Interaction Techniques using a Spherical Cursor for 3D Targets Acquisition and Indicating in Volumetric Displays

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Abstract

We present several innovative interaction techniques for 3D target acquisition and indication. These techniques make use of the shape of our cylindrical multi-touch interface, which we are developing as an interface for a volumetric display. Our interaction techniques are used to control a spherical cursor in 3D space. Notably, our techniques use a two-handed operation in which the position and size of the area touched is mapped directly to the position and size of the spherical cursor. This mapping can instantly determine the 4DOF of the spherical cursor, i.e., its 3D coordinates and its radius, and thus allows rapid 3D target acquisition and indication.

1. Introduction

It is useful to be able to select or indicate objects in 3D space when examining 3D models of objects such as artistic sculptures, ruins, and the structures of DNA sequences and proteins, and the 3D results of scientific visualization. When this is possible, users can use demonstratives in their discussions, such as "Look at this atom!" or "These will be too weak." Moreover, after selecting the objects in the 3D model, users can easily perform commands to examine the objects in detail.

A pointer is used in traditional 2D GUIs. To indicate an object, the user moves the pointer to the object. To indicate more than one object, the user first moves the pointer to the left top corner of the bounding rectangle of the objects and drags the pointer to the right bottom corner of the rectangle. Then the user can also execute some command by double-clicking or selecting a menu command.

The objective of our research is to develop easy interaction techniques for acquire objects or indicating a 3D area in 3D space. Here, the term *easy* means that these techniques do not force the user to wear any special devices, can be used even in public places, and are simple and thus easy to remember. Therefore, our approach differs from others (e.g., [4]) that use special input devices such as data gloves or Phantom.

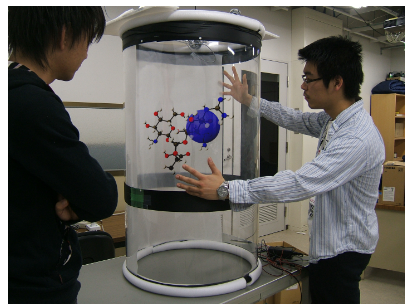

Figure 1. Conceptual image of two users controlling a spherical cursor using our interaction techniques on a CMTI.

This paper describes innovative interaction techniques for 3D target acquisition and indication. The techniques use our cylindrical multi-touch interface (CMTI) [5, 6][1], which we are developing as an interface for a volumetric display. Figure 1 shows a conceptual image of two users examining the 3D model of a complex molecule. The user on the right uses our proposed interaction techniques to control the spherical cursor of the molecular viewer to indicate the central part of the model.

The features of our interaction techniques are as follows.

- We use a semi-transparent sphere as a cursor. The sphere corresponds to the pointer in a traditional 2D desktop environment.
- We rely on two-handed operation to determine both the size and 3D position of the sphere simultaneously. The user can thus control the sphere rapidly. Moreover, because these techniques require nothing more than the user's bare hands, our techniques are suitable for use in public places.

The second of these features is particularly innovative.

[1] Our web site [5] contains CMTI demonstration videos.

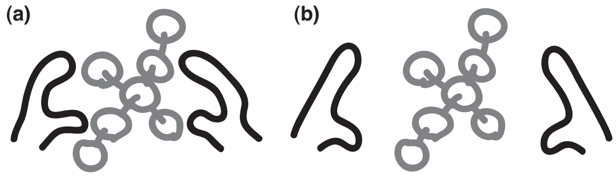

Figure 2. Gestures for pointing to 3D objects or for indicating 3D volumetric area in the real world.

In this paper, after a brief review of our CMTI, we present the basic concepts behind our interaction techniques. We then provide the design and implementation details of our interaction techniques using the CMTI.

2. CMTI: An interface for a volumetric display

Our CMTI[5, 6] is a multi-touch interface for volumetric displays. It allows users to conduct 3D operations for objects rendered in the cylinder in new ways that are made possible by the CMTI's cylindrical shape.

Our CMTI is designed to be used even in public places, such as museums, for browsing 3D models of artistic sculptures or ruins, and laboratories, for examining 3D data or the results of scientific visualization. Therefore, we adopted the sensing technique introduced by Han [3] to detect points contacted by the user's bare hands. The technique uses an acrylic surface and infrared LEDs. We used an acrylic pipe 600 mm in diameter and 1000 mm high as the basic structure of the CMTI. This size was chosen so that the pipe would be large enough for an adult to hold. Note that the structure of the CMTI allows the user to interact with the device from any direction.

