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Robot Task Execution with Telepresence Using Virtual Reality Technology

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ABSTRACT

Robotic manipulators are widely used to replace human operators in tasks that are repetitive in nature. However, there are many tasks that are non-repetitive, unpredictable, or hazardous to the human operators. With teleoperation, or remote control, such tasks can still be performed using robotic manipulators. A suitable platform with visual and mechanical feedback is deemed necessary to simplify the operation of such system. This paper describes the design and implementation of a telepresent robot control system using virtual reality (VR) instruments. The system includes a stereo Head-Eye Module (HEM) with 3 degree-of-freedom, a high-resolution stereo Head Mounted Display (HMD) for remote supervision, and a 6 degree-of-freedom articulated robotic manipulator. The motion of the operator's head and hand are tracked using 6 degree-of-freedom magnetic trackers. Implementation of the system includes the mechanical design and fabrication of the HEM, and the overall software and hardware integration. The operation of the system was subsequently demonstrated by performing 2 specific tasks

1. INTRODUCTION

Technological breakthroughs have allowed automation to replace many jobs that are repetitive in nature and hazardous to human health, thus replacing human operators in many work environments. However, it has also allowed a new phenomenon to occur: the remote control of physical systems by humans through the mediation of computers. Indeed, there are still many jobs that are non-repetitive, unpredictable and hazardous to humans. Clearing up a nuclear power plant leak or exploring the extreme depths of the ocean are just some examples. Reliance on specially designed automatic machines for such jobs may prove to be inefficient, less flexible and less cost-effective than a human operator is. Therefore, a remote control system by human operators using video inspection and master-slave mechanical manipulation (called teleoperation) is proposed.

A teleoperator is a machine that extends a person's sensing and/or manipulation capability to a location remote from that person. Teleoperators has early beginnings as far back as the sixteenth century, in the form of fire tongs, animal prods and other simple arm extensions. Raymond Goertz, *et al* [1] developed the first modern master-slave manipulator at Argonne National Laboratory in 1945 for the safe handling of radioactive isotopes. Electrical servomechanisms soon replaced the direct mechanical tape and cable linkages.

An anthropomorphic teleoperator has human like form, in that it senses its environment with what resemble eyes, manipulates mechanical objects with what resemble arms and hands. A semi-anthropomorphic teleoperator is developed as a research effort between Gintic Institute of Manufacturing Technology and the National University of Singapore. In addition to just being able to operate the teleoperator/robot remotely, the human operator experiences telepresence, which *"means that the operator receives sufficient information about the teleoperator and the task environment displayed in a sufficiently natural way, that the operator feels physically present at the remote site."*[*2*] In other words, a telepresence system immerses the operator in the environment where the robot is. By tracking the motion of the operator's head and hand, and providing stereo visual feedback through an immersive HMD, the telepresence system developed in Gintic enables the operator to immerse in the environment where the robot is in.

The telepresence system was demonstrated successfully with the performance of two tasks. By observing through the HEM, the operator controlled the robot manipulator by the hand motion to accomplish tasks (namely, to handle objects). The interaction between the operator and the remote environment was natural, thus a form of telepresence was achieved.

This paper describes the design and implementation of the telepresence system. Section 2 provides a brief survey of Virtual Reality Technology, Section 3 describes the telepresence system and Section 4 describes the application demonstration.

2. REVIEW OF VIRTUAL REALITY TECHNOLOGY

While virtual presence is not to be confused with telepresence, the technologies developed in the field of virtual reality complement the development of telepresence. During the course of developing the system, different types of virtual reality equipment were surveyed.

Head Mounted Device (HMD)

Goertz [3] and Chatten [4] showed that when a video display is fixed relative to the operator's head, and the head's pan-and-tilt motion drives the camera pan-and-tilt, the operator feels as if she were physically present at the location of the camera, however remote it is. This technique is now commonly used to achieve visual telepresence. Advances in virtual reality technology have brought about mini-CRT displays and LCDs (Liquid Crystal) that can be fitted in lightweight HMDs. These displays provide an equivalent wide angle of view as wrap-around screen projection systems (by turning the head and moving the video camera field) without incurring the cost of more pixels. Some of the commercially available HMDs include Visual Immersion Module, Liquid Image MRG2.2, Virtual research System VR4 and Virtuality Visette2 The HMD used in this project is a Virtuality Visette2 which is shown in Figure 1.

