Remote Interaction for 3D Manipulation

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Abstract
In this paper, we present a two-handed 3D interaction approach for immersive virtual reality applications on a large vertical display. The proposed interaction scheme is based on hybrid motion sensing technology that tracks the 3D position and orientation of multiple handheld devices. More specifically, the devices have embedded ultrasonic and inertial sensors to accurately identify their position and attitude in the air. The interaction architecture is designed for pointing and object manipulation tasks. Since the sensor system guarantees 3D spatial information only, we develop an algorithm to exactly track the position of interest produced by the pointing task. For the object manipulation, we have carefully assigned one-handed and two-handed interaction schemes for each task. One-handed interaction includes selection and translation while rotation and scaling are assigned for the two-handed interaction. By combining one-handed and two-handed interactions, we believe that the presented system provide users with more intuitive and natural interaction for 3D object manipulation. The feasibility and validity of the proposed method are validated through user tests.

Keywords
Remote control, 3D interaction, 3D manipulation, virtual reality

ACM Classification Keywords
H5.2 User Interfaces

General Terms
Algorithms, design and experimentations

Introduction
In these days, 3D virtual reality (VR) is becoming increasingly popular and its applications span a variety of areas, such as data visualization [1], simulation [2] and games [3]. However, the widespread adoption of 3D VR interface in consumer electronics is limited by unnatural interaction techniques since most of them depend on traditional input devices such as keyboards, mice, joysticks, etc.

In order to solve this problem, game console manufactures have introduced motion sensing input devices that allow players to intuitively interact with gaming interfaces. For example, Nintendo's Wii controller adopts accelerometers for users to control digital objects with natural gestures [4]. The gesture-based input device is very useful for such a specific gaming application. However, for the virtual environments, the authors believe that more general and natural interaction schemes are desired since those VR applications are not confined to a specific task.

For this purpose, we present a two-handed spatial 3D interaction technique using remote control devices for immersive virtual reality (VR) applications. More specifically, we attempt to enable an intuitive manipulation technique: directly pointing and interacting with the digital objects in 3D VR environments.

Remote Interaction with Vertical Displays
Large vertical displays are effective at displaying 3D information. In addition, interfaces for vertical displays are designed based on the implicit assumption that users are located at a distance, which prohibits popular multi-touch interfaces from being applied. In such situations, 3D remote interaction technique is desirable.

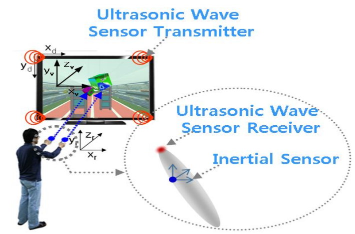


figure 1. 3D remote interaction system

Figure 1 illustrates the overall structure of the proposed 3D remote interaction system. The system includes sensor-embedded handheld devices and a display. The handheld devices have ultrasonic receiver, inertial sensors (accelerometers and gyroscopes), and a switch. The vertical display is equipped with four ultrasonic wave transmitters on the four corners. The combined ultrasonic sensing system and the inertial sensors provide accurate and reliable 3D position and orientation data of handheld devices. The six degree-of-freedom (DOF) motion data and the auxiliary button signal is transmitted to the main VR system (not shown in the figure) via wireless Bluetooth network. This system is different from Wiimote that uses IR camera and accelerometers [4]. The proposed system can detect full 3D position (x, y, z) and orientation information (roll, pitch, yaw or heading), while Wiimote provides rough 3D position, roll and pitch only. With the aforementioned advanced 3D measurement information, the proposed system can provide users with more flexible and freeform interaction gestures compared with Wiimote. For example, users can perform the natural multitouch-like gestures with the proposed system.

3D Direct Pointing Approach

The most popular and well-known approach to the pointing task at a distance is the indirect method based on mice or isometric joysticks [5]. Due to the limited 2D movement of such devices, the method is not efficient to point a digital object located in the complicated 3D virtual environment. For example, it is not an easy task to point an object on Z axis and occluded by another object. In the paper, we solve this problem by using depth perception (z-position) of the proposed system. The information of z-position enables mapping from real space to the corresponding virtual space very intuitively.

When a user tries to perform the pointing task, the presented system displays an appropriate visual guide on or around the target display. This approach is much like how one would point a laser pointer or flashlight at a desired point. However, since the adopted sensing system provides 3D tracking information only, we additionally develop an algorithm to identify the point of pointing as described below.