Compared to the hemispherical multi-touch surface [2], the CMTI is fairly compact in terms of the floor space it occupies, because a cylinder has a greater total surface area $2\pi rh$, where r is the radius and h is the height than a hemisphere $2\pi r^2$ for $h > r$.

3. Basic concepts

This section describes the basic concepts of our interaction techniques for pointing to objects or for indicating a volumetric area using a sphere as a cursor.

3.1. Real-world gestures for pointing to 3D objects or for indicating 3D volumetric areas

The design of our interaction techniques for pointing to objects or for indicating a volumetric area in 3D space is based on the concepts involved in the deictic gestures used in the real world (such as those shown in Figure 2. Suppose that two people are examining a complex molecular model. If one person wants to indicate a particular small area (e.g., one atom) of the molecule to the other individual, they would move both hands, as shown in Figure 2, while saying "Look at this area!" In contrast, to indicate a larger area within the molecule, the person would spread the fingers and use both hands, as shown in Figure 2b.

Note that the two deictic gestures indicated above specify both the size and the position of the target simultaneously. The target's size is specified using small or large hand gestures with both hands, whereas the target's position is specified by arranging both hands symmetrically with respect to the target. Our approach incorporates these intuitive deictic gestures to specify both the size and the position of a cursor in 3D environments.

3.2. Semi-transparent sphere as a cursor

Our interaction techniques use a semi-transparent sphere as a cursor. We refer to this sphere as a *spherical cursor*. The spherical cursor is *always* present somewhere in the cylinder, similar to the cursor in traditional 2D desktop environments. Our techniques enable the user to move the spherical cursor anywhere in the cylinder.

Moreover, because the spherical cursor has a volume, our techniques enable the user to scale the spherical cursor to the desired size. This allows the user to point to adjoining objects and to indicate a volumetric area, even a blank area, in 3D space. To execute a command on a group of objects, the user moves and scales the spherical cursor to contain the objects, and executes the command from a menu. To point only to a single object, e.g., one atom in a molecular viewer, the user scales the spherical cursor to the minimum size and moves it to the object.

Implementing scaling usually means increasing the DOF that the user must control. Therefore, it is challenging to develop interaction techniques for scaling and moving the spherical cursor easily and rapidly.

4. Design of interaction techniques using the spherical cursor on CMTI

This section describes the design of interaction techniques that enable the user to define the size and the position of the spherical cursor easily and rapidly, using the shape of the CMTI.

Our interaction techniques consist of two operations: a two-handed operation and a one-handed operation. The most significant feature of our design is the two-handed operation, which allows the user to scale and position the spherical cursor simultaneously, by directly mapping the

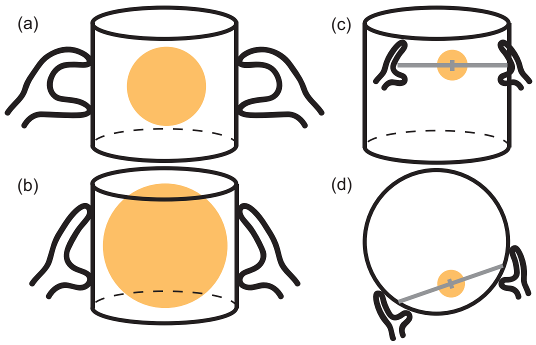

Figure 3. Size and the position of the spherical cursor in scale&position**. The sizes and locations of the two touched areas are mapped directly to the size and the position of the spherical cursor, respectively.**

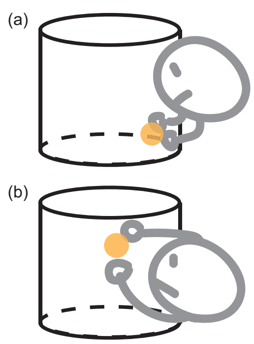

Figure 4. Sample usages of scale&position**.**

posture of the user's hands to the cursor's size and position. These two operations are described in detail below.

scale&position This is a two-handed operation to determine both the size and position of the spherical cursor. In this operation, the size of the two areas touched is mapped directly to the size of the spherical cursor. As Figure 3 shows, the radius of the spherical cursor decreases when the sizes of the touched areas decrease. Therefore, when the user contracts one or both hands while touching the surface, as if pinching something on the surface, the spherical cursor becomes small, as shown in Figure 3a. When the user expands one or both hands, the spherical cursor becomes large, as shown in Figure 3b. Moreover, the positions of the two touched areas are directly mapped to the position of the spherical cursor. More specifically, the center of the spherical cursor is placed midway between the two touched areas, as shown in Figure 3c and Figure 3d. Therefore, when the user wants to place the spherical cursor closer to the user's body, the user should touch the near side of the CMTI with both hands, as shown in Figure 4a. In a similar way, the spherical cursor can be placed in the upper part of the cylinder by touching the upper surface of the CMTI using both hands, as shown in Figure 4b.

