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テレイグジスタンスの研究（第７９報）
バーチャルボディを介した遠隔環境とのインタラクション

Study on Telexistence LXXIX
Remote interaction using humanoid virtual body

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Abstract: Telexistence systems require physical limbs for remote object manipulation. Having arms and hands synchronized with voluntary movements allows the user to feel robot's body as his body through visual, and haptic sensation. In this method, we introduce a novel technique that provides virtual arms for existing telexistence systems that does not have physical arms. These superimposed virtual arms follows the user's real-time arm movements and reacts to the dynamic lighting of real environment providing photorealistic rendering adapting to remote place lighting. Thus, it allows the user to have an experience of embodied enforcement towards the remote environment. Furthermore, these virtual arms can be extended to touch and feel unreachable remote objects, and to grab a functional virtual copy of a physical instance where device control is possible. This method does not only allow the user to experience a non-existing arm in telexistence, but also gives the ability to enforce remote environment in various ways.

Keywords: Telexistence, Augmented Reality.

1. Introduction

Experiencing hands and arms movements in a telexistence robot system is an essential element for the user to feel the sense of existence in robot's place. More importantly to allow the user to use his limbs to interact with objects by touching and manipulating them makes much stronger embodiment towards the remote environement. Full-scale telexistence systems such as TELESAR V [1] are equipped with mechanical arms, hands and touch/tactile sensors, and such systems are designed to perform complicated tasks remotely. However, the complexity and the cost of such systems can be decreased incredibly if the target applications do not involve the need of physical arms such as in investigation robots which need vision and head movement mainly. An example of such portable systems is the 6-DOF robot head: TORSO [2].

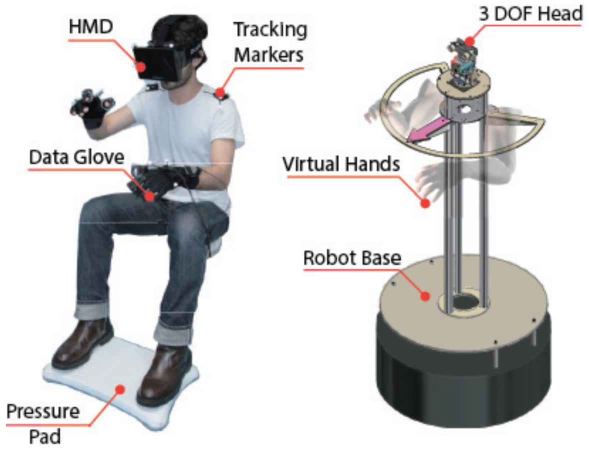

Figure 1 System overview.

To compensate the lack of arms and the haptic feedback, we propose to adapt an alternative method that deploys photorealistic virtual arms superimposed in the remote robot instead of physical arms as shown in Figure 1. Those virtual arms provide a natural experience of feeling your own body while interacting with the remote objects. However, virtual arms cannot collide with physical objects in the remote environment. A pseudo-haptic feedback method is developed which uses a depth sensor to scan the remote place and convert it into a 3D surface map in real-time, and the touch forces are calculated using virtual hands fingers and the 3D geometry surface map of the remote objects.

The visual quality of the hand plays an important role in order to understand that virtual hand is your own. Image base lighting (IBL) is an efficient method to estimate lights of real environment images, and to use it to illuminate virtual objects [3]. Here we propose a method using the captured images of the telexistence robot to apply it into the virtual arms in real-time.

In this paper, technique on how to integrate the virtual arms with the robot, generating the pseudo-haptic forces into user's hands, the process of generating and applying IBL into virtual arms was discussed. Also some user cases were discussed.

2. System Design

2.1 Robot Design

To realize this system, it is important to maintain the visual consistency between the user's head and robot's head motion. The best-case scenario is to use a 6-DOF robot head such as TORSO. However in this paper, we developed a 3-DOF robot head as shown in Figure 2 with higher dynamic response time to maintain user's head motion when looking around. Wide-angle stereo camera's are used in order to capture and display a wide angle of view (110°) of the remote environment. User uses an Oculus Rift DK 1 to experience the telexistence with virtual arms configuration

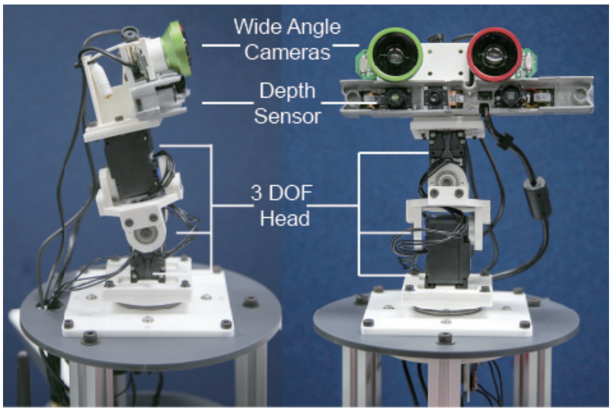

Figure 2 A 3-DOF robot head with depth sensor

A depth sensor camera is used to scan remote environment in real-time and to construct a representative 3D surface in the local part to be used when interactions happen from user hands. The depth sensor is mounted at the same joint of the camera part thus it shares the same point-of-vision.

