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HIT Lab researchers are collaborating with numerous medical advisers from a wide range of specialties to develop novel methods for interacting with clinical data and emerging advanced medical technologies. In particular, we are developing advanced interface technologies which will facilitate time-critical trauma care in battlefield situations (with clear applications in civilian clinical environments, as well). The primary goal of this project has been to provide some of the basic knowledge and understanding needed to develop practical human-computer interfaces for future "integrated" medical information systems. The LIMIT testbed developed under this DARPA grant now provides a resource for virtual prototyping and evaluation of a host of new medical devices and patient data representations. As products begin to emerge from the Advanced Biomedical Technology program we will be able to more rapidly integrate them into a clinically acceptable user interface.

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PI - Signature Date

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Introduction

ARPA's current biomedical programs are generating a host of new medical and information technologies which may change the face of health care (Satava, 1994). Successful deployment of these innovations will depend in large part on the clinical acceptability of each component, as well as their integration into the fabric of everyday clinical practice.

Clinical acceptability will be determined by at least four factors:

- functionality (Does it do something useful?)
- performance (Is is effective/reliable/safe enough?)
- usability (Can the average medical professional use it easily?)
- cost (Is is cost effective in comparison with existing alternatives?)

One common theme uniting many of these new technologies is the emerging electronic patient record. It is clear that integration must take place at the level of data structures, device communications and database access. Integrated access will require the coordinated interplay of a variety of devices, including traditional (e.g, workstations), ubiquitous (e.g., PDAs, portable smart tablets, and wall boards), and personal (e.g., body-worn, such as HMDs). Equally important, however, integration must take place at the level of the individual user's interface to the data.

Clinical acceptability may best be served by starting from the user's perspective (unconstrained by technology) and letting the vision of the ideal interface drive the development of appropriate technologies. In a sense the ideal medical interface of the future becomes the driving problem for a vast array of technology innovations. In reality, of course, both technology-push and applications-pull must work in tandem to move the interface forward. In our project, medical interface design has become an iterative process of unconstrained imagination followed by a hard engineering analysis of possible implementation approaches.

Problem - Why Look at the Interface?

The need for a ubiquitous, intelligent and usable human interface to physiological monitoring and imaging data streams, as well as to the archival patient record and reference databases, is clear. Our search for an integrated approach is motivated by a number of observations:

- **too much clinical data** to assimilate
- need for **seamless ubiquitous access** ("anywhere, anytime, anyhow")
- the need for **interoperability** among devices and databases

- need to take better advantage of **emerging human interface technology**
- need to support evolution of **medical information systems**
- need to tackle **clinical acceptability issues** up front

Advanced Interface Approaches

Display of critical medical information within a complex clinical setting presents a number of challenges, aside from standardization of the electronic patient record. Among these are the development of clinically acceptable data input methods, fail-safe access and communication methods, and the partitioning of the user interface across the variety of potentially useful devices.

We envision a rich interface "toolkit" for the medical practitioner of the future. Along with traditional workstations and device monitors, the medical interface environment of the future will incorporate four key emerging technologies:

- **Virtual Reality** (mediated by head-mounted displays, "cave"-type environments, and "holographic" or stereographic systems)
- **Augmented Perception** (mediated primarily by HMDs and other see-through devices)
- **Ubiquitous Computing** (including interface devices, such as wall panels, wireless pads and PDAs, which permit ubiquitous access to a common database)

The medical scenario of the future will include a mix of these interface approaches, along with a broad array of input modalities and methods, telepresence technologies, and computer-mediated assistance. The nature of that mix will be highly dependent on task, specialty, and clinical setting, and presupposes a robust and reliable electronic patient record. To be clinically usable these systems will require new interface metaphors and integration methods.

Virtual Retinal Display (VRD)

Among the more promising new enabling technologies for advanced interfaces is the Virtual Retinal Display (VRD) approach, the rapid modulation and scanning of light directly onto the retina to create a high-resolution coherent image. The fundamental VRD technology and a variety of VRD devices are currently under development at the HIT Lab (Kollin and Tidwell, 1995; Tidwell, 1995). The VRD is potentially superior to all other known image display methods, affording maximum brightness and a spatial resolution limited only by the frequency of the scanning method, rather than by the image source. These features make the VRD particularly well-suited for several emerging application areas, including see-through (augmented reality) display, small light-weight occluded displays, and portable high-resolution projection displays.

The mechanical resonance scanning technology developed for the VRD may also prove useful for spatial data acquisition (position tracking and scene acquisition). These technologies, based on reflecting scanned light out into the environment, could provide the low-latency head tracking required for many augmented reality applications.

Project Objectives

Clinical acceptability of medical information systems will be determined in large part by their ease of use. Interface requirements and preferences must be determined for medical practitioners performing various medical tasks under a variety of conditions. HIT Lab researchers are collaborating with the University of Washington's Image Computing Systems Lab, the Biorobotics Lab and the UW School of Medicine's Center for Videoendoscopic Surgery, along with numerous medical advisers from a wide range of specialties, to develop novel methods for interacting with clinical data and emerging advanced medical technologies.

In particular, we are developing advanced interface technologies which will facilitate time-critical trauma care in battlefield situations (with clear applications in civilian clinical environments, as well). The primary goal of this project has been to provide some of the basic knowledge and understanding needed to develop practical human-computer interfaces for future "integrated" medical information systems. The specific objectives addressed by this project were to:

- Develop a set of design guidelines for advanced interfaces that integrate medical concerns, human factors requirements, and practical system design.
- Establish an interface testbed to evaluate advanced interface concepts and prototypes.
- Test and evaluate advanced interface concepts.
- Develop selected prototypes of novel data interfaces.

