Exploring Volume Visualization with Whole-hand Multitouch Gestures

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Abstract
Exploded views and cutaway views have been demonstrated to be powerful visualization techniques to explore the complex internal structures in 3D volume data. Current approaches for creating them are mainly based on algorithms with very limited user controls. This paper proposes a novel set of whole-hand multitouch gestures for interactive creation and manipulation of these views on 3D volume data. Moreover, users can also interactively perform bimanual 'V'-shape cut and volume exploding, remove unwanted volume partitions to effectively create cutaway views, and create threshold-based volume segmentation and exploded views. Our proposed interaction design was also tried out by eight participants in a preliminary pilot study.

Categories and Subject Descriptors (according to ACM CCS):   [I.3.6]: Computer Graphics—Interaction techniques

1. Introduction

Volume data is now becoming increasingly pervasive in many disciplines of scientific study, appearing not just in medical scans, but also in meteorological studies, intergalactic simulations, and 3DCT of multi-material components. However, volume data often obscures complex internal structures that are occluded when viewed from the outside, and since we normally just show them on a 2D display, efficient visualization and interaction techniques are thus highly critical to improve the data exploration.

Regarding this, a wide variety of visualization methods has been proposed. Among them, exploded views [BG06] and cutaway views [JDE03] have been demonstrated to be very powerful techniques, evidenced by their wide applications in medical literature for technical illustrations and assembly manuals for mechanical devices. By these methods, we can explode and unveil volume data about or around the areas of interest rather than just using a partitioning plane to clip the volume. Hence, we can have more flexible controls with focus and context.

However, existing approaches for creating these views mainly rely on algorithms with very limited user controls [JDE03]. Hence, this work proposes a novel set of whole-hand multitouch gestures, where one can flexibly use hand-rail gestures to cut and explode the data volume, create threshold-based volume segmentation by density-range selection, and perform a flexible bimanual volume cutting and exploding. By this, we can take advantage of novel interaction devices, e.g., multitouch tabletops, where one can

explore the data with more degrees-of-freedom directly with multiple fingers, and we can also naturally use our hands to cut and explode the volume data similar to the way one would use a surgical knife to cut and slice body parts on a surgical table. The main contributions of this work are:

- First, we propose a set of novel whole-hand multitouch gestures, e.g., hand-rail gestures (edge of our hands) to naturally and directly cut and explode 3D volume data; these are view-dependent exploded-view manipulation methods subject to user's hand movement;

- Based on the proposed gestures and controls, we develop a volume visualization system on a multitouch tabletop; we also perform a preliminary pilot study for eight participants to try out our interaction methods;

2. Related Work

This section surveys the use of multitouch gestures on interactive surfaces and discusses touch-based volume data interaction. Cohé et al. [CDH11] designed the tBox widget for 3D transformation on touch screens. Wigdor et al. [WBP*11] proposed a set of hand-shape gestures to allow precise 2D object manipulation. Recently, Martinet et al. [MCG12] classified and evaluated multitouch interaction for manipulating 3D virtual objects. Compared with these works, which employed finger/hand gestures to manipulate 2D/3D models, this work proposes a novel set of whole-hand multitouch gestures for exploring volume data.

Elmqvist and Tsigas [ET08] classified existing occlusion management techniques, and presented several designs for

reducing 3D occlusion. Rydell et al. [RLY*10] developed a multitouch interface on a tabletop display for virtual autopsy, where users can manipulate and slice a volume data with fingers. Díaz et al. [DMNV12] developed a medical visualization system, supporting cross-sectional cuts and extruding the structures of interest. Coffey et al. [CML*12] proposed a world-in-miniature design by employing a multitouch table with a stereoscopic display wall for efficient slicing plane manipulation. Compared with these works, which employed slicing and clipping for volume exploration, the whole-hand multitouch gestures proposed in this work allows us to create and design cutaway and exploded views of the volume data directly with our hands.
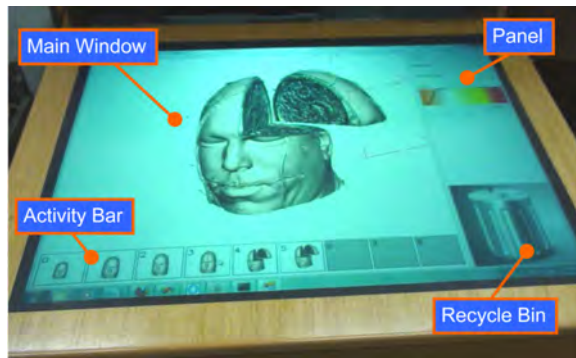