Figure 2 illustrates the proposed approach. Projection point (x, y) is a point which is projected from the input device position (x, y, z) onto x-y plane of display. The position of an interaction point consists of 2D direct pointing (x′,y′) and z-axis relative position (z′) from the input device. A change of the coordinate system is necessary since the position and orientation of the

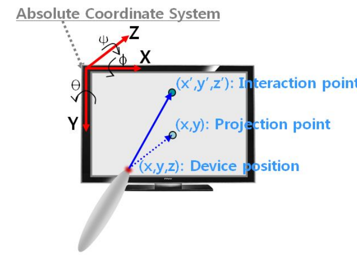


figure 2. 3D direct and absolute pointing

input device is given in tracking system coordinates. The resulting interaction point has to be transformed to calculate the corresponding 3D pointer position and an operating system specific mouse event is generated.

$$(x', y') = (x + |z| \tan\theta, y - |z| \tfrac{\tan\phi}{\cos\theta})$$

The relative position of z is obtained by equation

$$z' = T \cdot \frac{MaxZ - z}{MaxZ - MinZ}, \; MinZ \le z \le MaxZ$$

where MinZ and MaxZ are the maximum and minimum of position where the input device can be translated toward z axis in real 3D space, and T is the scaling factor for the 3D coordinate system between real and virtual space.

3D Manipulation

For the object manipulation, we selected gestures for four major tasks: selection, translation, rotation and scaling. After the preliminary empirical test of various gestures, we designed one-handed tasks (*selection and translation*) and two-handed tasks (*rotation and scaling*) for the intuitive and sophisticated 3D manipulation. The two-handed interactions provide users with the natural multi-touch like feeling of interaction at a distance. This design approach is possible because our sensing system can track 3D movement and orientation of multiple devices simultaneously.

- One-handed tasks

<Selection>

First, in order to interact with virtual objects, users need to identify the desired targets. This task has to be accomplished by an interaction technique itself. Selection can be simply implemented by using image-plane techniques [6].

<Translation>

When a 3D object is selected and translation is intended, a movement in 3D virtual space can be implemented easily. For example, the interaction information on the display projection's x and y direction can by mapped one-to-one to the virtual object. Also, when its translation along the depth axis of 3D virtual space is desired, users would use intuitively the gestures of a translation along the z direction of the absolute coordinate system.

- **Two-handed tasks**

<Rotation>

Rotation can be implemented very naturally. Figure 3 shows a rotation around an arbitrary axis **u** in 3D space. For instance, one hand pointer determines the center of rotation (a), while the amount of rotation ($\boldsymbol{\theta}$) is specified by circular movements around the center ($b \rightarrow c$). In 3D the center of rotation and the rotation axis have to be determined by means of a 3D point and a vector.

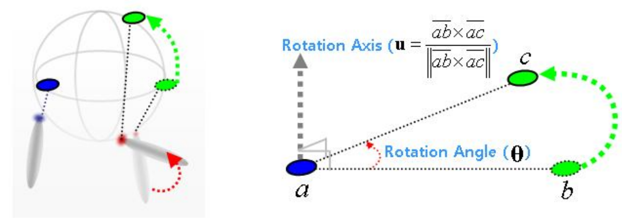
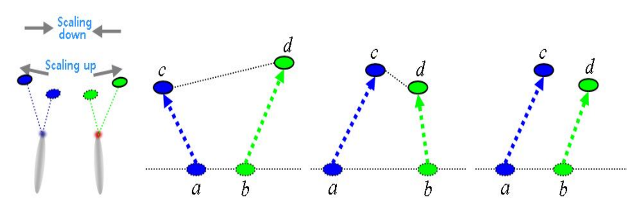


figure 3. Rotating Gesture & Rotation around an arbitrary axis

<Scaling>

Scaling in 3D space can be implemented very intuitively by means of two-handed pinch gestures ($a \rightarrow c$, $b \rightarrow d$ in figure 4). In order to scale a virtual object, we select it with the input devices and bring them together to scale down, or separate them to scale up.



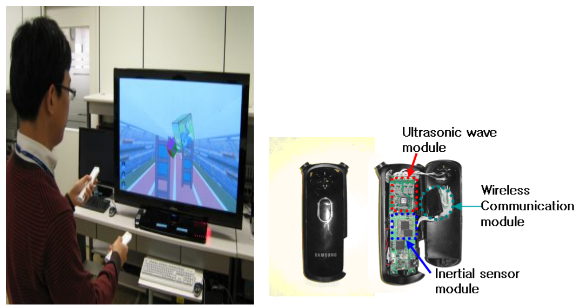
(a) Gesture (b) Scaling up (c) Scaling down (d) Non-scaling

figure 4. Scaling

If the movements of two devices are heading in different directions as shown in figure 4, the gesture can as well be treated as a zoom-effect.

