Study of Telexistence LXVIII
- Reaching a remote object with 6DOF point of view and arm endpoint accuracy -

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In Telexistence, point of vision through robot eyes and posture of the robot's hand should be in a close correlation in order to feel the extended body sensation and transfer realistic haptic sensation. However, present Telexistence robots mostly operate its torso in less than 4 DOF, thus it is difficult to map the vector between the point of vision to arm endpoint in operator to the same vector of slave robot. In order to address this issue we designed and developed TELESAR V, with a 5DOF torso and a 7 DOF arm attached to it so that the slave robot can have 6 DOF point of vision and 6 DOF arm endpoint accuracy with operator's posture. This structure enables the operator to freely move in his space and experience his extended bodily border while operating the robot and perform manipulatory task remotely. In addition ability to transfer the fingertip haptic and temperature sensation, operator can feel his bodily consciousness is extended to the robot.

Key Words: telexistence, haptics, 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 at a place other than where he actually exist, and to interact with the remote environment [1]. We have achieved human-like arm and hand movements in a Telexistence operation through TELESAR II [2] and human-like neck movements to visually interact and explore 3-dimensional details in a remote object through TORSO [3].

In case of an operator cannot reach a remote object in a telexistence operation, usually he will use the robot's mobile base platform to move [4, 5] sides/towards the object thru a joystick or similar technology because conventional robot upper body does not allow him to reach through his upper body. When this locomotive operation is performed, operator can see the robot's vision is being changed while he was kept on the same posture. Due to this conflicting visual feedback, operator confuse about the feeling of his body is attached to the slave robot. Thus, when grasping and touching objects in remote environment, operator cannot perceive the fingertip haptic sensation as his own fingers were touched.

In order to address the above situation two conditions has to be addressed. i.e point of vision and arm endpoint accuracy. We developed "TELESAR V" (as shown in Fig. 1) where the operator has to sit on a stationary chair and user's spinal, neck, head and arm movements are mapped into a dexterous slave robot and allows the operator to feel the vector between the point of vision and arm endpoint is similar to his own body vector between the same points. Furthermore we have added fingertip haptic and thermal sensation [6] when touching objects remotely. The ability to control the spinal, head and arm movements individually, it increases the level of dexterity in entire upper body.

Fig. 1 TELESAR V in a glass ball pouring Tele-operation

As a result of synchronized visual, auditory, and haptic sensation, TELESAR V makes the operator to feel the bodily consciousness is extended to the slave robot in a Tele-operation.

Also, been able to freely move the upper-body makes the operator feel that he is not restrained to a static body and increases the level of dexterity.

2. Related background study

Humans normally experience the conscious self as localized within their bodily borders. Due to high level of spatial unity perceived with multi sensory (audio, visual, kinesthetic and haptic) inputs makes human to think that the body they see, and can feel touch is their own body. Researches have proved that if the same spatial unity is kept with a high level of multi sensory applied to human, neurological conditions such as Rubber Hand Illusion (RHI) [7] and Body Transfer Illusion [8] can be felt.

3. Implementation

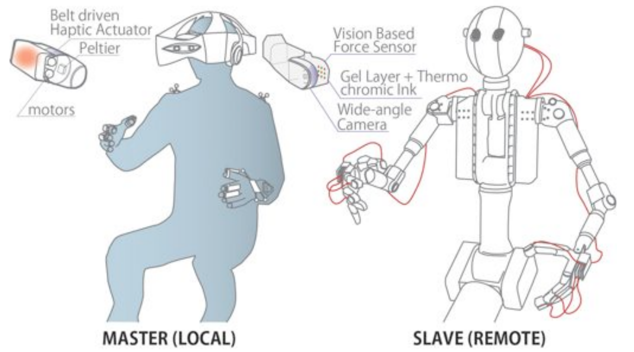

Fig. 2 TELESAR V, System Overview

As shown in Fig.2, TELESAR V system consists of a Master (Local) and Slave (Remote) system. A 54 DOF dexterous robot is developed with 5 DOF torso, 3 DOF head, 7 DOF arms and 16 DOF hands. Robot also has Full HD (1920 × 1080 pixels) cameras for wide-angle stereovision and stereo microphones situated on robot's ears as audio input from the remote site. Voice from operator is transferred to the remote site and output through a small speaker installed on robot's mouth area. Apart from bi-directional verbal communication, robot fingers have a vision based tactile sensor [11] to sense both force and temperature of robot fingertip.

In Master side, operator movements are captured using a motion tracking system (OptiTrack) and generates desired robot joint kinematics. Finger bending is captured with an accuracy of 5 DOF using "5DT Data Glove 5 Ultra". Operator perceives the visual sensation as seen from the robot through a HD (1280×800 pixels) wide angle Head Mounted Display (HMD). Remote fingertip proprioceptive sensation is reproduced using vertical and shearing forces excreted by two motor driven belt mechanism [12] while fingertip temperature is reproduced using thermoelectric actuators (Peltier) placed on the bottom side of operator fingertips.

