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From Manipulation to Goal-directed Human Activities in Virtual and Augmented Environments

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Abstract

Elemental reaching, grasping and object manipulation underly complex goal-directed human behaviors, like laparoscopic surgery, design, collaborative work, and interaction with computers. We conducted experiments on aiming and object manipulation, using the Virtual Hand Lab. This system married 3-D graphics and 3-D motion analysis systems to create virtual and augmented objects and environments in the grasping workspace on a desktop. Experimental results showed: the importance of superposition of display space on hand's workspace, the relative contributions of visual and haptic information on aiming, object orientation and transportation, and the importance of physical and computer-generated graphic constraints on object manipulation. We are designing an Enhanced Virtual Hand Lab: to add computer-generated object information in other modalities, to imbed basic prehension tasks in the context of complex activities (like training, surgery, design and collaborative work), and to provide rich data acquisition of goal-directed human behavior.

Key words: hands, human behavior analysis, minimally invasive surgery, virtual objects, 3-D motion analysis

1. Prehension Models for Interaction

With intelligence, ease and dexterity, humans use their hands to grasp and manipulate physical objects in daily activities. Grasping and manipulating objects have been researched in many disciplines. In our book, *The Grasping Hand (1),* Dr. Thea Iberall and I review what is known about classifications of static and dynamic grasps, time-evolving phases of pointing and prehension, and levels of constraints on natural human prehension. We discuss the relative contributions of visual, kinesthetic and haptic information in each phase, and distinguish motor control between exploratory and performatory movements (2, 3, see also 4). If our goal is to develop virtual and augmented environments as intelligent, usable tools providing a high degree of presence for goal-directed human activities, we must understand and incorporate principles and constraints of natural human prehension.

2. Manipulation to Goal-Directed Activities

Basic motions of reaching, grasping and object manipulation are elements in complex goal-directed human activities such as surgery, design, games and collaborative work. Human behaviors are hierarchical and parallel in organization, like TOTES (5).

From video analyses in the operating room and hierarchical decomposition of human laparoscopic surgical procedures, we identifed surgical steps, tasks, subtasks and motions (6). Each successive component had smaller durations. For a set of surgical tasks (e.g., suturing, tying knots), all reduced to the same basic motions: reach, orient, grasp/cut, hold, release (7). These corresponded to phases of prehension in our model (1). Thus, our attempts to simulate or provide augmented environments for complex behaviors will incorporate these basic prehensile tasks and motions.

3. Experiments in Virtual Hand Lab (VHL)

In the past five years, our collaborative team designed and implemented a VHL for experiments on perception, motor control and human-computer interaction. We examined pointing and object manipulation tasks using physical, virtual (computer-generated graphic) and augmented (computer-generated graphic, superimposed on physical) objects in the desktop environment.

Figure 1 shows that 3-D position data with accuracy less than 1 mm (OPTOTRAK, Northern Digital, Inc.) are used to drive 3-D graphics stereoscopic, head-coupled display (SGI Indigo Extreme), on-line in real-time, at 60 HZ, with approximately 25 ms lag. See (8) for calibration of this space. Kinematic data of human/object motion are later analysed for experimental inferences.

For pointing in HCI or augmented environments, we showed: that planning and control are based in hand space, regardless of the gain or control-display mapping (amplitude and target width on the display, 9); pointing performance is improved by reducing the scale of hand movements (9); advantages for superimposing the display over the workspace (10); differences between physical and virtual pointing are evident in the homing-in phase of movement for small targets (9, 10, 11).