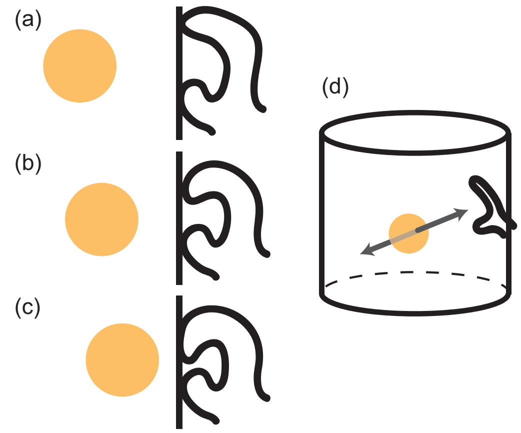

Figure 5. Amount and direction of the movement of the spherical cursor in move**.**

move This is a single-handed operation used to move the spherical cursor from its current position. As Figure 5 shows, the spherical cursor is moved to the touched area as the size of the touched area shrinks (Figure 5a → 5c). This operation imitates the action of a hand grasping a ball. Conversely, the spherical cursor moves away from the touched area as the size of the touched area increases (Figure 5c → 5a). More specifically, for both these actions, the direction of the movement is given by the vector between the center of the spherical cursor and the center of the touched area, as shown in Figure 5d. The amount of movement is determined by the amount of change in the touched area. The same action can be repeated two or more times to move the spherical cursor a long distance.

Note that the above scale&position can instantly determine four DOF of the spherical cursor, i.e., its 3D coordinates and its radius. The scaling of 3D cursors is usually problematic because it requires increasing the DOF that the user must control, but our scale&position is a novel solution to that problem.

Moreover, the combination of the above two operations on CMTI allows them to be used on a case-by-case basis, resulting in two distinct advantages. First, the combination does not force the user to always keep both hands on the surface; hand contact is required only when the size of the spherical cursor must be changed. Therefore, when only the spherical cursor position must be changed, one hand is free for other purposes. This reduces the burden of our interaction techniques. Second, although both operations can

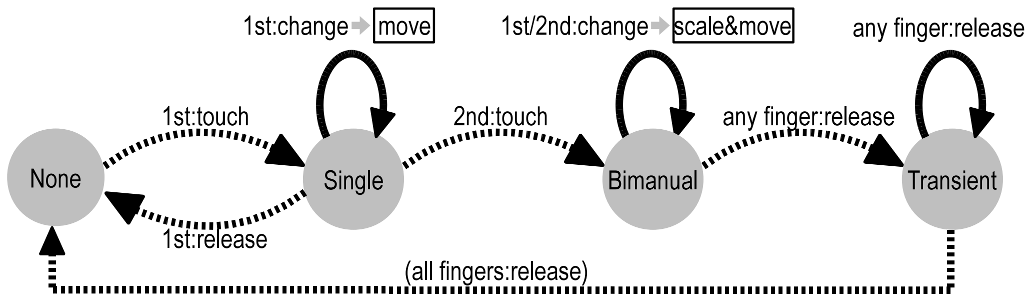

Figure 6. Finite state machine used to detect scale&position **and** move**.**

be used for adjusting the position of the spherical cursor, the user can use scale&position for coarse or large adjustments and move for fine adjustments. More specifically, because scale&position relies on a direct mapping between the positions of the touched hands and the position of the spherical cursor, scale&position is suitable for coarse/large adjustments. Moreover, although it is sometimes difficult for the user to concentrate on adjusting both the size and position of the cursor simultaneously, the user can use the single-handed operation for changing only the position of the spherical cursor. This combination of operations contributes to the usability of our interaction techniques.

Note that the size of touched areas jitters somewhat due to small involuntary hand movements, producing jitters in both the size and the position of the spherical cursor. However, because the user can readjust by touching the surface again immediately after lifting the hands, these jitters do not cause any serious problems.

5. Implementation details

Detection of operations

Our interaction techniques use a finite state machine, illustrated in Figure 6, to make the detection of scale&position and move robust.