Methods

This phase of our involvement in the DARPA Advanced Biomedical Technology Program was aimed at determining the interface design guidelines for a clinically acceptable integration of a number of advanced medical technologies, being developed both independently and under

DARPA sponsorship. These include various field personnel status monitoring and battlefield telemedicine technologies. To address these complex issues we adopted an approach that includes a cross-disciplinary team of physicians and engineers working jointly to develop a vision of an advanced interface to medical data that was both clinically acceptable and technologically plausible.

Design Philosophy

User preferences for ideal data display should be the driving force behind interface development. The precise enabling technologies should then be determined by what the user wants, where the user wants it, and how the user wants to interact with it. The technological solution will of course be subject to many additional constraints, such as the performance characteristics and costs associated with each approach, ergonomics and clinical usability, and the availability of reliable power and communications bandwidth.

In developing these concepts the project team has drawn heavily from the tradition of aircraft cockpit display research (Furness, 1969), determining for each medical specialty a set of ideal data display configurations for various clinical tasks. The basic notion is to design integrated interface systems around the user's needs for information, relying on domain experts to tell us where, when and how information should be displayed from their particular perspective. Customized traversal of the electronic patient record, for example, might be displayed privately in head-stabilized fashion, while imaging data of interest to several parties in the clinical setting might be patient-stabilized or room-stabilized. Given user requirements and other constraints, implementation options can then be designed and key enabling technologies developed.

Storyboard Approach

Throughout this project we have been exploring ideal medical information display requirements and possible interface configurations for a variety of medical specialties performing various clinical tasks. As a starting point, each specialist on our medical advisory team was asked to focus on their role in treating a hypothetical case set ten years in the future. The case, developed by the team, was designed to cover many of the advanced biomedical technologies being sponsored by DARPA, but in a plausible civilian scenario:

> John Doe is a traveling salesman with previously undiagnosed diabetes and a prior history of heart complaints. His home wellness system has warned him that his diet is bad and he needs more exercise, but he has not complied. Driving in his car (equipped with a GPS beacon in case of accident) and wearing his personal status monitor, Mr. Doe experiences severe chest pain and crashes into a tree. Paramedics are dispatched immediately by the regional medical C3 center

and arrive to find his knee crushed and his leg apparently ischemic. A cardiologist is consulted while en route to the appropriate trauma center. It is determined that Mr. Doe is experiencing an evolving myocardial infarction, which must be stabilized prior to surgery to repair his damaged popliteal artery. Following surgery, Mr. Doe is placed in an instrumented recovery bed which functions both as a portable ICU and as a passive rehabilitation environment. Despite an acute cardiac incident during recovery, Mr. Doe enjoys a successful rehabilitation, and is discharged to the care of a home health nurse and his reprogrammed set-top wellness advisor.

As a template for each medical specialist's interface concepts we have drawn heavily from the pioneering work on advanced cockpit displays introduced by the Air Force's SuperCockpit program (Furness, 1986, 1988). These revolutionary interface concepts include:

- circumambient spatial display (i.e., immersive information environment)
- augmented reality (i.e., computed generated graphics and video overlaid on the natural scene)
- data objects, rather than windows, are the unit of display
- multiple imagery stabilization points (as illustrated in Figure 1)
- multi-sensory multi-modal interaction with data objects

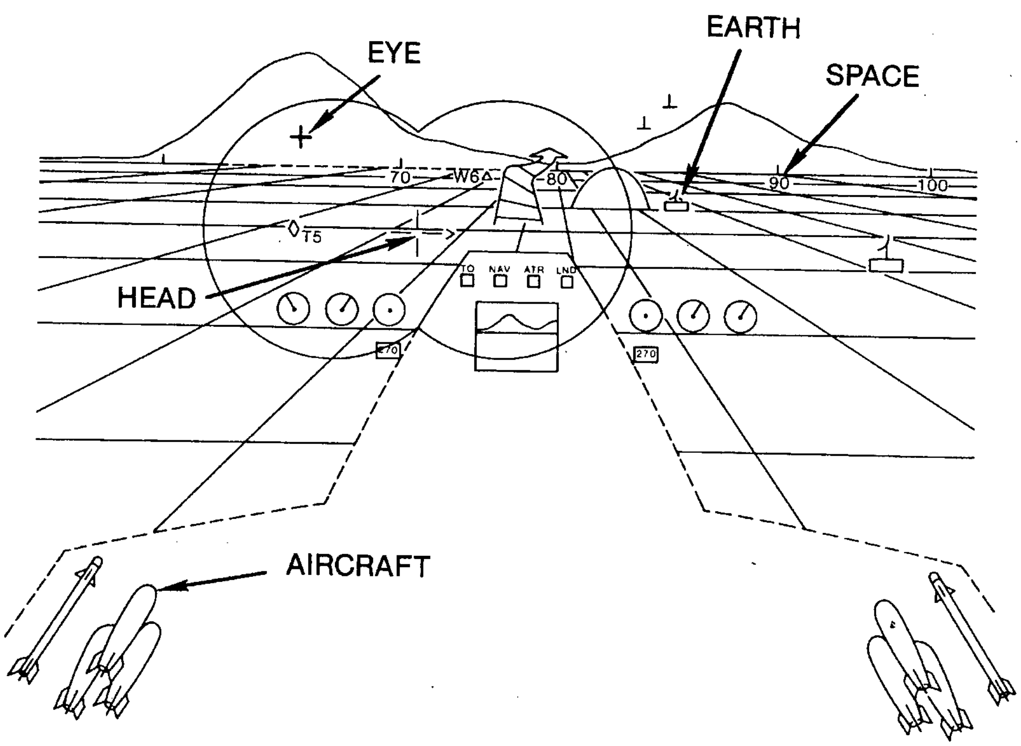

FIGURE 1. Stabilization references for various data items in egocentric Supercockpit display.

