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Study on Telexistence LXXXI
- Effectiveness of Spatial Coherent Remote Driving Experience with a Telexistence Backhoe Under Hazardous Conditions -

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In this study, a 6 DOF Spatial Cognition Telexistence Robot System (TORSO) was mounted on a driver's seat of a Unmanned Backhoe (BH). The drive efficiency and effectiveness of spatial Coherent experience of sitting on the Backhoe seat and manipulating the machine was evaluated through several experienced and non-experienced remote operators by giving them with a 8-shaped road track under various hazardous conditions. Furthermore, the effectiveness of spatial coherent drive experience towards working at construction sites and real hazardous fields was discussed.

Key Words: Teleoperation, Outdoor Operation, Telexistence

1. Introduction

Driving vehicles remotely could allow the human operator to perform actions at a distant location. Remote driving may helpful in daily activities, however, in this paper we focus on activities related to disaster and hazardous situations. If a human operator could isolate from the disaster site, while the operators human effectiveness can be projected into the remote locations he could perform operations with safety, effectively and much efficiently compared to visiting the site physically. During the past three decades, the majority of research in vehicle teleoperation has centered on rate-controlled systems [1] where the operator is looking at the remote environment through multiple displays showing the video feed from multiple cameras placed on the remote site.

More recent vehicle teleoperation systems have emphasized the use of multi-modal operator interfaces and supervisory control [2], [3] where sensor fusion displays combine information from multiple sensors or data sources into a single, integrated view [4]. Under supervisory control, an operator divides a problem into a sequence and resolves the problem on a sequential base manner. These systems provide distance information, collision avoidance information through notifications at the display. However, it's not practical to use these on a real disaster situation as the complex manipulations could not be performed faster, safely and confidentially.

There has been several works explaining the effectiveness of a humanoid robot to drive an industrial vehicle instead of a human operator [5], [6] from a remote site. It enables to use a general type of vehicle safely in a dangerous field as the decision is taken by the human operator and performs manipulations over the robot who sits on a cockpit of the backhoe and manipulates control levers for driving. Similar work has been done with only arm actuators for controlling

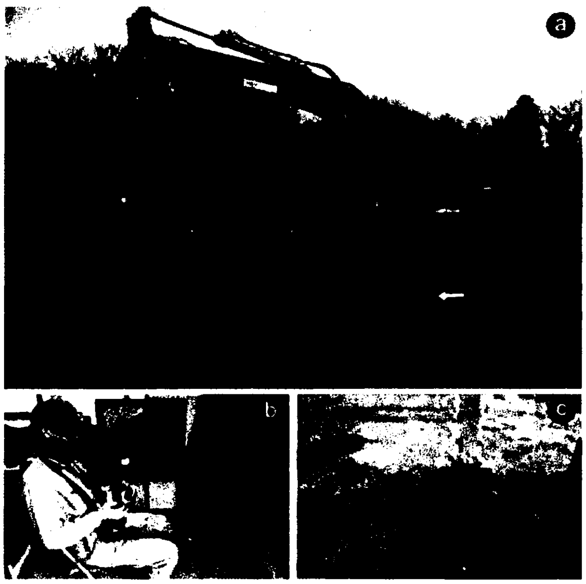


Fig. 1 System Description (a) Remote Backhoe, (b) Operator's Cockpit, (c) HMD view

the levers of the industrial vehicle with a pneumatic robotic system actuated by pneumatic rubber muscles (PARM) [7], [8] and CCD cameras for remote vision. These systems provide technical capabilities of driving a industrial vehicle remotely, however, the visual flow and spatial coherent relationship between the remote side and local side has not been mapped. Therefore, the human operator could not feel as if he is inside the machine while manipulation.

Telexistence enables a human experience spatial coherent mapping between the remote-local side and allow to have real-time sensation of being at a place other than where he actually exist, and to interact with the remote environment [9], [10]. These systems not only provide acoustics and visual sensation, with the development of TELESAR master-slave robot system [11], a combination of vision, auditory and kinesthetic sensation was achieved. However, these systems are very complex and not economical to be used for creating remote driving experience. Our research team has also achieved a minimal telexistence system “TORSO” [12] with human-like neck movements to visually interact and explore 3-dimensional details in a remote object in a more natural and comfortable manner.