Figure 1: *Our interface and custom-built multitouch table.*

3. Our System Setup

Hardware. Our system runs on an Alienware 51 ALX workstation (quad-core 3.20Ghz CPU, 12GB memory, and GeForce GTX 580), and a custom-built vision-based multitouch tabletop surface ($36.6'' \times 27.7''$) with an internal short-throw projector (1024×768) for detecting both fingers and hands movement, see Figure 1.
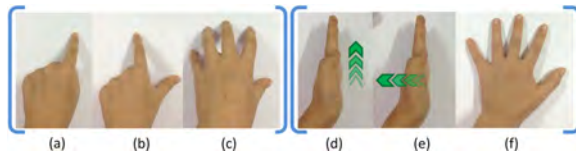

Figure 2: *Basic finger and hand gestures employed in our system; green arrows indicate the hand movement direction.*

User interface. Figure 1 also shows the user interface. The main window presents the volume visualization, which is done by CUDA-based ray casting, and supports various finger and hand gesture interaction. Below it is the activity history bar with an array of thumbnail snapshots for undo, redo, or changing the visualization state via a drag-and-drop. The panel on the right provides touch-enabled controllers on the volume visualization, and a recycle bin for disposing unwanted cut-away volume portions to reduce screen clutter.

Hand gesture detection. Our multitouch table detects

whole-hand and multi-finger gestures by processing and analyzing the infrared images captured from an IR CCD camera under the screen, see Figure 2. We distinguish between whole-hand and multi-finger gestures by examining the area of the convex hull surrounding the detected contact(s).

As illustrated in Figure 2 (from left to right), the supported finger gestures include one-finger drag, two-finger pinch, and five-finger pan, whereas the supported whole-hand gestures include hand-rail cut gesture, hand-rail explode gesture, and open palm gesture. To differentiate between the hand-rail cut and hand-rail explode gestures, we first detect the hand-rail orientation on the tabletop, say $\hat{d}_{rail}$, and the hand movement direction, say $\hat{d}_{move}$. If $\hat{d}_{rail}$ and $\hat{d}_{move}$ are roughly aligned within an angular difference of less than 20 degrees, we regard the hand gesture as a hand-rail cut gesture. Otherwise, we regard it as a hand-rail explode gesture.

4. Usage Scenario and Interaction Gestures

Given the setting of interacting with volume-based medical data on a multitouch tabletop, e.g., such as the one shown in Figure 1, that supports both whole-hand and multi-finger gestures, the usage scenario would involve: First, one can rotate, translate, and scale the volume data to examine it from different angles; then, he/she may want to cut it and explode (rotate and translate) the partitioned volumes. Further than that, one may also be interested in examining the data density threshold and seeing through the data, etc., see Figure 3.

To support the usage scenario presented above, we propose the following set of interaction gestures:

1) Basic manipulation. The interface provides 3 basic structure-preserving manipulations, namely 3D object rotation, scaling and translation: *One-finger drag* to rotate the volume object; for off-object area, this action applies to the entire 3D world; *Two-finger pinch* to scale the object and *Five-finger pan* to translate it parallel to the screen plane; for off-object area, these actions apply to the screen view.

2) Hand-rail cut gesture. We propose to use whole-hand hand-rail gesture as a natural way to cut volume objects similar to that of a surgical knife. The procedure is as follows:
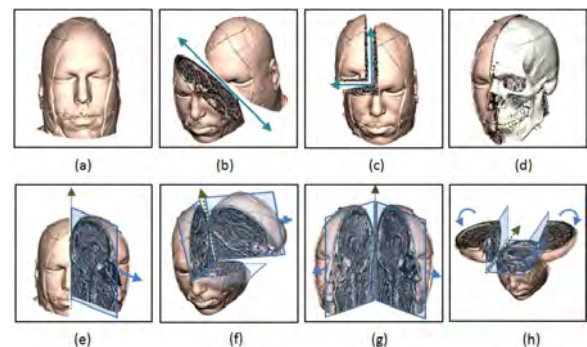