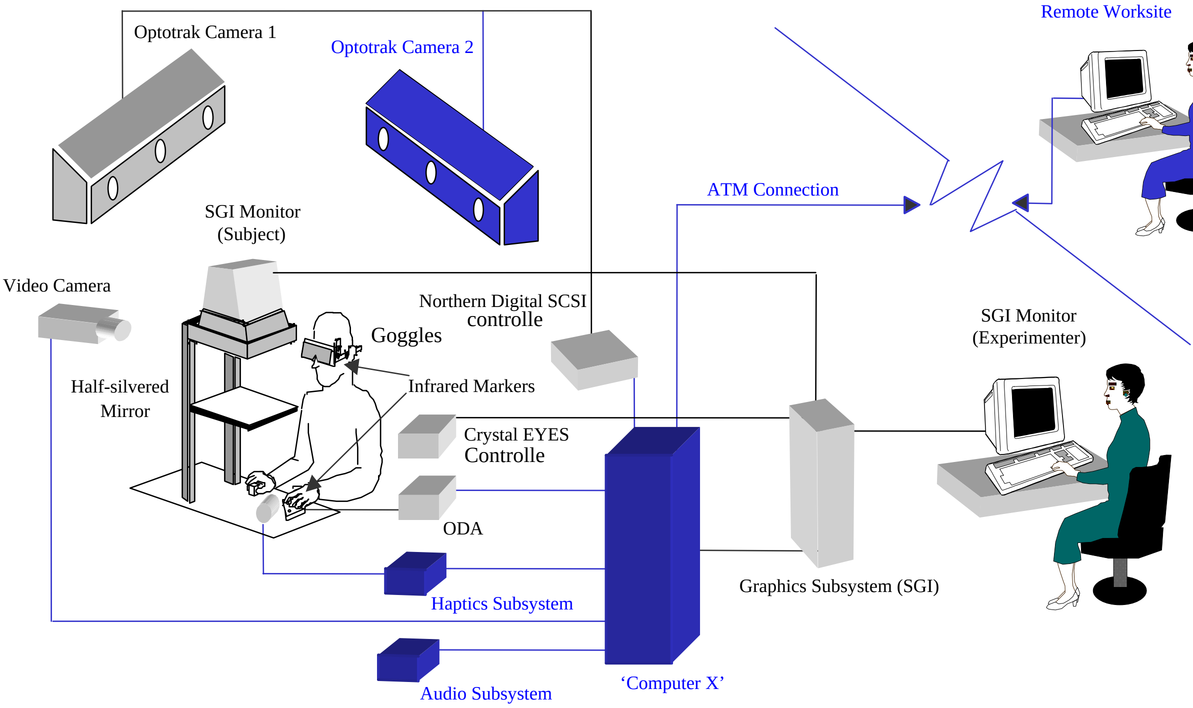

Figure 1. Virtual Hand Lab (VHL) components, shown in light gray, include a 3-D motion analysis system coupled with a 3-D graphics workstation. Markers on the subject's head, hand and objects in the the workspace are tracked in 3-D, and these position data drive objects in the graphics display. Special shutter goggles provide a stereoscopic, head-coupled view. Note the subject's monitor is upside down, and the monitor's image reflected in a half-silvered mirror. When a light beneath the mirror is on, we have an augmented environment, with the graphics display superimposed on the workspace above the visible physical desktop; when this light is off, only graphic objects are visible, but physical objects and environmental surfaces may be felt. In the **Enhanced Virtual Hand Lab (EVHL),** additional components will be added (bolded): a second camera, remote workstation(s) and haptics and audio subsytems so virtual and augmented objects could be through computer-generated graphics, haptic, or audio displays.

For manipulating a cube in an augmented environment, we showed: consistent, systematic structure wherein object transportation contained object orientation (12); large individual differences in bias, especially without vision of the manipulator (13); the importance of relative not absolute sizes of controller, cursor, and target for manipulation (14); that orientation disparity between seen and felt objects affects object orientation, not object transportation (15); that contextual visual and haptic constraints (surfaces) have different effects on object manipulation speed and accuracy (16).

4. Enhanced Virtual Hand Lab (EVHL)

Our vision for augmented environments is to place basic prehensile tasks and motions back in the rich, veridical context of complex goal-directed activities, like surgery, design, games, training and collaborative work (17).

The bolded items in Figure 1 show that computer-generated haptic, audio and olfactory characteristics of objects and interactions will be added to computer generated graphics for the Enhanced Virtual Hand Lab.

We are currently in the design phase as we acquire the additional components bolded in Figure 1.

Our collaborative team is interested in: the challenges of designing and implementing augmented environments; the human capabilities and constraints for interaction; and applications to specific domains like surgery, etc. Our objectives are: (1) to design and implement an Enhanced Virtual Hand Laboratory (EVHL), with integrated displays and controls, that exploits natural human perception and movement, providing a high degree of presence, and rich data acquisition/analysis of goal-directed human behavior; (2) to ask basic research questions about the processes underlying successful human manipulation and remote manipulation in goal-directed activities in natural, augmented and remote environments; and (3) to examine human-computer interaction in the performance of specific, selected tasks in the domains of surgery, design, remote manipulation and training, using a triangle strategy of user-task-tool.

To accomplish these objectives, we have milestones, with responsibilities under three themes:

System: Design/Architecture and Integration. Includes hardware and software development for the Enhanced Virtual Hand Lab. This will enable users to interact with virtual or augmented environments, using graphic, haptic, auditory and olfactory displays, and natural human movement for interaction. 3-D motion analysis and 3-D interactive forces will drive the displays, on-line, in real-time.

Human: Research on human goal-directed interaction. It includes controlled experiments on "simple" object manipulation in virtual and augmented environments, and field/observational research with task and work analysis, conducted in complex environments and specific domains, like endoscopic surgery, training, collaborative games, and collaborative learning.

Applications: This includes designing, developing and evaluating human performance on domain-specific tasks in the Enhanced Virtual Hand Lab setup, for the above application domains.

We emphasize that in addition to the development of the virtual and augmented environments for examining goal-directed activities, the research includes also the monitoring and evaluation of human performance on these tasks through video, task and motion analyses.

5. Conclusions

There is a huge chasm between our simple pointing and manipulation experiments using the current, impoverished graphical environment of Virtual Hand Lab, and our strategic vision of studying complex goal-directed human activities in multimodal, dense, augmented environments in the Enhanced Virtual Hand Lab. A five year update will be likely both humbling and enlightening!

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