Figure 1. Virtuality Visette2 Head Mounted Display unit.

Position Trackers

While the use of exoskeleton master arms, which can track the individual joint rotations of the operator's arm, is considered good for mobility, has large workspaces and general body tracking, there is often a mismatch between the master arm kinematics and that of the human operator's. It is therefore useful to consider other methods of position sensing.

The alternative is 3-D position sensing [5] where the translation and rotation of a moving object in 3-D space along and about the X, Y and Z axis, respectively are tracked. This method defines a data set of six numbers that can be measured sufficiently fast as the object moves. The 3-D measurement techniques are not intrusive and the sensors are considered "non-contact".

Most HMDs stated above provide for head position tracking, by incorporating one of the following sensors:

- **Ultrasonic sensors:** contains emitters and receivers with a known relationship to each other. The emitters are pulsed in sequence and by calculating the time lag, the distance to each receiver is measured. The location and orientation are determined using triangulation. Ultrasonic sensors suffer the disadvantages of long lag time and lack of accuracy.
- **Optical sensors:** uses a grid of light-emitting diodes mounted on the ceiling and a camera mounted on the user's helmet (head tracking). The LEDs are pulsed in sequence and the image from the camera is processed to determine the camera's position relative to the ceiling grid. This system is limited by the size of the grid and does not provide full 360-degree coverage. Another optical system uses several video cameras to capture simultaneous images of the object. This requires powerful image processing capabilities.
- **Magnetic trackers:** low frequency magnetic fields are produced by the "transmitter", which is an assembly of three orthogonal antennas. A second set of orthogonal antennas is placed inside a "receiver". The signal sensed by the receiver, is sampled by an electronic unit that uses an algorithm to determine the position/orientation of the receiver to the transmitter. However, the magnetic tracker faces interference from ferromagnetic objects and/or strong magnetic field within the sensing range. Shown in Figure 2 is the position tracker used in this project - the FASTRAK magnetic tracker by Polhemus Inc. [6].

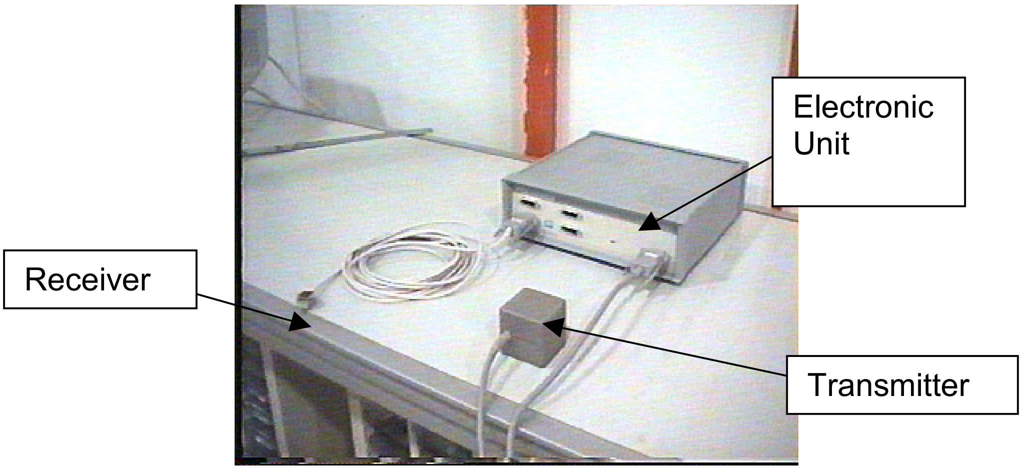

Figure 2. The Polhemus FASTRAK magnetic 3-D position tracking system.

3. SYSTEM DESCRIPTION

Figure 3 shows the basic parts of a teleoperator system (or telepresence system) which consists of three environments [7]. The master environment contains the human operator and the control system (known as the arm or master system). The slave environment is the work area of the slave arm. The X environment contains elements necessary to the understanding of the task description, that is, the human operator's mind. Kinesthetic data results from the operator's physical contact with the master arm through force feedback. The telepresence system developed here does not allow Kinesthetic data to be fed back. Therefore it is a unilateral system.

