Free-Form VR Interactions in Scientific Visualization

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ABSTRACT

This paper describes the use of "free-form" virtual reality (VR) interactions, specifically input from sweeping 3D movements of the hands in space, within scientific visualization applications. Use of this relatively unconstrained style of input for science is often limited because it can be difficult to control, however if controlled via appropriate interaction techniques, it can also provide natural and descriptive input for many tasks. Recent research that overcomes the control limitation in several contexts is reviewed together here. Resulting benefits to scientific workflows are discussed, including benefits to scientist-driven interactions, such as marking and selection within VR visualizations, and designer-driven interactions, such as prototyping the visual aspects of VR visualizations. Remaining limitations in applying this style of input to scientific visualization tasks may be reduced in the future through combining free-form user input with data-derived input constraints.

1 INTRODUCTION

A variety of scientific disciplines are likely to benefit from data visualization within virtual reality (VR). In this paper, free-form VR interactions are discussed with respect to their potential for scientific impact. Examples demonstrate the use of this style of interaction for designing new data visualization strategies and for interacting with existing VR visualizations.

One of the unique features of the virtual reality medium is the ability for users to interact with computers using their full bodies, performing actions at a life-size scale and using arms, hands, and fingers as descriptive inputs in ways quite different than what we typically see with a keyboard and a mouse. A compelling example is found in "free-form" 3D modeling applications [3]. In free-form modeling, sweeping movements of the hand or fingers through the air are tracked by the computer and translated into virtual form to produce a body-controlled virtual sculpture. In this paper, we call these sweeping, gestural inputs to the computer "free-form interaction". In general, this style of interaction is quite beneficial in artistic VR applications. Traditionally, free-form interaction is less appropriate for tasks within scientific applications because it can be difficult to control with precision. Try drawing a perfect circle by moving your arm through the air without a surface or similar real-world constraint to help you. You will end up with a shape that an artist may describe as an interesting gestural interpretation of a circle, but not a shape with an exactness we would judge as sufficient for scientific tasks.

Nevertheless, this type of input is extremely descriptive. If we can control it, then with just a few movements of the body, we can quickly convey a variety of complex spatial relationships to the computer, as seen in the examples that follow. This has great potential to impact scientific workflows in a number of disciplines.

In fact, recent user interface research has increased the level of control available via free-form input by making use of bimanual and haptic-aided techniques [4] and dynamically adjusted input constraints [2]. We review these techniques and describe their utility within several scientific workflows of our collaborators after first providing some brief scientific background.

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2 OVERVIEW OF THE SCIENCE: BIOFLOWS AND PATHWAYS

Examples from fluid flow and brain structure visualization are presented in this paper. The first fluid flow example, pictured in Figure 1, comes from study of bat flight [7]. Data under study are time-varying, multi-variate descriptions of air flow past the flexible wing membrane of a bat. The second example, pictured in the left and middle of Figure 2, comes from study of blood flow in arteries [6]. In each of these time-varying, multi-variate data sets, understanding requires forming connections between multiple layers of data variables as presented in visual form. Designing a visual that is successful in facilitating this understanding is a challenging task.

The final example, in Figure 2 right, comes from visualization of brain structures using data collected with DT-MRI. Selecting bundles of tracts within these data sets is a challenging interaction task that is critical to scientific analysis [1].

3 INTERFACES FOR VISUALIZATION PROTOTYPING

Designing successful VR visualizations is challenging. One reason is that perception and sense of presence in VR is different enough from the real world and from other computer media that existing design guidelines often do not apply in VR. These and other observations on the difficulty of developing VR visualizations were presented recently along with a methodology for prototyping designs via free-form 3D drawing in VR [2]. A new interface technique was critical in making this methodology possible. Haptic feedback combined with a two-handed approach to free-form input was used to make the 3D input smooth and controllable [4].

Scientific Impact: Figure 1 contains visualization prototype designs created via this methodology for visualization of air flow around a bat wing. The two 3D models on the right were created by student collaborators (one in computer science, one in illustration) using the interfaces described above. Each of these presents complex visual ideas. Four to six variables describing the flow are visible in each. The middle image targets a comparative visualization, with views of the wing at two different time steps visible. A simplified depiction of flow velocity is used and variation in pressure across the wing is intended to be highlighted in this design. Near-wing pressure is also highlighted in the right image, which shows just the right wing of the bat as it flies out of the page toward us.