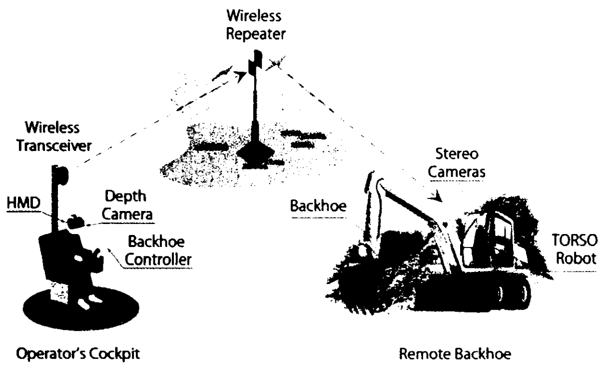


Fig. 2 Telexistence Remote Backhoe, System Overview

As shown in Fig.2, in this work, a modified TORSO robot system, full HD head mounted display (HMD), Backhoe remote controller, and a dedicated wireless IP up/down link is used to provide the user with kinesthetic and remote visual sensations at very low latency over networked operations and to create the spatial coherent remote driving experience for a remote backhoe.

2. Spatial Coherent Remote Driving Experience

With the advancement of technology, there’s many driving aids such as corner cameras, position detectors, visual navigation techniques etc. These driving aids helps the user with getting familiar with the vehicle boundaries and have outside presence. However, they are static, and does not change when the driver tries to look into a specific angle or something outside. To maintain the same spatial coherent experience of driving inside a remote backhoe, the operator should be provided with the same audio-visual feedback that he would expect when sits on the physical backhoe. This spatial coherent coordination without delays is important when doing complex tasks not because humans will not use vision, but they could perform multiple limb movements without thinking and looking at everything at once. Similarly, the user is supposed to see his own hands and arms at the same place that he would expect them to be.

In this system we achieve the spatial coherent correlation by capturing the stereo visuals from the backhoe and reconstruct on the operators cockpit with a head mounted display. When the operator changes the point of view (PoV), the remote side cameras has to capture on the same PoV. As shown in Fig. 1(a) a 6 DoF robot system is used to mount the camera head, where it follows the user movements synchronously. If the operators hands could be modeled and functional as a robotic hand in the remote robot, he would see his own hands operating the levers inside the backhoe. However, this could be very complex, and to maintain a low latency and photo realistic visuals mechanical arms might not be the best option. Thus the operators hands were captured using a depth camera, segmented from the background and provided as an overlay to remote video feed. As shown in the Fig. 1(b) the operator wears a wide angle binocular head mounted display that has motion sensors to capture the position and orientation of the head. These data has been used to model the kinematics for driving the robot torso and head. With the above configuration, when operator moves around to see some specific thing around the vehicle, as shown in Fig. 1(c) the robot moves accordingly and provides spatial coherent visuals together with his own hands superimposed so that he could feel the presence inside the remote backhoe manipulating the levers. Furthermore, with the awareness of the body in vehicle space, the operator could understand the vehicle borders with respect to the surroundings.

3. Implementation

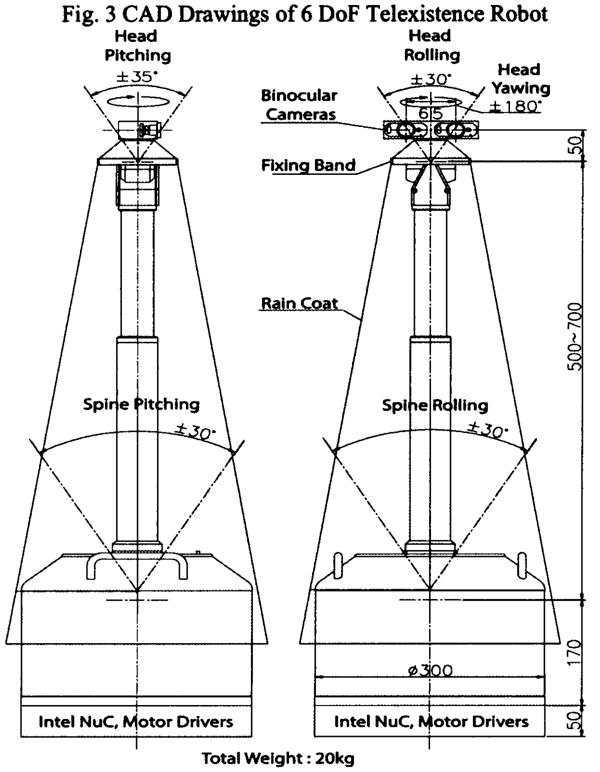
As shown in Fig. 2 the system consists of 3 sections. A cockpit where the operator manipulates the remote backhoe, wireless data transmission/re-transmission equipment and the slave telexistence backhoe. On the operator side, commercially available wide angle HMD (Model No: Oculus Rift DK2) is used to track the users head motion and provide processed video and audio data received from the remote telexistence backhoe. A depth camera placed on front side of HMD front captures the real time hands, controller and superimposed onto the remote video. A proprietary wireless transceiver operating at 2.4Ghz band was used to transfer the 3D video data as well as robot commands.