Figure 3: *Examples of cutaway views and exploded views created by our whole-hand multitouch interface.*
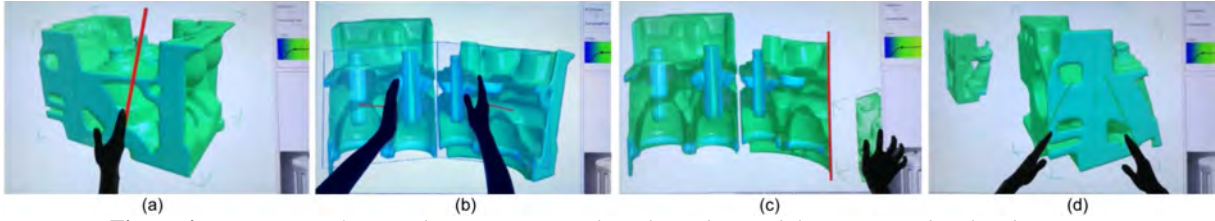
Figure 4: *A sequence of manipulation actions on the volume data and the corresponding hand gestures.*

First, one touches and slides his hand rail over the tabletop surface. The orientation and movement of the hand rail suggest the direction along which the desired incision is to be made. Simultaneously, our interface will draw a red line as a visual feedback to indicate the detected direction. Once our hand is lifted, the volume object is partitioned according to the red line. After that, we can also successively apply this simple cut gesture to continue partitioning the volume with more cutting planes. Note that if the cut crosses several volume pieces, we partition only the first volume piece crossed by the cut; this is to avoid unintentional cuts.

Furthermore, our interface also allows us to apply and move two hand rails simultaneously. Hence, we can create a 'V'-shape cut, as shown in Figure 1. Note that this style of cutting often appears in exploded-view visualization because it allows us to center on the internal structure (focus) while retaining more of its surroundings (context). Moreover, since the locations of the cuts are directly defined by our hand locations, we can have flexible controls on specifying the angular opening in the 'V' shape.

3) Open Palm gesture. To nullify an existing cut, we propose to use the open palm gesture on the touch surface, see Figure 2(f). Since unintended touches may happen on touch surfaces, having more undo capability can help to permit easy reversal of actions.

4) Hand-rail explode gesture. After the hand-rail cut gesture, we can further use the hand-rail explode gesture to create and manipulate exploded views. Our idea here is that a hand-rail moving along with the rail produces a volume cut while a hand-rail moving sideway produces a volume exploding. Hence, after the hand-rail cut gesture, we next can move our hand rail sideway, i.e., perpendicular to the cutting plane (red line), as a simple gesture to explode the volume portion that was partitioned.

In the implementation, we typically need to deal with one issue. Since our interface allows multiple cuts such as the bimanual 'V'-shape cut, there could be more than one way to explode the partitioned volume, e.g., after a 'V'-shape cut such as the one shown in Figure 5(b), which corresponds to an upward volume exploding, we could also explode it to the right. Hence, we propose a simple solution by selecting among the rotational axes (used in producing exploded views) based on $\hat{d}_{move}$, i.e., the hand movement direction. In detail, we select the rotational axis whose projection on the 2D screen is the most perpendicular to $\hat{d}_{move}$. Therefore, the resulting rotation that generates the exploded view could

follow the hand movement. This mechanism is particularly useful since we could perform a number of cuts and still can flexibly create an exploded view accordingly.

Moreover, similar to the case of 'V'-shape cut, we can also use two hand-rail explode gestures to produce exploded views with both hands at the same time. This gesture allows us to open up the cutting seam from the hand-rail cut gesture and to produce an exploded-view visualization like opening a curtain with both hands, see Figure 3(g) and Figure 4(b) for examples. Moreover, if we first cut the volume data horizontally, tilt our view up and cut it again, we can apply this bimanual hand-rail explode gesture to quickly create the exploded-view visualization shown in Figure 3(h).

5) Parallel-plane exploding. Other than using 3D rotations to create exploded views, another way of creating exploded views is to cut the volume and apply the translation gesture, i.e., five-finger pan, on the partitioned volume to explode its internal structures, see Figure 3(b). Moreover, we may also perform the 'V'-shape cut and then the translation gesture to create an exploded view, see Figure 3(c).