The system consists of four states: None, which is the initial state; Single, in which the user can use move after touching the surface with one hand ("1st" in the figure); Bimanual, in which the user can use scale&position after the user touches with the second hand ("2nd" in the figure); and Transient, which occurs after the user raises any finger or hand from the surface. In Transient, any finger movements are ignored, keeping both the size and position of the spherical cursor stable. This state is included to prevent unintended changes of the spherical cursor size and/or position from occurring after the user has set the desired size and position, because raising a finger usually involves changing the positions of other fingers. Commands, such as editing, can be executed in None, where a pull-down menu

(a)

(b)

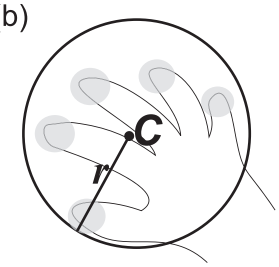

Figure 7. Image of the CMTI surface touched by the user's fingers, and the parameters calculated from the image.

appears after the user continues to touch the same spot on the surface with one finger. The menu can be manipulated with the finger in the same way that a pull-down menu is manipulated using a track pad.

Note that the above model allows the user to use the preferred hand for the single-handed operation. This approach is similar to the order-based approach [1], which assigns a role to each finger based on the order in which the fingers touch the surface. In our approach, the user can use either hand for the single-handed operation, depending on the user's position with respect to the surface.

Size and position of the spherical cursor

This section describes the algorithm to determine the size and position of the spherical cursor in our current implementation.

The size of the spherical cursor is determined by the *hand size*, which is r in Figure 7, when scale&position is executed. Our CMTI uses cameras to detect the user's touch on the surface of the cylinder. When the user's hand touches the surface, an image, such as that shown in Figure 7a, is obtained from the cameras. The white areas in this image are the CMTI surface touched by the user's fingers. The system then calculates the center of gravity of the touched areas (C in Figure 7b) for each frame. Now,

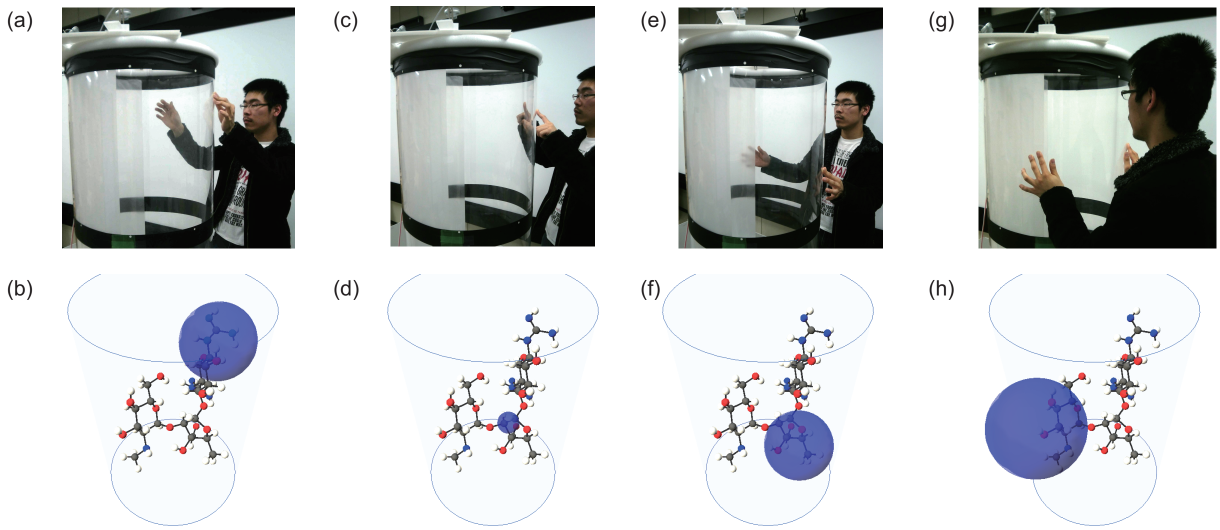

Figure 8. Photographs of the user using scale&position**, one of the proposed interaction techniques, to control a molecular viewer. (upper) When the user touches the CMTI, (lower) both the size and the position of the spherical cursor change.**

r is the length of the line between C and the point in the touched area that is farthest from C. The size of the spherical cursor is a linear function of the size of both hands. The maximum diameter is the diagonal of the bounding cuboid of the cylinder, enabling the spherical cursor to be enlarged to cover the area of the whole cylinder. The minimum diameter is a predefined constant.