A radio controlled backhoe (Model No: Acera Geospec SK135SR-2) is used as the main carrier. It can remotely controlled for over a 2km distance with the stocked remote controller. 6 DoF telexistence robot system is mounted on the backhoe’s drivers seat adjusting to match the exact height of a typical operator.

Fig. 3 shows the 6 DOF telexistence slave robot used as the main component to design and implement the spatial coherent remote drive system. The robot not only has 3 rotational DOF dexterity acts as the neck, but also 2 rotational DOF as hip and 1 translational DOF as the spine. The position and posture of the operators head and body streamed from the cockpit was received over the network and used to calculate the necessary reference angles through kinematics to drive the slave robot’s motors. At the same time, the present angles of each joint is captured by a sensor (e.g., encoders), and the position and posture of the slave head follow those of the operator.

Each joint has a DC motor, an encoder and a photo interrupter. The photo interrupter determines the zero position of the encoder. The driving performance of each joint is adequate because each joint can move at a speed higher than the maximum speed of motion of the human head. Two Full HD camera modules (Model No: Logitech C615) were used to custom create the stereo camera module required by the system. To match the Oculus interpupillary distance (IPD), two cameras were placed at a distance of 64mm. To match the field of view (FOV) of the Oculus, camera's stock lenses were replaced by wide conversion lens unit (Model No: MAGICA-WM) to archive a FOV of 100°. The camera lens unit is very light weight (320g) so that the dynamics of the human head could be maintained.

Fig. 3 CAD Drawings of 6 DoF Telexistence Robot



For video grabbing, inverse kinematics and motor control algorithms, a mini PC (Model No: IntelR NUC Board D54250WYB) is used. A PCIe to PCI bus expansion box (Model No: ECH-PCI-CE-H4B) is used to connect the D/A, A/D and Interrupt Counter boards that has been used in the robot. PCI expansion box connects to mini PC via a MiniCard (mPCIe) to PCIe X1 bus adaptor (Model No: KZ-B26-030) The A/D and interrupt counter boards connects to the encoders and photo interrupters where as motor drivers connects to the D/A board.

Fig. 4 shows the data flow diagram of the spatial coherent drive system. Operators head position and orientation is captured from the Oculus DK2 camera, sent to the remote side via the UDP control bus. The received data is used to calculate the Inverse Kinematics and resultant joint angles were used to drive the 6 DOF robot's motors. The robot moves according to the operator, and the stereo camera data was grabbed at 720p resolution at 60fps with I420 format. The frames were then H264 encoded and steamed with a UDP payload. On the operator's side the payload was demuxed, H264 decoded and images were further processed for lens distortion correction, color space correction, and finally converted to oculus ready data. A depth camera (Model No: Leap Motion) is mounted on the front surface of