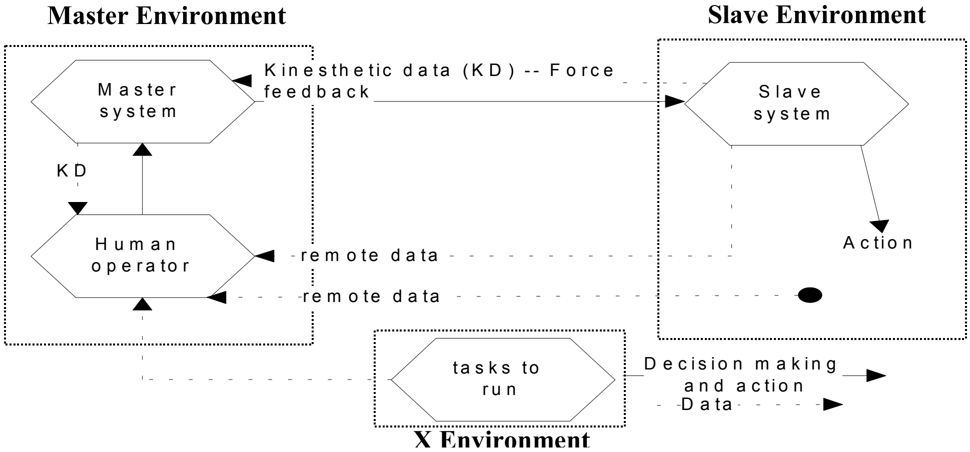

Figure 3. The 3 environments of a teleoperator or telepresence system.

System Overview

The system developed here consists of the two environments: the master and the slave. The PC acts as a main controller interfacing between the equipment (slave) and the operator (master). Figure 4 shows the relationship of the system components.

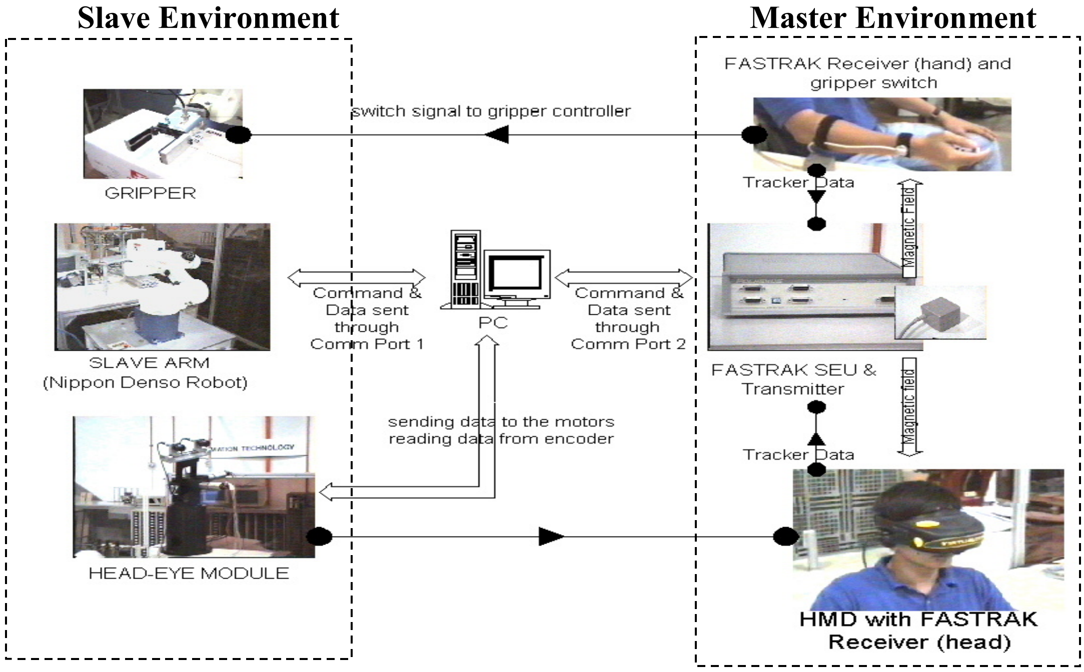

Figure 4. Overview of system components.

Master Environment Components

The components of the master environment are shown in Figure 5.