3.1 Point of view (POV) and arm endpoint accuracy

In Telexistence, it is important to have the ability to see the remote site with the same point of view as if you would see with naked eye and change the point of view synchronous according to the head movements of operator. Furthermore approaching vector of the manipulator arm should be same as the operator lower arm vector in order to feel the arm is part of your extended body.

In human anatomy, wrist joint has a higher DOF compared to conventional robots. Similar to conventional robots, in TELESAR V wrist is restricted with 60 to 105 degrees respectively due to mechanical restrictions. In conventional robots, even though operator can reach a remote object with position accuracy, approaching orientation becomes different from the operators wrist.

Thus, in order to achieve a 6 DOF arm endpoint accuracy of under the mechanical limitations of the robot wrist, we use remaining DOF's of robot upper arm and torso to compensate the lower arm orientation error.

Since the 7 DOF arm is attached to the 5 DOF upper, the orientation of the upper body has a close relationship with the final arm endpoint accuracy. i.e if the robot torso does not follow the operator spinal movements it will reduce the level of dexterity of the slave robot. In order to overcome this situation we modeled the robot torso to follow the operator's all spinal movements (extension, flexion, lateral flexion, and axial rotation). This does not perform a exact match, but a approximate model so that the error can be compensated by using the remaining DOF's of torso. With correct shoulder center point and 3 DOF of Head, point of view is accuracy is obtained. Thus with the development of TELESAR V, above two conditions could be satisfied.

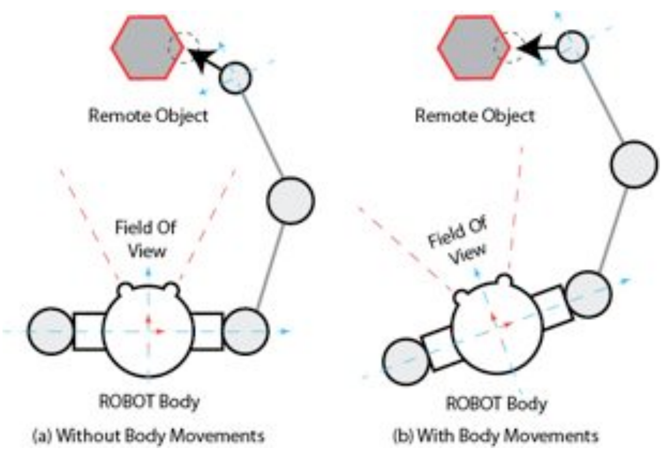

Fig. 3 Remote object's orientation accuracy obtained through body rotation (remote object position is fixed)

With this configuration, as shown in Figure 3(a), operator tries to reach the remote object through correct orientation, but due to the joint limitation of the wrist it is not possible. This kind of a situation is naturally resolved by humans by use of spine to rotate the body and approach using the extended right hand. As shown in Figure 3(b) with TELESAR V, such situation can be naturally resolved with the ability of rotating the robot's body synchronous with operator's spinal movements.

Any spinal movement of operator will result in recalculating the arm trajectories to compensate both position, orientation and maintain good endpoint accuracy. Thus, it can compensate on both horizontal and vertical planes giving operator to move in x-y and x-z planes. With this setup, we have achieved a high level of dexterity and less complexity in object manipulation.

4. Tele-Operation scenarios

Due to the independent control mechanism of TELESAR V head body, arms and hands it defines many new interactions in Telexistence.

4.1 Body compensated hand movements with fixed head orientation.

As shown in Fig 4(a) conventionally when the operator is not able to reach a remote object by fully stretching the arm, he needs to move the robot base close enough to reach in it's fully extended arm. But TELESAR V can rotate its body with an axial rotation as shown in Fig 4(b) and extends the reach easily. This eliminates the use of moving the robot base and preserves the human natural body movements. In addition operator can see the remote object clearly and does not need to change his head orientation while taking the axial rotation.

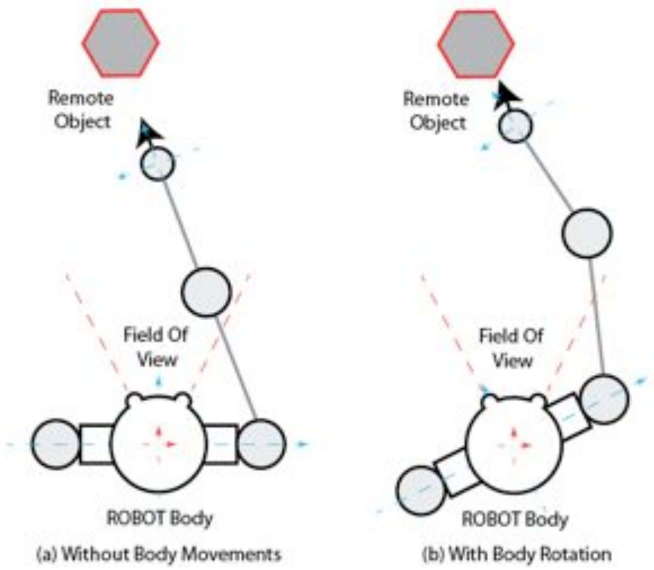

Fig. 4 Axial rotation of body helps to extend the reach.