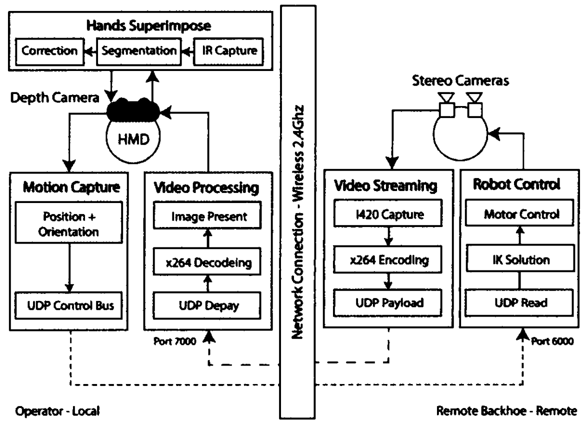


Fig. 4 Data Flow Diagram of Spatial Coherent Drive System

the Oculus to capture the operator's hands and other selected devices such as controller. Captured IR data cloud is segmented, corrected and the hands were masked out from the other noise data. With the above system, operator could experience motion parallax and binocular parallax 3D vision of the remote backhoe. Since the 6 DOF robot (TORSO) can express the upper-body motion of humans in a more natural and accurate manner to reflect the characteristics of humans than conventional robots. Thus, it can acquire motion parallax information without moving its entire body.

The network end-to-end latency was measured by feedbacking a video test pattern through the remote camera and it was found that the latency is 130ms. Since the Oculus DK2 has 20ms latency from input to display on the screen, total delay was calculated as 150ms.

4. Field Experiments

The spatial coherent remote drive system with a telexistence backhoe was constructed successfully. It has been proved that the end-to-end latency was not an issue to construct the remote presence experience. However, in order to fully understand the capability of operating the backhoe remotely, it has to be driven by ordinary machine operators.

A 8 shaped test drive route was decided to evaluate the telexistence backhoe remote driving experience. 3 red traffic cones were placed on the turning points to indicate the center of turning point. The center-to-center distance was kept at 7000mm which is the standard strict turning curve specification of the backhoe. Operator subjects were chosen to be ordinary backhoe drivers (non remote control), remote control based backhoe drivers, and ordinary users who does not have any driving experience of backhoe.
The experiment was carried out with remote backhoe

operators (2), ordinary backhoe operators (3) non backhoe operators (35). Ordinary backhoe drivers and ordinary users giving instructions on how to use the remote controller to move front, back, curve and turn manipulations. Remote controller backhoe drivers skipped this step. Next, they were given HMD to wear, and a controller on their hand. They were asked to look straight front to initialize the local position and connected to the remote backhoe. Once connected, they could see as if they were inside the backhoe (Fig. 1(c)). Also, before moving to the start point, when they look down, they could see their own hands on the remote backhoe and holding the remote controller. Telexistence backhoe was parked few meters behind the start point. They were asked to move forward, and time taken to follow the entire course from start point, 6 turns and return back to start point was measured.

Fig. 5 Experimental Conditions of Telexistence Backhoe Remote Drive System

The operator was situated on a separate cockpit room around 8m close to the start point and the data communication was occurred through the dedicated wireless transceiver beamed by two collinear antennas one on the cockpit room and other on telexistence backhoe. A helper personal was kept on the cockpit room in case of if anything goes wrong to stop the operation. The helper person could see the remote backhoe in his vicinity. Experiments were carried out at Obayashi Coorporation, Tokyo Machinery Plant, Kawagoe and Public Works Research Institute, Tsukuba. Before assembling the 6 DOF robot on the drivers seat, remote backhoe operators were given the same route manipulating directly sitting on the backhoe. The same subjects were asked to control the backhoe in the route with remote controller while looking at the backoe from outside. At this step the operators moved with the backhoe as they could not see the visuals from first person perspective. Next, they were given HMD and drive under completely remote.

The telexistence backhoe was experienced by ordinary backhoe operators as well as non backhoe operators. With just understanding the remote control commands, almost everyone was able to complete the route successfully without hitting the traffic cones.

5. Conclusion

We proposed a spatial coherent remote driving system where the operator can manipulate a telexistence backhoe as if he is inside the machine. The effectiveness of spatial coherent remote driving experience was evaluated with many remote backhoe, ordinary backhoe, and non backhoe operators giving them the road course of a 8 shaped test road track. It was confirmed that the completed system can perform the full operation of a backhoe including navigation and arm operations under various environmental conditions. In this experiment, the backhoe was controlled on a distance of around 100m wireless. However, as the next step we plan to expand the remote reachability for even much longer distances.

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