User Study

The primary goal of the user study is to evaluate the feasibly of the proposed interface for the selection, translation, rotation and scaling tasks. The study was conducted on a PC-class desktop computer with a 50" Full HD display. Figure 5 (a) shows a user participated in the user study and fig. 5 (b) depicts the developed controllers of the proposed 3D interface. The sensing system can track 6 DOF 3D movements of the devices.



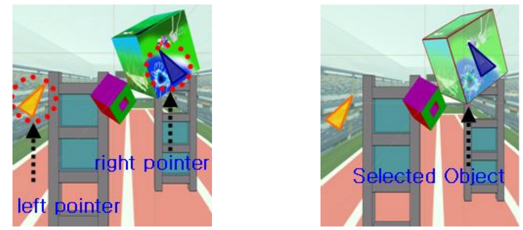
(a) User Test (b) Input Devices

figure 5. Remote interaction system for 3D manipulation

A component of our VR system receives the 3D tracking data of the input devices and transforms them into the corresponding commands for the virtual environment. Figure 6 shows our designed selection, translation, rotation, and scaling tasks for 3D manipulation.

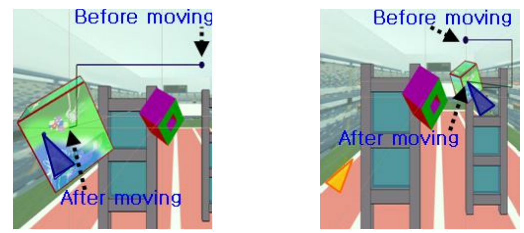
Ten subjects (8 males and 2 females), aged 20~35, participated in the experiment. All participants stand 3 meters away from the display. Before the user study, all subjects were asked to practice 7 gestures for 3D manipulation with the input.

<Selection>



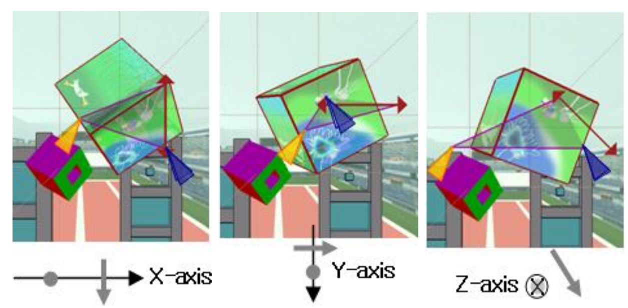
(a) Pointing (b) Selection

<Translation>



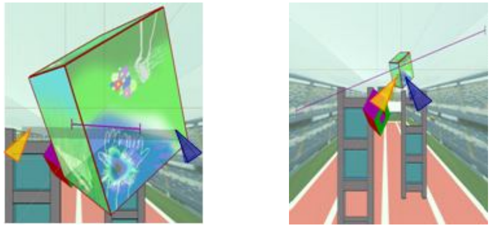
(c) Moving forward (d) Moving backward

<Rotation>



(e) x-rotation (f) y-rotation (g) z-rotation

<Scaling>



(h) Scaling up (i) Scaling down

figure 6. 3D manipulation

After all subjects performed each gesture by 100 trials respectively, we evaluated the success rate of the 3D manipulation tasks. As mentioned before, selection and translation tasks were used by one-handed device and rotation and scaling tasks were performed by two-handed device.

The average rate of correctly recognized gestures was 95.6 percent. The averaged recognition rate for each of the seven gestures in shown figure 7. During 3D manipulation tasks, all subjects completed quickly and easily.

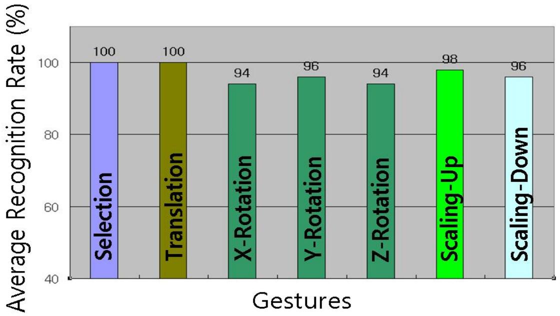


figure 7. Average recognition rate of 3D manipulation

Conclusions

In this paper, we presented a two-handed spatial 3D interaction approach using handheld devices with hybrid 3D tracking system to intuitively manipulate an object in a 3D virtual environment. The feasibility and validity of the proposed method are validated through user tests. The future research along the same line includes the comparison of the proposed method with other 3D interaction techniques, refinements of the interaction architecture with additional 3D world navigation capability, and the extension to the multi-user environment.

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