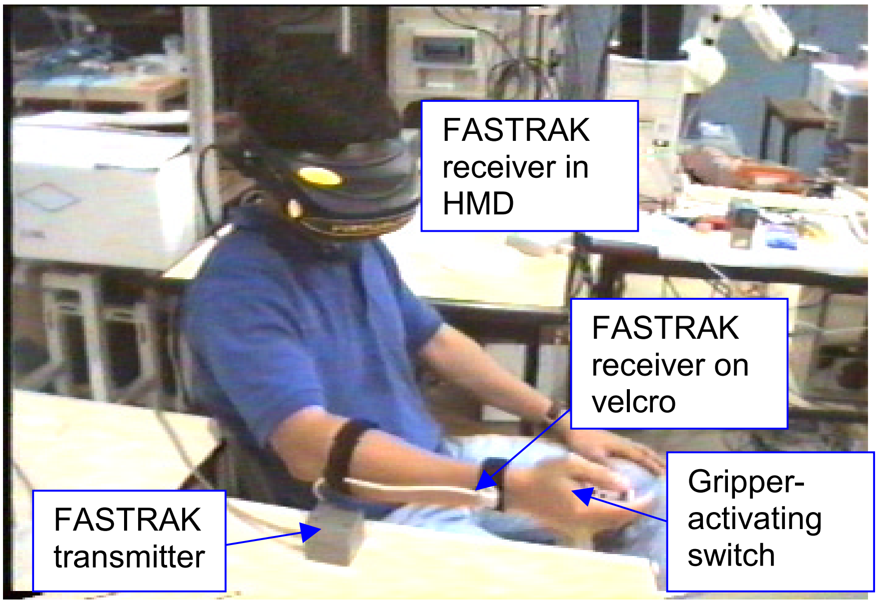

Figure 5. The master environment components.

1. **Position Tracking using Polhemus FASTRAK Magnetic Position Sensor**

   For our system, two receivers are used. One is attached to the wrist of the operator by means of a velcro strap, the other is fitted in the back of the HMD worn on the head of the operator. They are used to track the motion of the operator's arm and head respectively so that data can be fed to the robot controller and HEM's servo motor controller respectively

   The azimuth (Ψ), elevation (θ) and roll (ϕ) angles define the current orientation of the receiver coordinate frame with respect to the transmitter reference frame.

   The Euler angles are transformed into X, Y and Z direction cosines (or normal, orientation and approach vectors), which are required by the robot controller for positioning the robot arm in Cartesian coordinates.

2. **Gripper Activation**

   The gripper is activated by means of a simple switch connected to the controller.

3. **Head-Mounted Device**

   The head-mounted device is a Visette2 from Virtuality. It uses liquid crystal displays to feed both eyes with images.

Slave Environment Components

1. **Eye Module (EM)**

   The EM is designed to carry two Teli colour CCD cameras for stereoscopic vision. Each camera is mounted onto a "carriage" by a camera holder that can be swiveled to provide a certain amount of "toe-in" (The "toe-in" is required for fixation on an object). The "carriages" can be adjusted to allow equal distance between both cameras from the center. The EM can be attached to any mounting plate with 4 screws. At the present moment, it is attached to the Head Module (HM) to form the Head-Eye Module (HEM).

2. Head Module (HM)

The HM provides 3 degrees of freedom motion through rotation about the 2 orientation frame axes (x, y) and 1 reference frame axis (Z). The axes are designed to coincide at a single point, so that the rotation of the operator's head about the base of his/ her neck can be duplicated. Rotation is provided by 3 directly-coupled servo motors. As shown in Figure 6, motor1 (tilting motion) controls rotation about the y-axis. Motor2 (rolling motion) controls rotation about the x-axis. Motor3 (panning motion) rotates the tilting and rolling motion assemblies about the Z axis of the reference frame. Motors 1, 2 and 3 will therefore turn correspondingly to the elevation, roll and azimuth angles.

3. Hand Module (Robot Slave Arm and gripper)

The slave arm is a Nippon Denso 6 DOF Robot Arm. In Cartesian mode, referenced to the center of the robot end effector is the mechanical interface coordinate frame. Like the receiver coordinate frame in the FASTRAK system, position data represents the translation of the origin of the mechanical interface coordinate frame from the base coordinate frame located at the base of the robot arm. Orientation is defined by a series of 6 numbers representing the orientation and approach vectors (Y and Z-direction cosines) as described earlier.

