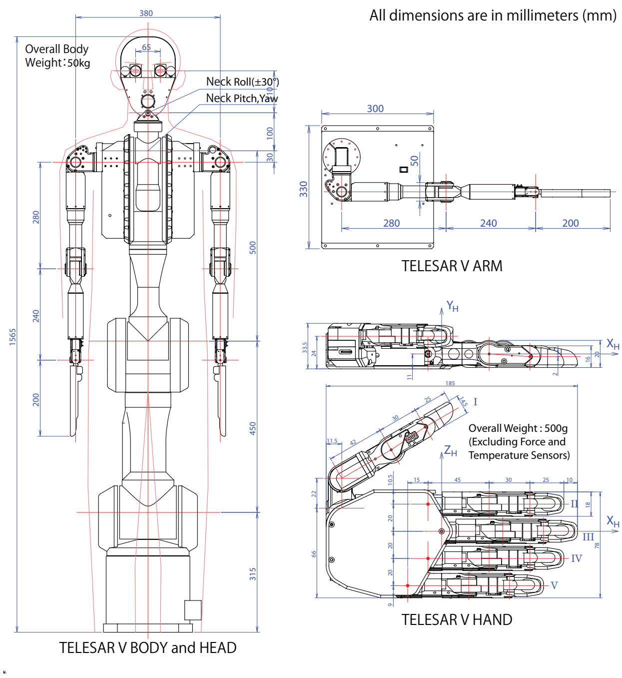

Fig. 3. Kinematic Configuration

Arm joints are driven with 12V DC motors and first 3 joints (J1, J2, J3) implements Harmonic Gears to maintain a very low backlash and vibration while provide the necessary torque. As for the hand, a custom designed human sized anthropomorphic robot hand is used. The hand is having similar number of joints compared to an ordinary human hand. 15 individual DC motors drive robots fingers and dynamically coupled using wires and a pulley driven mechanism couples the remaining joints that does not directly attach to a motor.

Table. 1. JOINT LIMITS OF 7 DOF ANTHROPOMORPHIC ROBOT ARM

Joint	Mechanical Angle limit		Electrical Angle Limit	
	Negative	Positive	Negative	Positive
J1	-90°	145°	-90°	+145°
J2	-100°	+20°	-100°	+18°
J3	-152°	+32°	-150°	+30°
J4	-135°	-2°	-130°	0°
J5	-93°	+93°	-90°	+90°
J6	-15°	+45°	-15°	+40°
J7	-45°	+60°	-40°	+60°

All the DC motors are connected to standard DC motor drivers with a combination of optical encoders and potentiometer reading as position feedback. Communication between the motor drivers and PC is carried out through a PCI-Express x1 bus.

3.2 Trajectory mapping Algorithm

In the trajectory generation for torso, first condition is to freely move without any constrains while robot should follow the operator's spinal movements (extension, flexion, lateral flexion, and axial rotation). This is achieved by modified numerical kinematics for 6 DOF serial-chain. In order to feel that the robot's point-of-view is exactly same as the operator's, following condition (Eq.1) has to be satisfied.

$$ {}^{w}_{sl-eye}T = {}^{w}_{ms-eye}T \quad \text{................(1)} $$

Secondly, when robot head, body and arms are dynamically moving, it is necessary to maintain the eye-to-hand vector seamlessly mapped between the operator to robot's. (Eq. 2)

$$ {}^{sl-eye}_{sl-hand}T = {}^{ms-eye}_{ms-hand}T \quad \text{................(2)} $$

This is kept tracked by dynamically generating the arm trajectories based on the slave robot's shoulder joint coordinate frame satisfying Eq. 3.

$$ {}^{sl-sh}_{sl-hand}T = {}^{sl-eye}_{sl-sh}T^{-1} \cdot {}^{ms-eye}_{ms-hand}T \quad \text{................(3)} $$

Apart from the above conditions, operator should see the robot's forearm vector similar to his own. However since operator cannot see his upper arm it is not necessary to maintain the same vector between shoulder to elbow. In the dynamic trajectory generation, any compensation is appended to the upper arm while keeping the forearm vector mapped.

3.3 Communication protocol for telexistence

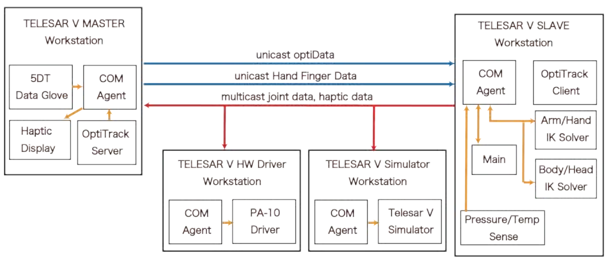

Fig. 4. Communication Architecture

When designing the telexistence master-slave platform, we had to consider a multi platform PC environment in order to support all the hardware limitations. Thus, it was necessary to share the same data among 4 workstations and synchronize the data with real-time. We have been trying UDP datagrams at the beginning, but it was slowing down the entire execution cycle of the PC due to rapid data receive. After lot of experiments, multicast and unicast was selected as the most efficient data transferring protocol. Each workstation has it's own shared memory which contains raw rigid body tracked data, finger bending data, joint space data and sensor space data etc… These data are real-time synchronized between 4 workstations as seen from Fig. 4. All the communication speed has a constant refresh rate of 1Khz because for our application it is not necessary to have a higher update rate. In order to preserve the higher details of tactile data and to keep a low latency, currently the setup is constructed in a way that it works on a local environment.

4. CONCLUSION

We have constructed a 53 DOF anthropomorphic robot for performing telexistence experiments. With a combination of 3 DOF head, 6DOF torso, 7 DOF arms in TELESAR V the individual joints can be kept in a close posture to the operators' at all time. Furthermore the eye-to-hand vector is seamlessly mapped between master and slave in order to keep the same viewpoint while maintaining the forearm vector similar to operators'. With this setup, we were able to transfer haptic sensation (force, tactile and thermal) in a more realistic manner. Furthermore, with auto stereoscopic vision, binaural audio and haptic sensation, operator can feel robot's head, body and hand, as his own. Thus can perceive his bodily consciousness is with the robot's body boundaries.

Note: Mechanical components of Arm, Hand and Head are developed in KAWABUCHI Mechanical Engineering Laboratory, Inc.

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