Figure 2 illustrates one example of such an interface design from this emergency room scenario. In this case the viewpoint is that of a cardiologist who has been called to the trauma center. In addition to rapidly traversing the patient's archival record in his upper field of view, the cardiologist is monitoring the patient's vital signs and EKG, while consulting with the trauma doc and the telepresent vascular surgeon about the arteriogram and the stability of the patient's cardiac function.

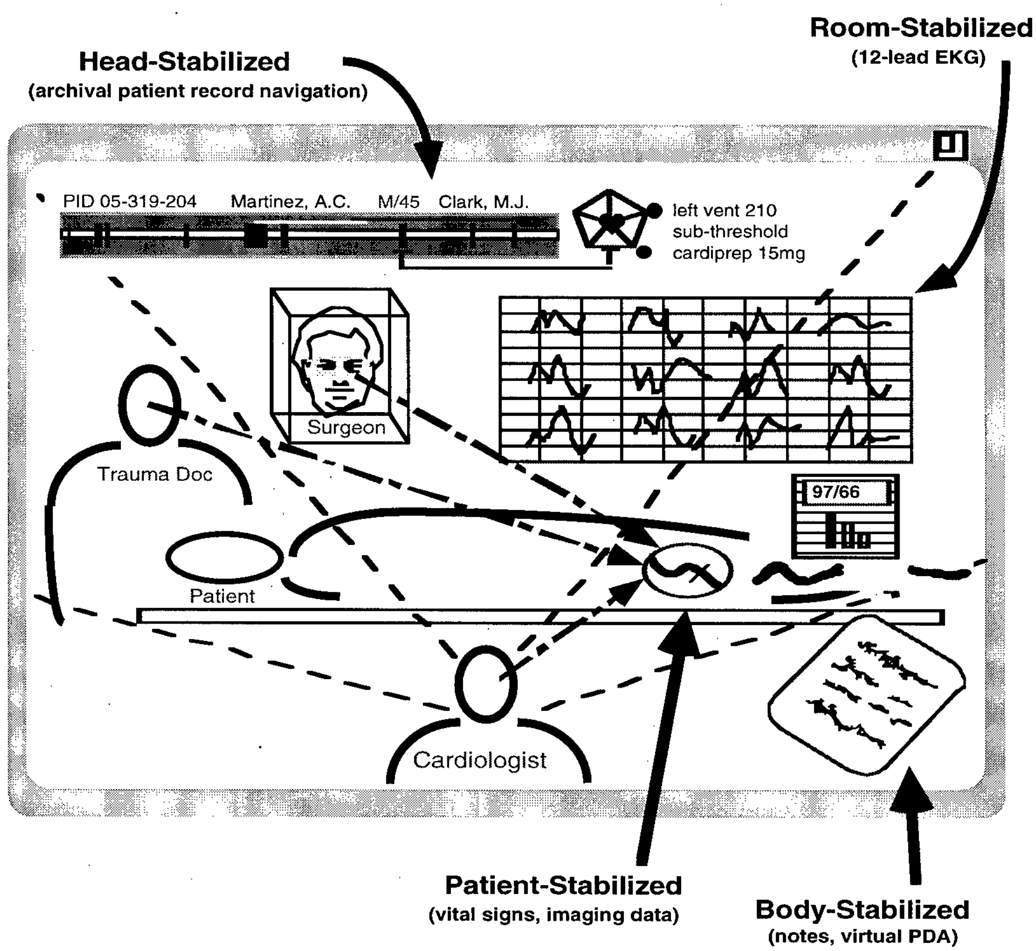

FIGURE 2. Physician-designed visual display for cardiologist in trauma center.

The 12-lead EKG or the patient's vital signs, appear stabilized with respect to the room or the patient ("world-stabilized" or "patient-stabilized"). Since the EKG is of interest to most people in the room, a likely display option for that data element is a live wall panel. In contrast, data of interest to only one or a few individuals are presented via a personal (rather than public) display device. An archival timeline, for example, which represents a customized exploration of the patient record, is presented here in the upper portion of the cardiologist's field of view in "head-stabilized" fashion. The presentation of various data fields in the patient record, such as patient name or referring physician, could be color coded by the user. Patient record navigation could be controlled by a variety of modalities, including voice, eye movement, or gesture. Critical points along the timeline could thus be exploded to reveal graphical representations of study results or clinical notes.

Data which the cardiologist wants to keep accessible but not always in his or her field of view might be "body-" or "vehicle-stabilized", virtually traveling with the cardiologist as he moves around the facility but not continually in the visual field. Personal notes are a good candidate for such a display. Finally, in this example, we show that the telepresent consultant should be placed (virtually) in a location that allows for seemingly natural interaction about the subject of mutual interest (in this case an imaging study of the damaged artery, overlaid on the patient's knee).