4.2 Body compensated hand movements with dynamic head orientation.

Sometimes operator needs to explore the grabbed objects carefully before or after picking it up. (For example picking up a chemical container and reading the label). In a similar situation, humans will naturally use a combination of head and arm movements to rotate and explore the entire 360-degree rotation. The operator can move his body and head around to explore while preserving the approaching vector of the hand. As shown in Fig. 5, a similar scenario can be executed with TELESAR V by first keeping arm end posture fixed and move the body and head around.

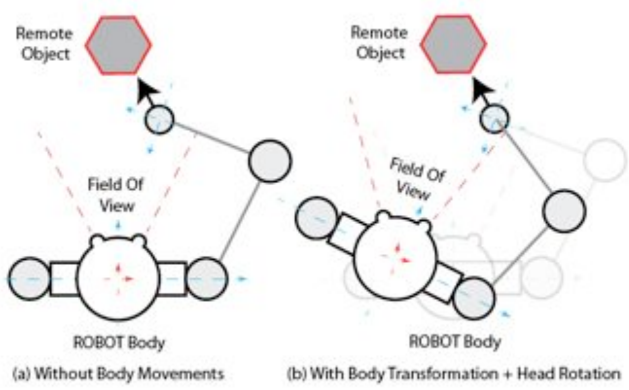

Fig. 5 Expanding field of view through combined body and hand movements.

4.3 Active compliant force

When manipulating objects humans usually use their body as a support structure for arms and legs. (i.e back muscle supports the arm movements.) It helps to generate impulse forces when necessary. Similarly as shown in Fig .6 in human anatomy the operator can induce an accelerated force at the end point by a combined movement of body and arms. This is not possible if the combined forces have a delay or if the body and arm has different posture from the operator.

As shown in Eq. 1 the tangential force element created by the body rotation adds to the arm trajectory and accelerates the end point movement. These accelerations help to generate stroke and impulse motions.

$$F_{resul} = F_{arm} + F_{body} \times \cos(\theta) \quad \ldots\ldots\ldots. \quad (1)$$

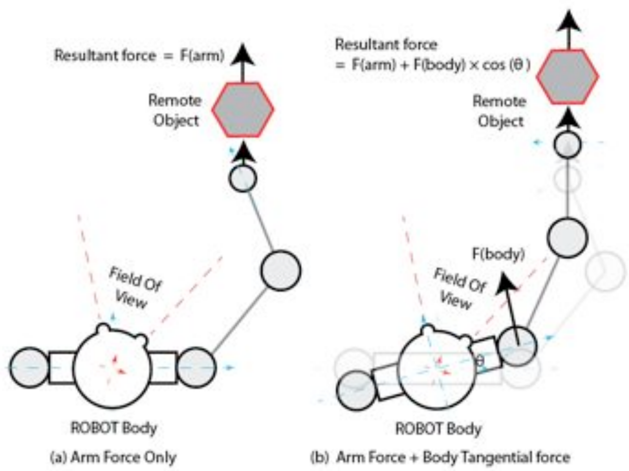

Fig. 6 Combined motion results in accelerated force

With the use of active compliant force, TELESAR V can draw Japanese calligraphy. When performing the above operation, operator was able to use his body and arm separately (Fig. 7) to maintain a fine brush strokes.