The robot gripper is the Takano Bearing Model RH707 and it allows manual handling of objects and acts as the hand of the operator. This robot gripper has two parallel jaws (1 DOF) which are either in the open(default) or closed position.

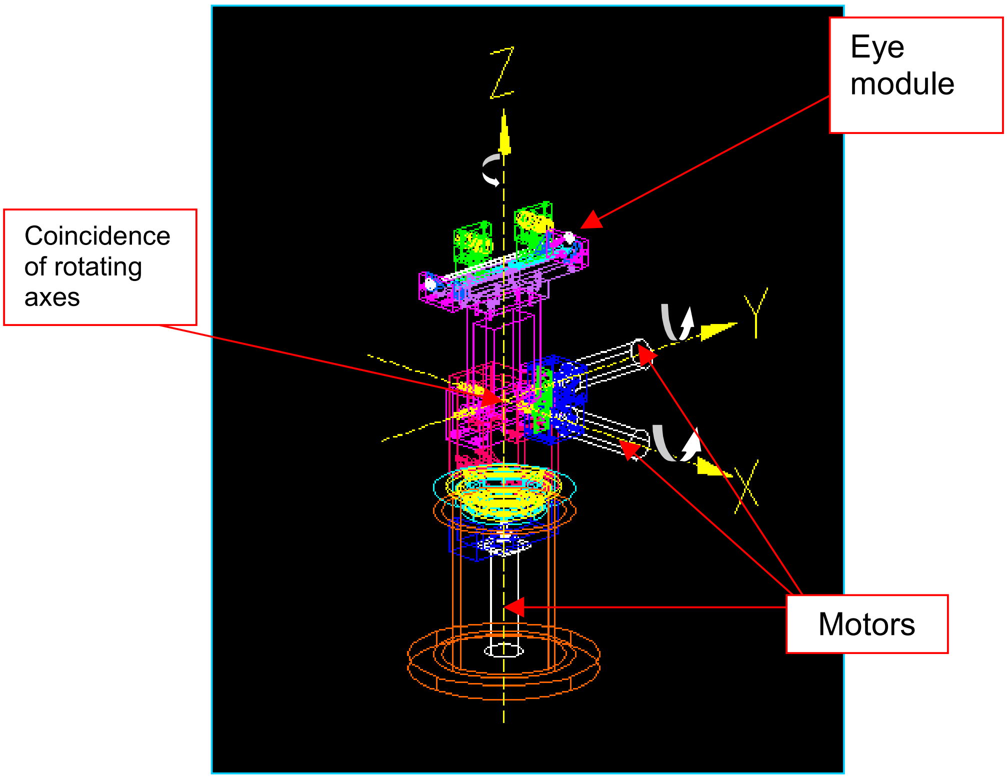

Figure 6. The design of the Head-Eye Module(HEM).

System Integration

The integration of the software and hardware is done through ‘C’ programming using the National Instruments’ LabWindows/ CVI. A virtual instrument panel is created which allows the user to start the system and observe the positions of the master and slave components.

4. APPLICATION/ DEMONSTRATION

Design criterion for high-quality visual telepresence requires the viewed image to follow the head motion with no apparent lag or jitter. Other problems consist of achieving sufficient field of view (at least 60 degrees), depth of field and correct focal length, image separation for stereoscopic fusion. However much as one may seek an objective measure to say visual telepresence has been achieved, telepresence is still a subjective sensation [2]. An objective measure would be to say that if the operator cannot reliably tell the difference between telepresence and direct presence, then telepresence has been fully achieved. This objective measure is difficult to achieve due to latency in data transfer from the FASTRAK device to the PC and from the PC to the robot arm and HEM.

For the purpose of determining the performance of the telepresence system, two tasks were selected, as illustrated in Figure 7. The first task is a calibration task, which is to pick and place a can, and subsequently return it back to its original position. This task requires the operator to move the robot end-effector away from a given position and return exactly to the same position. At the same time, positioning of the end-effector relative to an external reference (the can) in different degrees of freedom is also tested. The second task is to position and stack wooden blocks. This is a task that involves grasping and ungrasping, free movement as well as movement near obstacles.