LIMIT Testbed

In fleshing out the storyboard scenario and discussing various design options, it became apparent that we needed to address many of these questions within the context of a more realistic clinical environment. To accomplish this we constructed a virtual reality simulator for designing and assessing new ways of interacting with clinical data. This VR testbed, called the LIMIT (or "Laboratory for Integrated Medical Interface Technology"), consists of several photorealistic texture-mapped environments constructed from video image scans of clinical settings, rudimentary male and female patient models, and a collection of clinical data objects which can be manipulated, scaled and positioned anywhere within the environment (in anticipation of clinically acceptable augmented reality and ubiquitous computing interfaces). Two physicians manipulating data objects in the LIMIT's Virtual ER can be seen in Figure 3.

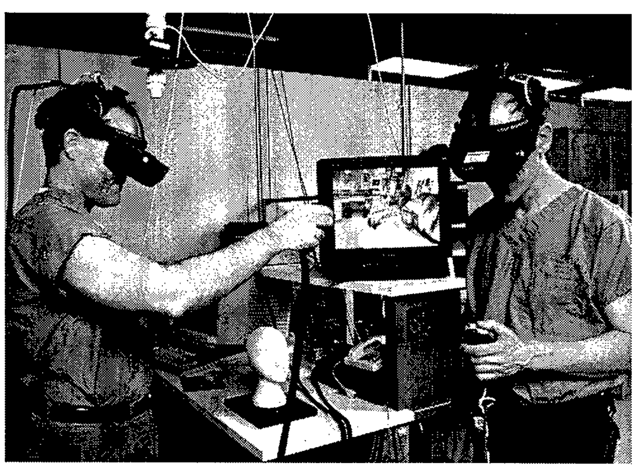

FIGURE 3. Configuring the data display environment in the LIMIT virtual ER.

Building upon concepts developed in our earlier discussions, the primary purpose of the LIMIT is to provide a testbed for designing the clinical interface of the future. We anticipate that other uses will include:

- clinical protocol development
- individual and team training, and
- determining performance requirements for electronic patient data delivery systems

One of the primary advantages of this approach to interface design is that VR affords the possibility of performing pseudo-field experiments in which extraneous variables are controlled for and variables of interest are manipulated in ways that approximate real clinical environments. Since interaction with the virtual world is mediated by the computer, it can be thought of as an instrumented research environment.

Current Capabilities

The LIMIT is currently implemented on two VR software platforms, both running on SGI reality engine machines: Division's DVS, and Sense8's WorldToolkit. Both versions make use of code enhancements developed in-house and include support for multi-modal (voice and gesture) interaction. Three immersive texture-mapped environments are currently available:

- an **emergency room** from Harborview Medical Center, Seattle (a Level 1 trauma center)
- an **operating room** from the 18th MASH unit (as configured at Madigan Army Hospital, Ft. Lewis, Spring 1996)
- a **treatment room** from the 18th MASH unit (as configured at Madigan Army Hospital, Ft. Lewis, Spring 1996)

The LIMIT development team, which consists of both HIT Lab software engineers and our consulting health care professionals, has focused the majority of its efforts thus far on emergency room procedures. However, the data display methods and interaction tools we have developed are designed for use in any clinical environment.

Data objects are rendered independently and have several generic capabilities:

- multiple frames of reference for **location stabilization**, enabling head-stabilized, patient-stabilized, and room-stabilized data
- object orientation adapts to the physician's position by **bill-boarding**
- all objects can be **arbitrarily scaled and positioned**

- all objects can be grabbed and relocated by **direct manipulation** (using both linear and non-linear mapping of the user's physical and virtual hand)

- object **visibility can be toggled** by keyboard or voice command

Data objects are currently encoded as either texture maps or files of integer values. Texture maps have been acquired for rhythm strips, intake charts, patient demographics, teleconsultant video frames, and various radiology images. Real-time data streams have been implemented for trend data, and navigation methods are being implemented for multi-image radiology studies using the HIT Lab's "working surfaces" interface approach (Hollander and Tidwell, 1997). As an aid to run-time reconfiguration of the interface by immersed physicians, we have also added a non-linear mapping of the user's reach for direct selection and manipulation of both close and remote objects (Poupyrev *et al.*, 1996).

In addition to these generic data "presentation" techniques, we are exploring a number of data "representation" techniques which make use of 3D interaction capabilities. Several novel data representation methods have been implemented for ECG data (as described in Kaufman *et al.*, 1997) and others are being designed for lab values and vital signs data.

Three testbed enhancements are currently under development:

- **secondary task loading** and other measures for assessing display effectiveness

- **multiple participants**, with shared and independent data objects

- porting from VR to Augmented Reality test environment, using our "shared space" **collaborative AR** software for mutual registration and calibration

The secondary task we are implementing is a waveform monitoring task, in which the user must watch to see when a trend drifts outside a threshold window and then indicate the appropriate baseline adjustment. This task is performed while also monitoring the data object of interest (the primary task). In the tradition of avionics display research, performance on the secondary task is taken as an additional measure of the goodness of the primary data display.

Adding support for multiple participants will enable us to explore a host of issues related to inter-user negotiation of common display space, methods for sharing data and communicating about common artifacts, and team coordination and training issues. And porting to a shared AR environment will enable us to test new prototype displays and interaction techniques in actual clinical settings.

Results

Medical Advisory Team

The following individuals have been active as HIT Lab medical advisers during Phase 1 of this project, and will continue to be available as consultants in follow-on phases:

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The backbone of our project has been the involvement of a strong team of medical advisors, including specialists in anatomy, surgery, radiology, otolaryngology, ophthalmology, cardiology, orthopaedics, emergency medicine, anesthesiology, family medicine, radiation oncology, nursing, medical informatics, and electronic patient record systems. Our medical advisers meet weekly with HIT Lab engineers and scientists to exchange information about emerging technologies and clinical requirements, and individual advisers have worked closely with lab engineers to specify and develop clinically appropriate prototype displays and interface methods.