6) Threshold-based segmentation and exploded view. We employ a double-ended slider for specifying a density range. By this, we can create *threshold-based segmentation and exploded views*. Our idea is as follows: First, we tune and select a density range on the right panel before cutting and exploding the volume data on the tabletop. Then, during the hand-rail explode gesture, only voxels outside the selected density range will be affected by the cut/exploding while other voxels will remain untouched. For example, we can apply this method to fix high-density voxels such as bones, and produce the cutaway-view visualization shown in Figure 3(d). Note that we disposed the exploded volume partition by dragging it to the recycle bin, see Figure 1.

5. Results

Working scenario. Figure 4 shows a sequence of actions on manipulating a machine part volume data. First, we apply a hand-rail cut gesture to the volume data (see the cutting plane in red), see Figure 4(a), followed by a bimanual hand-rail explode gesture to open up the two partitioned volumes, see Figure 4(b). After that, we further cut the partition on the right and remove the new partition by the recycle bin, see Figure 4(c). Lastly, we change our view and perform a 'V'-shape cut on one of the remaining volumes, see Figure 4(d).

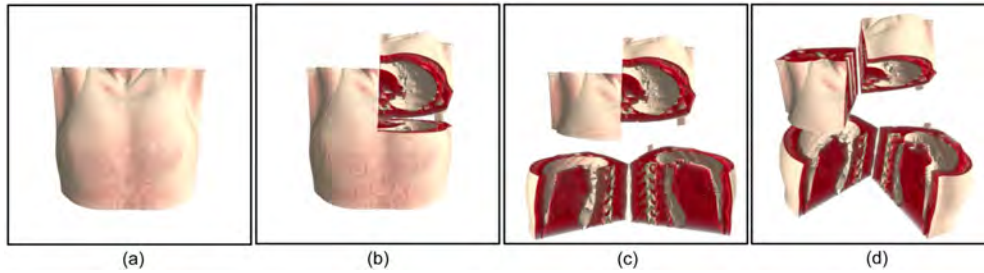**Pilot study.** We conducted a pilot study with 5 males and 3

Figure 5: *The task in the pilot study.*

females (aged from 22 to 28) to try out our interface. Four of them had experience in manipulating 3D volume data, and none of them have used large multitouch tabletops before.

In this study, we defined two states: an *initial state* (see Figure 5(a)), which is the initial condition of the visualization, and a *target state* (see Figure 5(d)), which is the target visualization that the participants were expected to derive by using the gesture set. Each participant first had around 2 minutes to practise and get familiar with our interface. After that, they can try our interface and perform a volume manipulation task, which required them to at least cut the volume data twice, and explode it in order to arrive at the first intermediate state (see Figure 5(b)). Next, they can translate and cut the lower volume part, and explode it to reach the second intermediate state (see Figure 5(c)). Lastly, they can rotate the entire 3D world to see the partitioned volumes from another view and reach the target state (see Figure 5(d)).

Table 1: *Pilot study results.*

User	1	2	3	4	5	6	7	8
Time Taken (sec)	60	54	92	115	74	48	65	42
Ease-of-use	3	5	4	4	4	4	5	4

Discussion and Limitations. Our program also recorded the total time taken by each participant to perform the task in the pilot study: starting from the moment when the participant hit a start button till the moment when the target state is reached. At the end, we also asked each participant to rate the ease-of-use of the proposed gesture set in a scale of 1 (totally disagree) to 5 (totally agree). Table 1 summarized the results: Most participants can finish the task within two minutes while the ratings were mostly positive. During the study, one participant complained that he could not cut a small partial volume accurately, which is due to the precision with touch-based interaction. Second, our method has hand occlusion problem like common multitouch interfaces. Lastly, the cutting seam in our current system must be straight.

6. Conclusion

This paper proposes a novel set of whole-hand multitouch gestures, enabling users to quickly design and create cutaway- and exploded-view visualizations. A number of novel interaction methods are proposed in this work, e.g., hand-rail gestures for creating cutaway and exploded views, a flexible 'V'-shape cut method that employs both hands

simultaneously, a curtain-opening exploded-view action, as well as the threshold-based segmentation and exploded view method, which allows us to select and control the affected voxels. By these means, we can readily and easily design and create various kinds of cutaway- and exploded-view visualizations directly with our hands and fingers.

Future work. First, we plan to develop a new method called "cutting plane snapping," in which the cutting planes drawn by the hand rail can automatically be snapped to certain axis in the object space to improve the controlling precision. Second, we plan to generalize the cutting seam to allow it to be curved rather than straight. Lastly, we will include new visual feedback, such as multi-touch widgets, etc.

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