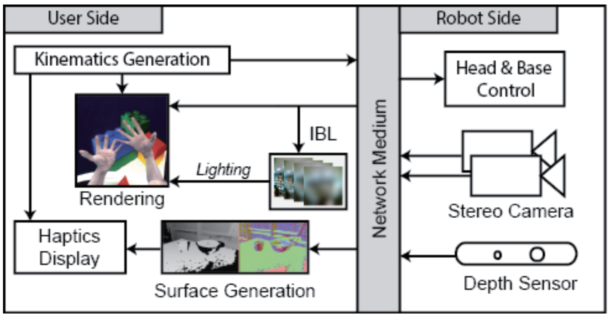

Figure 3 System pipeline.
User side and Robot side main functions

Figure 3 shows an overview of the system pipeline. Most of the tasks related to the arms such as generating IBL, animating the arms, 3D surface calculation, force estimation and haptic display are carried on the user side only. The robot side has very limited resources, and only provides main functionalities such as head/base movement, and sending stereo video feed and depth map information over the network.

2.2 Superimposed Hands

Similar to head movement of the robot is designed to follow user's head motion, arms movement and hand trajectory follows the same movements as the user's. Thus our inverse kinematics implementation takes into consideration these points, and it generates the arm joints posture in real-time by tracking user's hands, arms and head. Thus, joint space is generated with kinematics and a 3D model representing the user's upper body (arms and hands) is animated and superimposed over the real robot at remote environment. The robot head is also controlled using the same joint space of the virtual representation to ensure the synchronized motion of physical robot and virtual body.

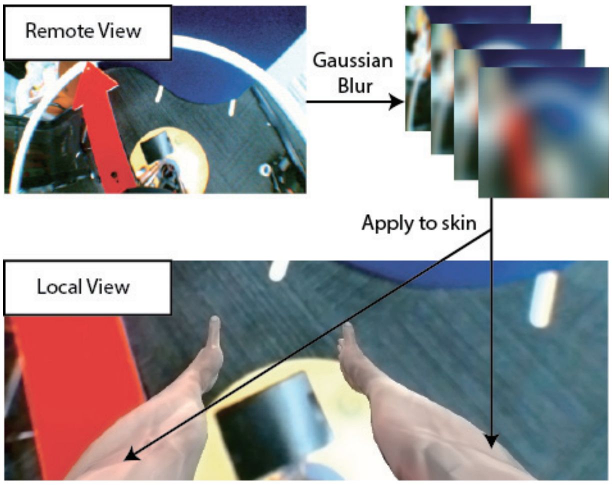

Figure 4 IBL processing to the skin. Notice how the skin has reddish and bluish color tone.

To improve the visual appealing of the virtual arms, an Image Based Lighting (IBL) method was developed using the captured real-time image feed. Figure 4 shows the result of applying IBL to the arms, the ambient reflected color changes dynamically when the contents of the remote view changes. However, this estimation method only captures the colors from the front view and it lacks back contents.

2.3 3D surface generation and touch forces estimation

Due to the lack of physical arms in the robot side, it is not possible to provide physical touch sensors at the interaction points. So to overcome this limitation, an estimation method was developed using 3D surface representation of the remote environment and the collision between the virtual hands trajectories.

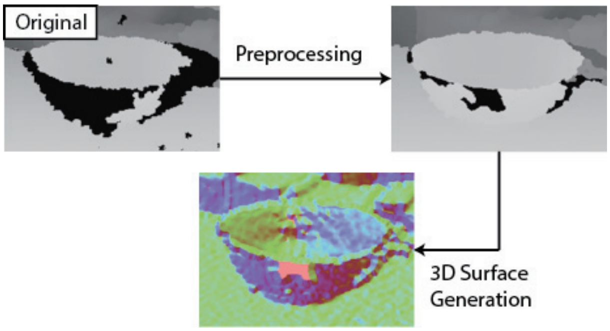

Figure 5 Depth data processing and 3D surface generation

A depth sensor mounted on the robot side matching its point-of-view is used to capture depth information of the remote environment and is sent into the user side as an image stream, forming a RGBD data stream. Next, a preconditioning is applied to the raw depth data resulting removing noise and recovering missing depth information before generating the 3D surface of the remote place. Most of the gaps can be resolved using temporal recovery methods [4], and noise of the depth map was resolved using bilateral filter in order to preserve the hard edges while removing the high frequency noise. Figure 5 shows how the depth map is processed to produce a 3D surface normal map.