Other physicians, nurses and allied medical personnel from a variety of medical specialties have occasional involvement with the project, and are available for advice and consultation. Our DARPA-sponsored activities have provided a sounding board for new medical interface ideas and have catalyzed a number of other collaborative projects. Perhaps the greatest strength of this working group is that it provides an opportunity to explore both specialty-specific and clinically generic interface needs.

Review of Emerging Technologies

Anticipating the interface of the future requires that we be on top of the latest developments in computing, communications, and interface technologies. Through its ongoing Knowledge Base program efforts the HIT Lab has become a nexus of on-line information about emerging technologies (via the Virtual Worlds Consortium, moderation of the internet newsgroup *sci.virtual-worlds*, our active WWW and FTP sites, and through production and maintenance of numerous on-line resource guides), and we have worked closely with our research librarians and our engineering staff to remain current in the area of advanced interface technologies in medicine. A comprehensive guide to relevant web sites, vendors and published literature is located at **www.hitl.washington.edu/projects/knowledge_base/medvr/**.

Concept Demonstrations

In addition to assessing the medical interface advances of other groups, collaborating labs working on this project have developed demonstrations of several enabling technologies and promising approaches, including:

- teleradiology consultation tools and optimized user interface for telemedicine (using the Mediastation 5000 workstation)
- fractal tissue generation (for rapid model building when patient-specific data is not required)
- optimizing photorealism in tissue modeling using texture mapping methods

- multi-modal expert surgical assistance (using voice, position, and instrument location) for simulation and real-time procedure support
- collaborative (multi-participant) augmented reality

Interface Design Methodology

As a vehicle for organizing the vast amounts of information and issues relevant to advanced interfaces for medicine we have adopted a scenario-based approach to interface design (as described above). Working through a hypothetical medical case set in the year 2005, our medical advisers have formulated descriptions of anticipated medical advances and an ideal integrated interface, as they carry out various tasks related to the case. In group brainstorming sessions we are able to develop candidate concepts in medical interface design and to anticipate issues that will arise in multi-participant situations.

In developing new medical interface concepts we have drawn heavily from previous DOD work, in particular the SuperCockpit program sponsored by the U.S. Air Force throughout the 1980s. Among the most fruitful of these is the framework the SuperCockpit program provided for visual imagery stabilization based on a set of distinct reference points (the user's eye, head or vehicle, along with the earth and inertial space). We have adapted this framework to applications in the medical domain, as described elsewhere (Weghorst, 1996b, 1997).

A second major influence on our design approach has been the tradition of multi-modal interaction with computing systems. In particular, we are leveraging off of other HIT Lab projects which combine gesture, voice, and gaze behavior to enable a more intuitive and natural interface (Billinghurst *et al.*, 1996).

VR Clinical Simulation Testbed

We have developed a fairly extensive virtual reality simulation of a possible medical interface environment of the future. In addition to the basic LIMIT clinical settings and data interaction methods, we have accomplished the following:

- initial characterization of **data types and display requirements** for a wide variety of clinical data objects, including vital signs data, clinical images, lab results, and anesthesiology data
- specification (by clinical specialists) of desired **interaction methods** for each of the above data types

- development and demonstration of **novel presentations of ECG** (and other trend data), including real-time waveform production and an abstract heart model which shows correlated real-time electrical activity

- development of display performance **metrics** and assessment **methods**

Surgical Training Initiative

As an offshoot of DARPA project discussions, the UW Surgery Department's Center for Videoendoscopic Surgery (CVES) has incorporated a simulation thrust into their surgical resident training program. Current activities include analysis of the costs and benefits of physical and virtual simulation (as well as hybrid methods) for various levels of training (e.g., skills training vs. procedure training). Physical simulation "packs" for basic skills and for laparoscopic cholecystectomy have been developed by a regional company, SimuLabs, and incorporated into the surgery curriculum. The CVES will also serve as a test and development site for HighTechsplanations' TELEOS simulation software. A joint study demonstrating a positive correlation between videogame expertise (two-handed 3D Tetris) and laparoscopic skill acquisition in first-year surgery residents was reported at the Medicine Meets Virtual Reality meeting in January 1996 (Weghorst *et al.* ,1996a).

Spin-off Collaborations

Our DARPA-sponsored activities have also significantly strengthened several other new joint initiatives, including HIT Lab work on surgical simulator fidelity requirements analysis and evaluation for the Army-sponsored ENT simulator effort with Lockheed Martin and Madigan Army Medical Center; joint proposals with the telemedicine evaluation team for Project Seahawk; ongoing discussions of advanced displays with several medical system vendors and Harborview Medical Center; interface evaluation for ACTS satellite-based teleradiology with the Department of Radiology; and a new technology development project focused on "shared space" (collaborative augmented reality) jointly sponsored by Virtual i-O and the Washington Technology Center.

Although official commercial partnerships have not yet been established, discussions are under way with PhysioControl (heart monitors and defibrillators), EmTek (electronic patient data systems), ATL (ultrasound equipment), and others, to incorporate live data streams into the LIMIT and to provide a prototyping testbed for producers of clinical equipment.

Discussion

Of the project outcomes detailed above we believe the most significant is the evolution of the clinical simulation testbed. By providing a sense of presence in a controlled clinical setting, we are able to prototype and test candidate interface elements in an environment which approximates the target application setting.