These examples appear flat and inanimate on paper, but when seen in VR, they provide scientists with a valuable tool – a chance to critique a hand-crafted (quickly assembled and editable) visualization prototype before a software engineering team begins to develop the fully data-driven visualization. When a final visualization is produced, it is likely to be highly valuable to the scientists because of the visual refinement process that these free-form interaction tools help to make possible.

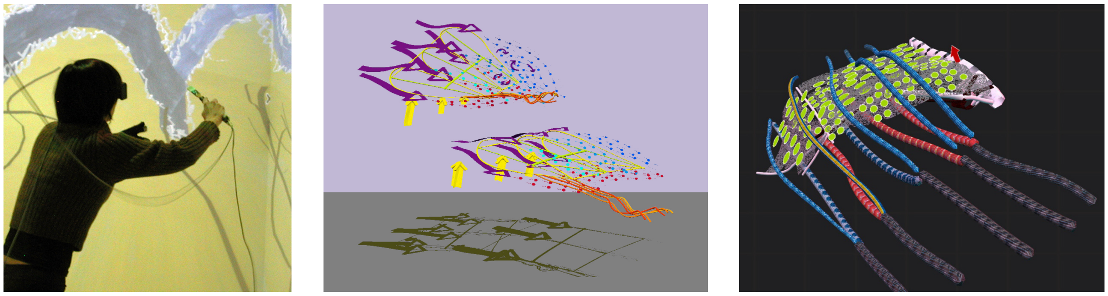

Figure 1: Free-form 3D sketching within VR is used to prototype visual designs for VR visualizations. Left: Hands are tracked to record the sweeping movements that generate virtual form. Middle and right: These hand-sketched 3D visualization prototypes demonstrate strategies for visualizing time-varying multi-variate flow over a bat's flexible wing membrane.

Figure 2: Left and middle: Free-form input from the hands is used to select a large region in a simulation of blood flow through a branching coronary artery. A lasso is drawn around the region of interest. Right: In dense data sets, such as this neural fiber data, a similar 3D lasso selection metaphor is used, but more sophisticated input techniques are required to control the input sufficiently for tasks of this complexity.

4 Interfaces for 3D Selection in Visualizations

Selection of 3D flow-lines and pathways within VR is a challenging problem as the geometries usually used to represent these data are very thin and densely packed. Free-form interfaces may be used to select these features via lassoing movements. Again, a limitation is controlling these movements with precision. A recently developed one-handed technique helps in this regard. It works by introducing a level of indirection into the input. A brush is dragged behind the user's hand by a virtual "rope" [4]. The inset image in Figure 2 right shows an example of the progression of this dragging motion. This "rope" constraint acts as a filter allowing the user's input to be much more refined than without it. An extension to this interface uses a dynamically adjusted rope length which makes it possible to utilize the technique to input curves of widely varying curvature [5].

Scientific Impact: Applications of free-form interfaces to 3D selection within VR are shown in Figure 2. In the left and middle images a region of fluid flow is being selected by a user in a Cave VR environment by circling it with a tracked prop. Large, relatively simple regions like this one can be input directly from movements of the hand. In the rightmost image, white selection curves were drawn through this brain imaging data set to partition the tracts into bundles. This is a far more difficult selection task, made possible by the dynamic extension to the interface mentioned earlier [5].

5 Conclusions and Future Directions

Free-form style VR interactions are rich and descriptive, but are often limited in use for science because of the difficulty of making precise movements in the air with one's hands. With interface refinements, much of this limitation may be removed, enabling new scientific applications, such as the visualization prototyping and selection techniques described here. Future refinements required for many scientific tasks are still possible. A promising future direction is to build upon successful 2D sketch-based interfaces [1] by combining the descriptiveness of free-form input with data-derived constraints. Scientific workflows in VR are likely to benefit from interfaces that exhibit a similar mix high-bandwidth, descriptive user input and data-derived input guides.

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