Normal map is derived from the pre-conditioned depth map, and each pixel represents a 3D normal vector of the surface. Those normal are calculated by deriving the depth map along X and Y space and calculating the cross product of both vectors:

$$\overrightarrow{N_{x,y}} = \left\| \overrightarrow{\partial U} \times \overrightarrow{\partial V} \right\| \qquad (1)$$

The combination of depth map and normal map will result a surface map relative to camera space. Using the above surface map and virtual fingers position, it is possible to calculate touch forces and shearing forces to be applied to the haptic display of the telexistence operator.

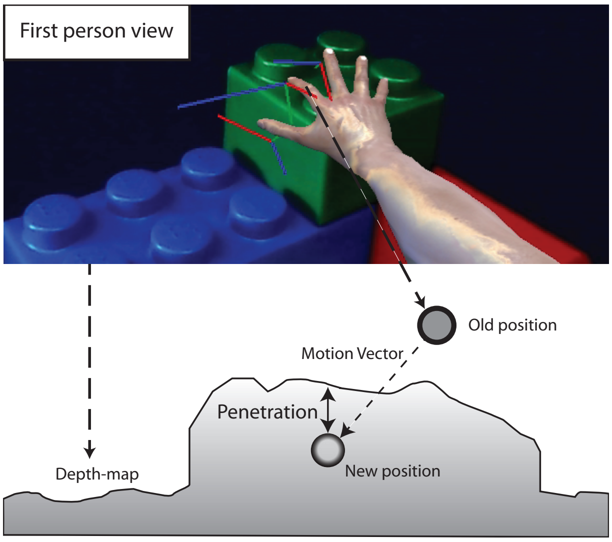

Figure 6 Calculating touch force using depth map

Figure 6 shows how vertical forces are calculated and touch is estimated using depth map and finger position. The pushing forces are simply calculated using Hooke's law:

$$F_z = -kx \qquad (2)$$

x is amount of penetration in the depth map.

Shearing forces are calculated using the tangential motion vector of fingertips along the normal map. To display these forces on the fingers, gravity grabber haptic display [5] was mounted on each finger, and driven using the calculated forces.

3. Applications

Interacting with the remote environment is an essential thing in telexistence systems. In this system we achieve the interaction using virtual arms in the remote environment. Figure 7 shows different scenarios in which the virtual arms can be used. Further explanation about each scenario is presented in this section.

3.1 Using functional objects

Controlling home appriances in the remote environment is possible if the remote robot has physical arms. However, with virtual arm we developed an method to grab a virtual copy of it's fuctional remote controller. This way the physical properties are preserved in the remote environment, but remote participants can interact with the virtual copy as it is a physical remote. By linking the digital behavior of the objects (like light switchs, speaker volume,..) with virtual objects over the internet, the remote interaction becomes possible with virtual arms.

Using virtual arms to operate and use those functional copies gives a natural interaction with the environment by grapping and operating it. As an example we show in Figure 7 (a) using a virtual remote control to turn on the TV.

Figure 7 Various scenarios using virtual arms. (a) Turning on TV using functional object of the remote control. (b) Extending the arms to touch far objects. (c) Writing on remote whiteboard (digital screen)

3.2 Superhuman body manipulation

Virtual arms representation has advantage over rigid physical arms, they can be extended, shortened depends on the situation to reach a target which is not in reach. For example, the ability to modify the length of the arm to expand the reaching space allowing the user to touch far objects beyond the distance of his arms. Or else, reaching far functional objects without the need to change the locomotion as in Figure 7 (b).

3.3 Collaborative work

Collaborative work between two places can be tedious specially when the spatial difference between the two environments can vary. For example, when using a shared digital workspace that remote participants can access as well as the robot operator in a same spatial dimension. Here an example of using digital screen to act as a shared whiteboard shown in Figure 7 (b) allowing both participants to interactively draw on it. The operator perceives the screen as he is being physically next to it.

4. Limitations

Currently the interactions are mainly focused on the local side or the user operating the robot. Since the avatar robot does not have physical manipulators, participants in the remote place will not be able to know whether the user driving the robot is currently touching or the current posture of the arms, thus it is lacking mutual communication between both participants.

The limitation of manipulating the remote environment can be partially resolved using virtual functional objects that can be interacted with to do a specific function, such as the examples mentioned in the Applications section.

5. Conclusion

In this paper we presented a novel method for real-time virtual arm substitution in armless telexistence robots. We showed here the process of generating photorealistic superimposed virtual arms that follow operator’s body movement in real-time. Depth-map based pseudo haptic estimation method was used to compensate the lack of force sensors in the robot side, allowing the operator to touch and feel the physical objects at the correct distance as if he is there. Using this method allows enforcing the remote environment to become active regardless the lack of physical arms.

Acknowledgement

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