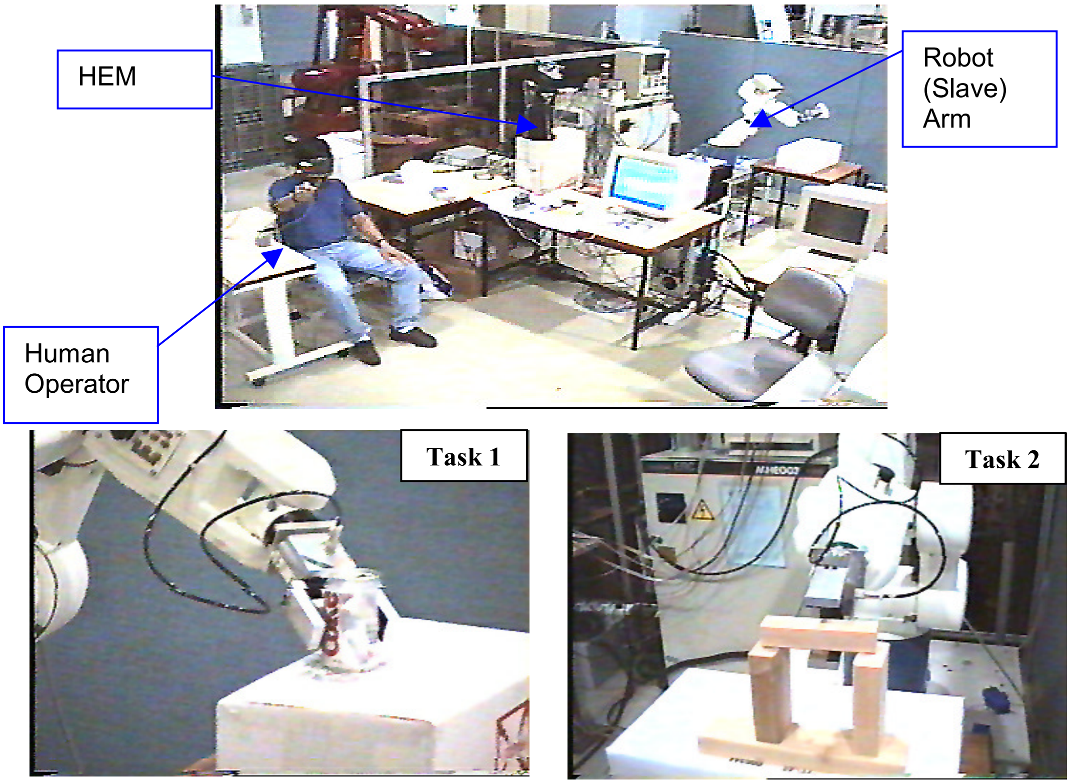

Figure 7. View of the telepresence system and the demonstration tasks.

The demonstration has shown that an untrained operator can quickly learn to use the system and perform the tasks with ease. These tasks, though simple, illustrated the capability and usefulness of the telepresence system developed.

5. CONCLUSIONS

With the successful integration of the hardware and software components, the HEM moves almost simultaneously with the robot arm. The human operator's arm and head positions are successfully obtained by the FASTRAK and sent to both the servo controller (for the HEM) and the robot controller via the PC. This unilateral control method provides the human operator with visual telepresence and enables him/ her to remotely control the robot arm as an extension of the arm.

The potential applications for this system are numerous. In Singapore, the military still uses manual methods for clearing blinds (explosives that fail to explode upon activation). Instead of using soldiers for this potentially hazardous task that requires very careful and skilled handling, the telerobot can be used. Remote piloted vehicles that are used for surveillance can also benefit from the use of the HEM that can provide the human operator a feeling of being on the craft itself, for better results. Underwater dredging or salvage operations can be conducted by teleoperated submersibles. Telesurgery can also be conducted through the use of the telepresence system. Operation rooms can be set up at location remote to the hospital and may save lives as precious time can be saved from the transportation of the patient to a hospital. The system can also be used for entertainment where the robot can be made to perform tasks like humans.

One limitation with the current telepresence system is the lack of force feedback during task execution. Current efforts are aimed towards using a haptic device on the operator side. The haptic device is to be employed for fine motion required in tasks requiring force/motion interactions. Gross motion can still be achieved either by moving the base of the haptic device or through the same magnetic tracking system tracking the operator's hand.

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