The position of the spherical cursor is determined by C and r. When scale&position is executed, the center of the spherical cursor is placed at the midpoint of the segment between the two C. When move is executed, C and r are used to determine the direction and amount of movement, respectively. Note that the center of the spherical cursor is kept within the cylinder for move.

6. Testbed system and sample application

To validate our interaction techniques, we implemented a testbed 3D molecular viewer, which displays molecular data in MOL format on our CMTI. Figure 8 shows how the user can manipulate the 3D molecular viewer using our interaction techniques. Note that all of the four photographs in the upper row of this figure were taken from the same location. In these photographs, the user executes scale&position by touching the CMTI with both hands. When the user touches the CMTI surface, as shown in Figure 8a, c, e, and g, the spherical cursor in the molecular viewer changes size and position appropriately, as shown in Figure 8b, d, f, and, h, respectively. This demonstrates that the user can set the spherical cursor size and position by changing the posture of the hands, as if making deictic gestures to point to 3D objects in the real world. Note that because the CMTI allows operation from any direction, the user can go to any side of the CMTI to examine any part of the 3D object more closely (Figure 8g) and touch the CMTI immediately to adjust the spherical cursor, as if examining some interesting part of a large sculpture in a museum.

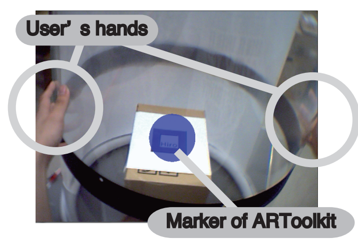

Figure 9. Photograph of the image, including the spherical cursor, seen by the user wearing a video see-through HMD.

Although, we originally designed our CMTI to be used with a volumetric display at the center, we are currently testing the proposed interaction techniques using two alternative installations. One uses a sheet of tracing paper pasted on half of the CMTI surface, which appears as the white surface of the CMTI in Figure 8a, as a screen for rear projection. The other uses a video see-though HMD. Figure 9 is a photograph of the image, including the spherical cursor, seen by the user wearing a video see-though HMD. We currently place an ARToolkit marker at the center of the CMTI bottom base, as shown in Figure 9. A camera is attached to the HMD to track the position of the CMTI relative to the camera. The user's view, which is rendered on the HMD, is constructed by combining the image from the camera, which includes the CMTI and the user's hands, calibrated 3D models, and the spherical cursor.

Tests of our interaction techniques indicate that our proposed techniques work well for controlling volumetric displays.

7. Related work

The idea of using a semi-transparent volume as a cursor is generally the same concept as that of the Silk Cursor [10] and other 3D volume cursors. That is, semi-transparency provides occlusion cues during target acquisition. There are some systems, such as the 3D Bubble Cursor [8], that use a sphere as a cursor. Moreover, many other research initiatives have explored the use of two-handed interactions to control a volume cursor. For example, two-handed interactions to control a scalable volume cursor have been evaluated [7]. Among the most closely related works is Balloon Selection [1], in which a spherical cursor above the surface is controlled by multi-fingered interaction on a flat multi-touch panel. Another closely related work is a 3D selection technique for a volumetric display using the hemispherical multi-touch surface [2]. In contrast to the above works, we focused on providing novel interaction techniques for controlling four DOF using both the cylindrical shape and the multi-touch sensitivity of the CMTI.

Our interaction techniques use a touch panel as its input device. However, our touch panels are not gesture-based interfaces like those used in many other interfaces based on touch panels, such as that described by [9]; these sometimes force the user to remember a complex command set. Our interaction techniques require the user only to become accustomed to the mapping between the size and position of the user's hands and those of the spherical cursor. Therefore, we believe that our techniques are well suited for use in public places.

8. Summary and future work

We have presented innovative interaction techniques for 3D target acquisition and indication. The techniques use the shape of our CMTI, which we are developing as an interface for a volumetric display. Our techniques consist of two operations. scale&position is a two-handed operation to determine both the size and the position of the spherical cursor. In this operation, the extent of the two touched areas is directly mapped to the size of the spherical cursor. move is a single-handed operation used to move the spherical cursor from its current position. The most innovative feature of our work is that scale&position can instantly determine four DOF of the spherical cursor, i.e., its 3D coordinates and it radius, and thus allows rapid 3D target acquisition and indication.

As future work, we plan to develop a filter to remove the jitter of the touched areas caused by small involuntary movements of the hands. This will make the spherical cursor easier to see during scale&position. We also plan to place a real volumetric display in the CMTI and to conduct a formal user study of our interaction techniques.

Acknowledgements

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