The Visual Haptic Workbench

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Abstract

Multimodal interfaces have been shown to increase user performance for a variety of tasks. We have been investigating the synergistic benefits of haptic scientific visualization using an integrated, semi-immersive virtual environment. The Visual Haptic Workbench provides multimodal interaction; immersion is enhanced by head and hand tracking, haptic feedback, and additional audio cues. We present the motivation and design goals for this system, discuss its current implementation, and describe some initial applications. Preliminary results indicate that visualization combined with haptic rendering intuitively conveys the salient characteristics of scientific data.

1 Introduction

Haptic interfaces have been shown to be advantageous as an interaction modality for specific tasks [25, 2]. They provide bidirectional interaction via position sensing and force feedback, thereby utilizing additional sensory channel bandwidth of the user. By combining haptic rendering and visualization, we hope to increase intuitive understanding of scientific data.

For this purpose, we have designed and implemented a testbed system, comprised of a SensAble PHANToM 3.0 and a Fakespace Immersive Workbench. Using this system, we are investigating the synergistic benefits of combined visual and haptic data rendering.

There are a several important issues to resolve when building such an integrated system. The hardware components must be carefully selected based upon their performance characteristics, ease of integration, and flexibility for future enhancements. The software infrastructure requires a modular design, efficient cooperation between its elements, and performance optimization. Robust calibration and coregistration of the individual device workspaces will enable an integrated environment capable of *bounded error interaction*. This can be quantified as a unified error tolerance which bounds the total system error throughout the physical workspace.

After developing a software infrastructure for our hardware setup, we experimented with synergistic rendering techniques using vector field data. Preliminary results based on informal user evaluation indicate that the Visual Haptic Workbench is an effective tool of discovery for the exploration of scientific datasets.

2 Previous Work

Virtual workbench environments [15] have been employed successfully for a multitude of purposes over the last several years. Similarly, haptics research has produced many interesting results, a recent survey of which can be found in [10]. Much of this research is concerned with geometric interaction, but several applications of haptics to scientific visualization are relevant to the development of our system.

Early integrated systems include Project GROPE [3], the Nanomanipulator [17], and the Nanobench [8]. These projects focused on rendering aspects of molecular dynamics, drug docking simulations, and real-time interactions with a scanned-probe microscope. An Argonne Remote Manipulator and a PHANToM were used as the haptic interfaces, and the visual displays ranged from a desktop monitor to a custom workbench. A related system used a PHANToM with an augmented reality display for examining seismic and geological data [22]. Iwata et al. proposed and implemented simple vector field interactions using a custom HMD and haptic interface [13].

Research on haptic volume rendering used scalar data value and gradient as force model parameters to explore and modify volumetric data [1]. A treatment of haptic rendering and scientific visualization is given in [7], with emphasis on tools for the visually impaired. Recently, research on combined visual and haptic display methods used a custom haptic interface and commercial visualization software for exploration of certain scientific datasets [12, 16].

While there is a small but growing body of research on this topic, there remains much to discover about the synergistic display of scientific data. The Visual Haptic Workbench is a testbed system for conducting this research.

3 Design Goals and Implementation Issues

Building a multimodal system for synergistic display of scientific data involves identifying a set of performance criteria and dealing with the following implementation issues:

- **Calibration** The visual and haptic workspaces must be accurate to provide faithful data rendering. Ideally, a high-fidelity synergistic display yields a direct mapping between virtual and physical spaces. Position tracking enables user-centered visual display and immersive interaction. Large tracking inaccuracies are unacceptable, as they lead to incorrect stereoscopic projections and inconsistent manipulation and navigation. Haptic interfaces enhance interaction by creating kinesthetic cues via proprioceptive feedback. To avoid perceptual conflicts, they must be kinematically calibrated from reproducible fiducials.

- **Coregistration** Individually calibrated workspaces need to be coregistered to accommodate their relative location, orientation, and scale. By fusing multiple workspaces, a uniform bound can describe position, orientation, and temporal errors in physical space.

- **Compensation** Latency in the system can seriously degrade interactivity, which has been shown to impede user performance [6]. Device communication and computational delays can be compensated by predictive filtering, parallel computation, and a careful runtime mapping of the application to the underlying hardware.