The LIMIT testbed provides unique support for:

- exploration and **rapid prototyping of clinical data display methods** and interface metaphors, including traditional WIMP workstations, ubiquitous computing interfaces, novel teleconferencing methods, and both virtual (VR) and augmented reality (AR) methods.

- clinical display **performance metrics**, including many adapted from aircraft displays research, for assessing both generic and task-specific display effectiveness

- clinical **protocol development** and **training** within this set of simulated environments

- methods for rapid construction of **additional texture-mapped environments** and **data objects**

The LIMIT can be readily adapted to support a variety of image, trend, and alphanumeric data. In addition to vital signs data, lab results, and radiology and pathology images, the LIMIT can be further adapted to support research on candidate interfaces for teleconsultation and teleoperations. By incorporating alpha-mapped live video textures, for instance, we will be able to experiment with various representations of remote consultants. And by simulating telemedicine activities within a distributed virtual environment we will be able to develop and assess various methods of communication with the local participants and with shared artifacts.

Our discussions, story-boarding, and virtual simulation methods have led us to the following general conclusions:

- The interface of the future must advance beyond "what-you-see-is-what-you-get" to **"where-you-need-it-is-where-you-get-it"**.

- **Spatial** interface methods demand **interface metaphors** that go beyond "desktop windows" to make optimal use of human 3D capabilities.

- The **functional integration** of "ubiquitous", immersive, and traditional displays requires a seamless and intuitive user interface to the electronic patient record.

- Interface demands differ across specialities, tasks, clinical settings, and individuals, and should therefore remain fluid, while supporting **intelligent defaults** and **individual preference** configurations.
- The medical interface of the future must take advantage of both **artificial intelligence** (AI) and **intelligence augmentation** (IA) technologies, in combination with multi-modal interface methods.

Although individual clinicians performing different tasks prefer different display configurations, certain conventions are beginning to emerge. Visual clutter in the central field-of-view, for instance, will not be acceptable when a clear view of the patient is required (as it is for the trauma doc, or in open surgery). Critical data should be more readily accessible (perhaps head-stabilized), and transient data should be dismissed after it is noted.

Future Work

Ultimately interface configuration, training and operational systems will be mediated by an integrated software infrastructure; the design of such a system will benefit greatly from both computational and interface simulation. Building upon our experience in Phase 1, our primary objective for Phase 2 of this project is to construct an enhanced virtual/augmented reality environment which will allow us to rapidly simulate various clinical information human interface options. Such an environment will permit interface design both unconstrained by existing technologies (i.e., the ideal clinical info display) and then constrained in various ways (e.g., limited to ubiquitous devices, or limited by noise or communications lag).

As with the current LIMIT environment, research participants will be medical professionals who will be given tools to rapidly build and test their own information environments, working alone and on collaborative clinical tasks.

Phase 2 Objectives

Specific objectives of Phase 2 are as follows:

Augmented reality emulation. As suitable see-through visual displays become available during Phase 2 we will begin to prototype clinical AR interface emulations. Augmented reality simulations will display data objects within the physician's local workspace, either unconstrained spatially or overlaid on tracked physical devices.

Real-time data acquisition. Enhance simulator realism by incorporating realistic patient data streams. Discussions have begun with Emtek, Quantum-Siemens, SpaceLabs, and other imaging and patient monitoring companies to simulate advanced interfaces to their systems.

Configuration tools. Develop additional tools for data display configuration by clinicians. These would include immersive methods for defining defaults, more fluid generic interaction methods, and additional data-specific presentation methods.

System performance studies. Study clinical acceptibility under various simulated performance constraints (including communications lag and reliability, display device characteristics, and database access errors).

Clinical teams. Simulate multi-participant scenarios (data display collision, etc). Incorporate multi-participant software tools as distributed VR systems (such as the HIT Lab's Greenspace project) evolve.

Electronic patient record. Incorporate expert system assistance, appropriate filtering tools for the emerging multi-media electronic patient record, and other AI archive navigation tools.

Sytem performance requirements. Develop performance specifications and high-level software architecture for Phase 3 prototype development effort.

For this enhanced simulation phase we will incorporate as many simulated target technologies as possible. This will allow us to rapidly assess the clinical utility of various configurations of physical devices, and to anticipate how they might be used, prior to committing to an implementation system architecture. System parameters to be simulated include:

- data display constraints (e.g., spatial resolution requirements)
- target interface device constraints (e.g., ubiquitous only, or restricted field of view)
- data communications lag
- lag variability
- data integrity and noise requirements
- effects of bandwidth constraints
- resource management strategies
- resolution strategies for multi-participant display conflict
- responses to system failures

Phase 3 Objectives

In Phase 3 we propose to develop an actual working prototype of the required interface integration software. The interface hardware implementation will be open and user-definable. For example, the display could be private (HMD) or public (terminals, electronic whiteboards). In the case of public displays, protocols for who controls the contents of that display will have to be established; in the case of private displays, they will be tailored to, and customized by, the individual users. Similarly, interaction with the system could be through mice, gestural and gaze recognition, voice commands, or other methods.

Specific objectives of Phase 3 are as follows:

Refine high-level software architecture. Building upon results of Phase 2, define (software) object classes and hierarchy, specify methods and object behaviors.

Construct prototype system. Build a software environment for intuitive integration of various clinical data streams, including display of personnel status monitor (PSM) data, telemedicine, and electronic patient record data, using ubiquitous, traditional, and personal interface devices. VRD-based devices and other high-resolution high-luminance displays will be incorporated as they become available.