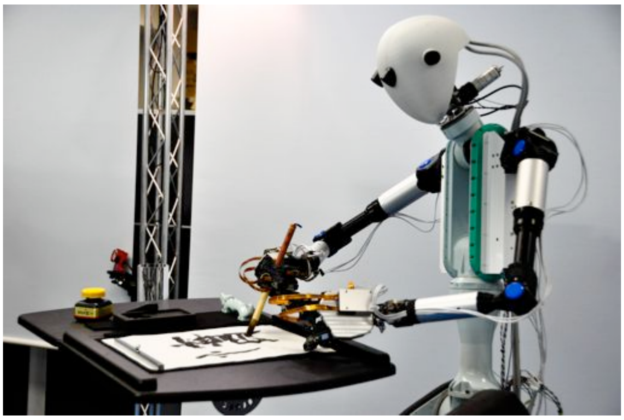

Fig. 7 TELESAR V, drawing Japanese Calligraphy

4.4 Haptic sensation with 6 DOF end point accuracy

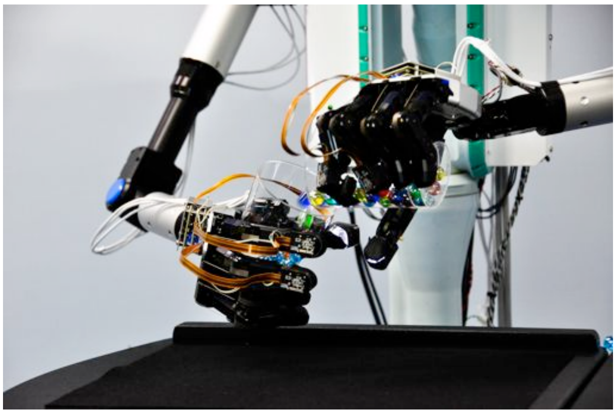

Fig. 8 Haptic Sensation when pouring glass balls.

With all the above enhancements enabled we have performed few tests to explore how the haptic sensation enriches in a Telexistence operation. As shown in Fig. 8, Operator grabs 2 cups placed on the table and pours the glass balls from one to another. In this experiment operator cannot only explore the above explained scenarios of body and arm movements, but also can feel the tactile feedback generated when glass balls hit the cup. The ability to see the glass balls falling, hear the sound of glass ball hitting the cup and feel the haptics sensation makes the operator feels that he is inside the robot and perceive that his bodily consciousness is extended to the remote slave robot.

5. Conclusion

With TELESAR V Telexistence system we have been able have an exact mapping of robot's vision point of view and arm endpoint between the operator and slave robot. Furthermore the ability to freely move and use spinal movements increased the level of dexterity in entire upper body and perform human like motion. With this configuration and ability to feel the multiple sensor inputs at the same time, operator forgets his own body and feels that he is inside the robot. Furthermore he can feel that his bodily consciousness is extended to the remote slave robot.

Acknowledgement

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References

[1] Tachi, S. "Telexistence" *World Scientific* 2010.
[2] Kawakami, N. and Sekiguchi, D. "TelesarPHONE - Communication Robot based on Next Generation Telexistence Technologies", *International Symposium on Robotics* (pp. 1-4), 2005.
[3] Watanabe, K., Kawabuchi, I., Kawakami, N., Maeda, T., and Tachi, S. "Torso: completion of egocentric telegnosis system", *ACM SIGGRAPH 2007 emerging technologies,* ACM, New York, NY, USA, SIGGRAPH '07. 2007.
[4] Tachi S., Arai, H., and Maeda, T. "Tele-existence master-slave system for remote manipulation", *Proceedings. IROS '90. IEEE International Workshop on,* 343 –348 vol.1. 1990.
[5] Bauml, B.; Schmidt, F.; Wimbock, T.; Birbach, O.; Dietrich, A.; Fuchs, M.; Friedl, W.; Frese, U.; Borst, C.; Grebenstein, M.; Eiberger, O.; Hirzinger, G.; , "Catching flying balls and preparing coffee: Humanoid Rollin'Justin performs dynamic and sensitive tasks," *Robotics and Automation (ICRA), 2011 IEEE International Conference on* , vol., no., pp.3443-3444, 9-13 May 2011
[6] Sato, K., Minamizawa, K., kawakami, N., and Tachi, S. "Haptic telexistence" *ACM SIGGRAPH 2007 emerging technologies,* ACM, New York, NY, USA, SIGGRAPH '07. 2007.
[7] Botvinick & Cohen, Rubber Hand Illusion *(RHI)*, 1998
[8] Slater, M., Spanlang, B., Sanchez-Vives, M. V., and Blanke, O. "First Person Experience of Body Transfer in Virtual Reality". *PLoS ONE*, 5(5), e10564. Public Library of Science. 2010.
[9] H. Henrik Ehrsson. "The experimental induction of out-of-body experiences" *Science*, Vol. 317, p. 1048, 2007.
[10] Bigna Lenggenhager, Tej Tadi, Thomas Metzinger, and Olaf Blanke. "Video ergo sum: Manipulating bodily self-consciousness" *Science,* Vol. 317, pp. 1096– 1099, 2007.
[11] Katsunari Sato, Kazuto Kamiyama, Naoki Kawakami, Susumu Tachi, "Finger-Shaped GelForce: Sensor for Measuring Surface Traction Fields for Robotic Hand," *IEEE Transactions on Haptics,* vol. 3, no. 1, pp. 37-47, Jan.-Mar. 2010
[12] Minamizawa, K., Kamutaro, S., Fukamachi, S., Kawakami, N., and Tachi, S. "Ghostglove: haptic existence of the virtual world" *ACM SIGGRAPH 2008 new tech demos,* ACM, New York, NY, USA, SIGGRAPH '08, 2008.