We also considered specific research applications to pursue with our system. At the SCI Institute, a variety of datasets are routinely investigated. Typical examples include volumetric CT/MRI/MRA data, computational fluid dynamics data, and finite element solutions to bioelectric field problems. Recent research has focused on diffusion tensor MRI and multimodal medical data such as fused MRI/EEG volumes [14]. These datasets range in size from megabytes to gigabytes and may be static or time-varying on a variety of grid types. Considering our research needs, the supporting software must be efficient, modular, extensible, and scale well with data size.

4 Current Implementation

We have constructed a prototype system consisting of a SensAble PHANToM 3.0 mounted in a T configuration above a Fakespace Immersive Workbench (see Figure 1). The PHANToM is suspended above the workbench with a cross-braced lumber frame. While not as structurally stiff as desired, it is an inexpensive means to experiment with the design parameters for the final mounting. We replaced the original "push to interrupt" switch with a "step to operate" footswitch as a more convenient safety mechanism. The infrastructure of our system can be described in terms of its hardware components and software architecture.

Figure 1. The Visual Haptic Workbench.

4.1 Hardware Components

The Visual Haptic Workbench consists of five hardware components, as shown in Figure 2. The dominant hand of the user experiences haptic feedback from the PHANToM, and the subdominant hand navigates through a menu interface via Pinch glove contact gestures. Head tracking is done with a Polhemus Fastrak receiver mounted on a pair of Stereographics CrystalEyes LCD shutter glasses. The subdominant hand can also be tracked with a separate receiver to facilitate more complex interaction paradigms. The audio subsystem gives the user additional reinforcement cues to clarify the application interface. Finally, the Immersive Workbench provides a correct stereo perspective view for the user based on the tracked head location. These components are handled by five concurrent processes running on an SGI Onyx2 with 250 MHz R10000 processors and InfiniteReality2 graphics.

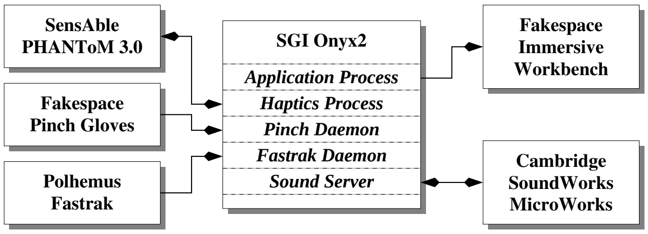

Figure 2. Hardware components of the system.

4.2 Software Architecture

We designed and implemented a software framework using the GHOST SDK for application development on the Visual Haptic Workbench (see Figure 3). The ghostGLManager class is overridden to support semi-immersive virtual environments. This extension is built upon the VGL library, internal VR software that provides graphical rendering and an interface for a variety of tracking and interaction devices. In addition, we derive a set of classes for haptic data rendering techniques from the gstForceField class. These haptic rendering classes are part of a library for synergistic display techniques. The SD Library also contains visualization methods [19, 26], interface widgets, dataset classes, menu functions, and geometry tessellators. The application and haptics processes access common GHOST state through shared memory. We use the NCSA VSS software package for audio support [24]. The application client communicates with the VSS server asynchronously via UDP messages to produce audio feedback. To maintain interactive update rates, each software component runs on a separate processor with appropriate scheduling priority (see Figure 2).

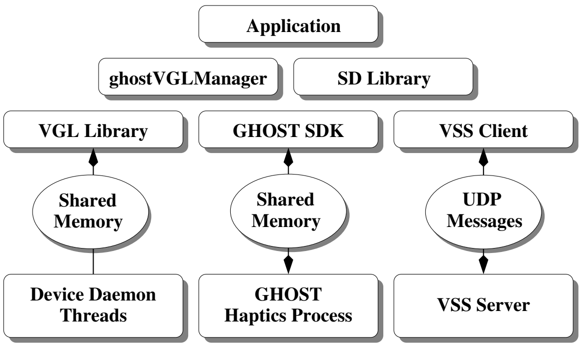

Figure 3. Application software architecture.