Clinical field demonstration. Study clinical acceptibility of the prototyped system in an appropriate clinical setting.

Vendor relationships. Establish links with relevant equipment vendors and other product vendors for clinical demonstration support, participation, and licensing agreements.

FDA approval. Pursue course of action required for FDA approval of system software, as appropriate.

Conclusions

The value of this interface integration approach to clinicians has been demonstrated. It has also become clear, however, that imagining effective applications of novel inclusive interfaces can be very difficult for many of us. This is especially challenging for multi-participant scenarios, as we try to imagine the interaction effects among individual data representations, or methods for jointly configuring shared display real estate (a wall panel display, for instance). Design of these multi-modal "egocentric" data interfaces is an area ripe for visualization using VR simulation of a more dynamic and realistic clinical environment.

The LIMIT testbed developed under this DARPA grant now provides a resource for virtual prototyping and evaluation of a host of new medical devices and patient data representations. As products begin to emerge from the Advanced Biomedical Technology program we will be able to more rapidly integrate them into a clinically acceptable user interface.

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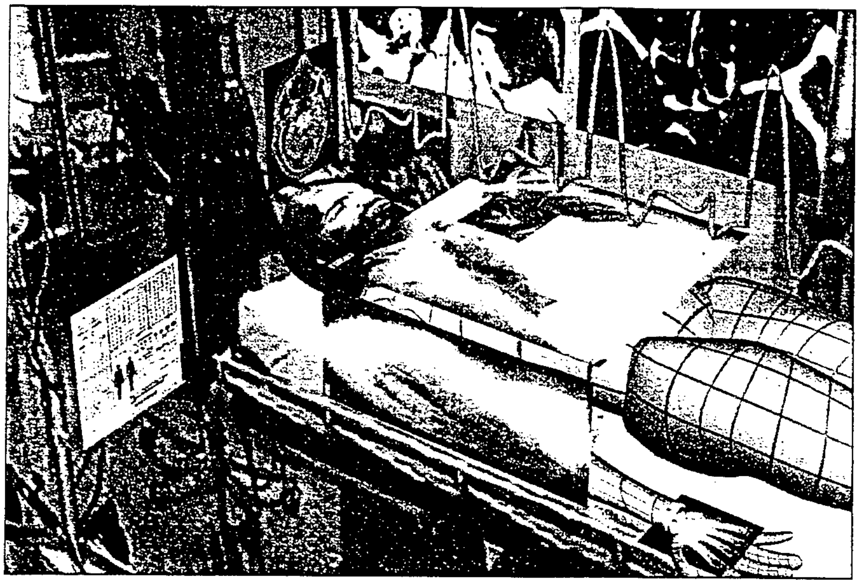
Appendix A

(Trade press project descriptions)

Virtual Emergency Room



To create the Virtual ER, HITLab artist Peter Oppenheimer mapped photographs of the Harborview Medical Center's trauma unit as a continuous texture map onto a cylindrical geometry. Such an approach provides a strong sense of presence within the environment and is suitable for situations in which the user's virtual position remains relatively stable. Image data courtesy of Don Stredney, Ohio Supercomputer Ctr.; the NLM Visible Human project; the EMBBS Web site; J.W. Rohen and Yokochi's *Color Atlas of Anatomy*; Peter Dunbar, MD; and Harborview Medical Center, Seattle.

It might not be the stuff of a hit TV show, but a recently built ER is a "HIT" product nonetheless. As part of an ARPA research grant to study advanced medical resources, the University of Washington's Human Interface Technology Lab (HITLab) has developed a virtual emergency room in which medical personnel can explore the design space for medical interfaces of the future. The environment will be used to help physicians and planners determine how immersive augmented space might best be utilized.

Inside the virtual ER, users can grab various items, such as X-rays, EKG readings, and heart rhythm strips, and place them anywhere in the space. Each object can be stabilized relative to a number of different reference points, such as the room, the patient, and the user's head and body, and objects can be made visible or invisible at the user's command.

The HITLab's virtual ER is a replica of the trauma center at Seattle-based Harborview Medical Center. According to researcher Suzanne Weghorst, director of interface design at the HITLab, the environment was created using a technique similar to QuickTime VR. "Frames from a video capture of the Harborview trauma unit were stitched together and massaged in Photoshop on a Mac into a seamless texture map, which we projected onto a cylindrical 'room' in the VR system, along with texture-mapped virtual data objects [created with software from Alias/Wavefront and a patient model]."

The environment is currently running on an SGI Onyx RealityEngine^2 using VR software from Division and Sense8. A Polhemus motion-tracking system captures head and hand motion, and an in-house wand facilitates navigation. Various PC-based voice recognition packages are being investigated to incorporate voice commands, but, according to Weghorst, "this has given us lots of problems in our noisy lab environment."

As with all ambitious VR projects, the success of the virtual ER depends on the degree to which the feel of the space is believable. According to Weghorst, "The texture-mapped room works well for creating a strong sense of presence in a clinical environment, but now we are challenged to incorporate real-time patient data streams and interaction metaphors and techniques that are appropriate for each data object." In addition, she notes, "this application cries out for multiple live video textures, so we can show more realistic dynamic objects, such as ultrasound studies and teleconsultation."

The HITLab has submitted a proposal to ARPA for the next two phases of the Advanced Medical Interfaces project. The second phase involves building a more robust and realistic simulation environment that will enable the researchers to simulate clinically meaningful tasks and to perform usability assessment and system specification studies. The third phase involves the design and implementation of a spatial data display system that will incorporate an array of medical interface technologies currently under development. The system will be tested in an actual clinical setting.