5 Initial Evaluation

To evaluate our initial development efforts, we examined two static 3D vector field datasets. One is an analytical electrostatic charge field, and the other is a simulated tornado funnel. Synergistic data rendering is accomplished via advanced visualization techniques [26], and extension of the vector field haptic rendering ideas presented in [21]. Figure 4 shows a user interacting with the simulated tornado dataset.

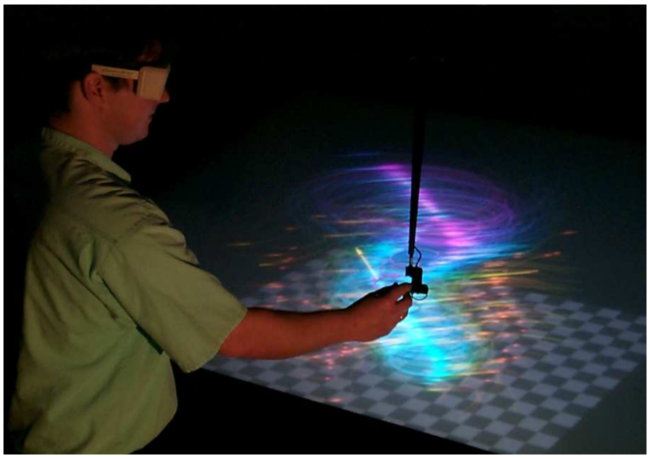

Figure 4. Synergistic data display on the Visual Haptic Workbench.

Our initial implementation addresses some of our design goals, as described in Section 3. Methods for quantifying and correcting magnetic tracker distortion have been developed and are incorporated into our system [11]. The PHANToM uses the standard GHOST "calibration" procedure, which is insufficient to satisfy our performance criteria. The workbench display is driven by an Electrohome 9500LC projector with folded optics and a nonlinear diffusion surface. Unfortunately, these characteristics limit our current display calibration to the adjustment of projector parameters. We coregister the visual and haptic workspaces indirectly by measuring the PHANToM "calibrated" endpoint with a tracked receiver. Detailed analysis of the runtime characteristics of our software, followed by careful matching of hardware devices to machine resources yields a highly interactive application.

To date, we have demonstrated our prototype to over one hundred visitors, the majority of whom found the demo applications compelling. During these demonstrations we observed a variety of new users, whose reactions suggested further improvements to our system.

6 Conclusions and Future Work

The current implementation can be improved in several respects: better tracking technologies, stereo digital projector for improved display calibration, primary surface mirror and linear diffusion material for crisper display, higher performance graphics hardware, 6DOF enhancement for end-effector torques [4], kinematic calibration of the PHANToM, and improved device control for high-fidelity haptics.

Currently, we are experimenting with a variety of volumetric data, including brain MRA and diffusion tensor MRI, and the Visible Human [20]. We are also extending our methods to render a wider variety of flow data, both steady and unsteady, on regular and irregular grids. In addition, we intend to explore methods for quantum molecular dynamics, meteorology, and terrain applications. Our overarching goal is to provide comprehensive synergistic display for a wide variety of scientific data.

In addition to focusing on synergistic display techniques, there are other useful applications to consider. One could interactively segment and register datasets more rapidly than using image-based approaches. Novel applications for computer graphics have already been developed [9, 23, 5]. A characterization of haptic widgets was published in [18], which we intend to extend for our own interface needs. Educational applications could intuitively render haptic manifestations of abstract or unfamiliar concepts. Vector calculus and classical physics are examples of subjects that could be made tangible to students for improved comprehension.

We have designed and built a prototype system for synergistic display of scientific data. By developing and demonstrating initial applications, we have been able to refine our system and identify future research directions. To meet our design goals and address research needs, significant work remains to be done. Nevertheless, the Visual Haptic Workbench is an exciting project and we are compelled to realize its potential.

Acknowledgements

The authors thank Hope M.F. Eksten for her help with various construction and fabrication projects. Support for this research was provided by ARO DURIP grant DAAG-559710065, the DOE Advanced Visualization Technology Center (AVTC), and NSF Grant ACI-9978063.

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