As the project progresses, says Weghorst, "our biggest challenge is coming up with visionary inspirations that are both technically plausible and clinically useful. It requires constant iteration and cross-checking between our engineers and our consulting physicians." ●

TECH WATCH

EE TIMES 9/12/96

EXPERTS' PROGNOSIS: TECHNOLOGY HAS POTENTIAL AS TEACHING, DECISION-MAKING AID

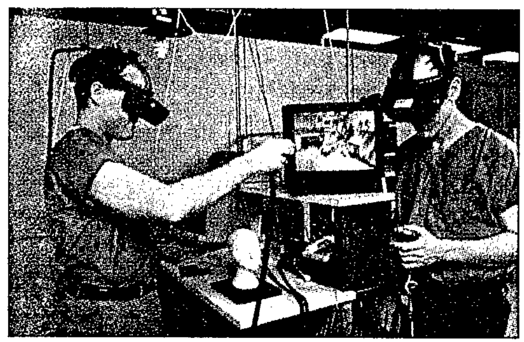
Dose of VR prescribed for medical data

BY CHAPPELL BROWN

Seattle — While virtual reality (VR) has captured the imagination of the public as a new form of entertainment, the technology could also find serious applications as a route to integrating diverse information in real-time environments. One prime target is medical applications, where complex, interrelated forms of information need to be accessed by teams of specialists, often in a time-critical situation. Experts working with the new approach are finding that VR offers a unique opportunity to integrate activity and information in a surgical theater or emergency room to aid physicians in split-second decisions.

The move toward virtual reality in medicine is an outgrowth of the success of telemedicine, where videoconferencing technology has brought remote physicians to the bedside, conferring with the patient or local physicians to resolve medical problems. The logical extension of that form of diagnosis is to use modern electronics to model virtual environments, which can be accessed over networks such as the World Wide Web while immersing specialists in a data environment relevant to a problem.

This latest trend in medical technology has spawned its own conference, Medicine Meets Virtual Reality, held annually in San Diego. To date, the most ambitious design is being put together at the University of Washington's Human Interface Technology Laboratory here. A prototype system, modeled on the emergency room at a local hospital, is allowing medical students to get "hands on" experience without leaving the classroom. The emergency room itself was modeled by taking an extensive set of photographs and merging them onto a cylindrical virtual surface.



HIT Lab researchers explore a virtual ER.

Total integration

The project, called the Laboratory for Integrated Medical Interface Technology (Limit), represents a total approach to medical data integration. The format for the system is a realistic rendering of the operating room that a number of doctors share via a fully immersive virtual-reality system. The real space metaphor is used to not only depict the patient, but also integrate all of the relevant data. For example, instead of clipping X-rays on a wall-mounted light table, a physician moves an X-ray window over the patient's body that displays any X-ray data available for that area. Other data sources such as EEG charts, or CAT scans can be positioned as virtual objects that float in space in front of the user. The data elements can be moved around and positioned like objects, so that participants in the virtual operating theater have instant access to relevant data, which they can share and confer over in a natural setting.

While that capability would be welcomed by the medical community, actually getting to a practical and economic realization of Limit's design goals represents a formidable technical challenge. We need to integrate a lot of diverse technical elements—PDAs, laptop and desktop computers, medical instrumentation—that were never designed to work together," explained Suzanne Weghorst, a computer scientist on the project. Added to those problems is the high cost of VR interface technology. "While we are beginning to see 'ubiquitous' computing in the form of low-cost personal digital assistants and laptop computers, it still seems to be farther away with virtual-reality components," she said.

The other thorny area that represents a serious computer-science challenge is the problem of merging different data types into a single environment. Medical applications use a variety of instrumentation that has evolved in specialized scientific areas. Those components were not designed with a totally integrated environment as the final goal. The Limit concept requires all of the diverse data types and approaches to data representation to fit together seamlessly as a whole. "One reason for initiating this project was to provide a testbed to try out various approaches to achieving that kind of data integration," Weghorst explained. The project is being funded by Darpa in a three-phase structure. The first phase has been looking at the computational issues of representing data as physical objects, multiple participant interaction and the integration of voice-recognition capability. The next phase will attempt to put subsystems together into a full clinical system that could actually be used by medical personnel. The third phase will put together a full medical data display system that can be accessed by multiple participants in the virtual-reality clinic.

Surgical tool

Even with the initial interface technology that has been constructed, some medical experts on the project have devised useful systems that can aid surgeons and medical students. The HIT Lab team combined a medical expert system used to assist surgeons performing operations in the nasal cavity with voice recognition and VR simulations of the actual anatomy. The system has been successfully used both as a teaching tool and as an on-line assistant that can help a surgical team make quick decisions about the complexities of the nasal passages during an operation. The ability to query the system and get expert advice instantly has already revealed a potential to reduce errors during surgery. The project is now working toward a general system for generating VR expert systems for a given surgical specialty.

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List of Project Personnel

The following is a list of all personnel receiving pay from this negotiated effort, along with a brief description of their roles:

Kathryn Best (graphics engineer)
Mark Billinghurst (graduate research assistant)
James Cabral (graduate research assistant)
Toni Emerson (knowledge base engineer)
Jon Mandeville (lead software engineer)
Peter Oppenheimer (research engineer)
David Parsons (graduate research assistant)
Konrad Schroder (systems administrator)
Suzanne Weghorst (project manager/research scientist)