Deployment and Evaluation of Networked Surgical Simulations

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1 Project Purpose

Problem Definition. From 44,000 to 98,000 Americans die annually from mishaps due to medical management [1]. Medical management problems pose growing ethical and economic burdens. The extent of the problem has resulted in the dramatic rise of patient safety as a national health care policy, with initiatives in the United States and other industrialized nations. Patient safety can be measurably improved with new methods for medical education and training of health care providers. In turn, professional education can be improved through the "use of simulations whenever possible" [1]. The Institute of Medicine recommends that health care organizations and teaching institutions should participate in the development and use of simulation for training novice practitioners, problem solving, and crisis management, especially when new and potentially hazardous procedures and equipment are introduced. Early successful use in emergency departments and operating rooms indicates that simulations should be more widely applied.

Proposed Solution. In this project, we will develop, deploy, and evaluate *networked virtual environments for surgical simulation*. Virtual environments are a promising new medium for surgical planning and training. The user interacts with virtual environments through haptic devices which allows him to perform surgery on a simulated patient by manipulating simulated organs (i.e., no mannequin is involved) using simulated surgical instruments (e.g., scalpels and laparoscopes), as shown in Figure 1. Simulations are interactive; can be recorded, replayed, and evaluated; can support planning and training with different techniques and uncommon but critical scenarios; and are especially suitable for minimally invasive surgery, which makes use of an abstract and restricted user interface. The accessibility of surgical virtual environments would be substantially extended by network communication. The resulting network simulations will enable continuing education and advanced training over wide geographical areas. Furthermore, networks will support remote access to surgery planning tools that require sophisticated computing facilities or that provide for surgeon collaboration.

We will develop enabling technologies that are required for and immediately applicable to the broad areas of simulation of general endoscopic, percutaneous, and image guided procedures. We will then include a specific test bed in the area of minimally invasive abdominal surgery (laparoscopy). We will demonstrate the feasibility of the approach, deploy

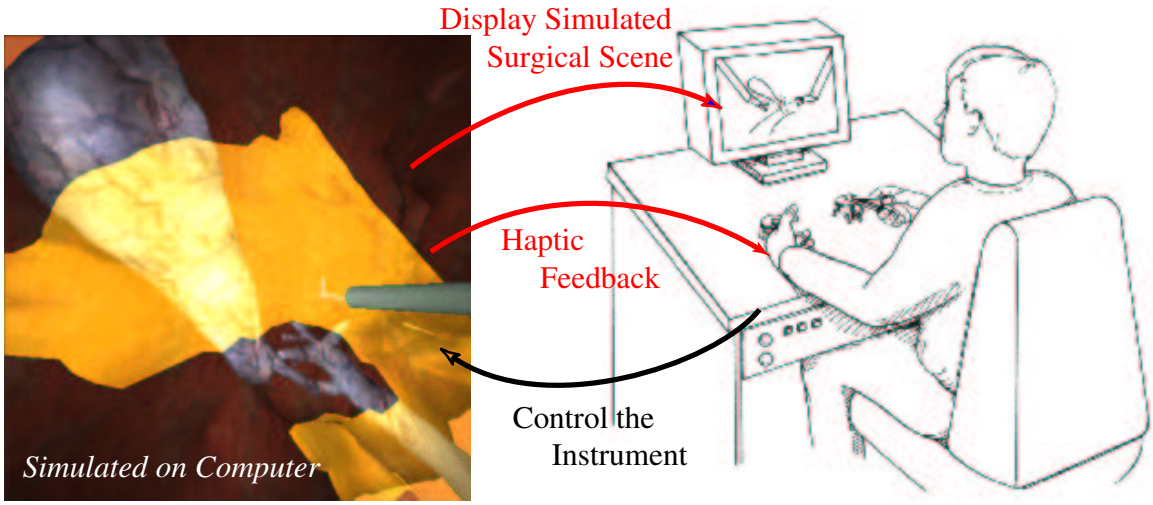


Figure 1: Surgical training simulator concept. Simulation snapshot courtesy of F. Tendick [42].

our system in a regional hospital system, and quantify the effectiveness of the approach. The project holds clear promises that it can be replicated across the nation due to the use of network communication for improving the accessibility to virtual surgical environments. Our longer-term vision is that a compelling surgical simulations will be continuously accessible to all health care professionals anytime from any appropriate network access point.

Project Outcomes. The evaluation of the project will include both technical and educational metrics. On the technical side, the quality of virtual environments will ultimately affect their adoption by practitioners, instructors, researchers, and trainees. The technical outcome is a networked surgical virtual environment that presents a high degree of fidelity and realism even over a network that is subject to varying degrees of Quality-of-Service. A set of experiments (Appendix C) will be executed to establish the quality of the virtual environments over networks. We expect that the networked simulation will show high fidelity and responsiveness due to the network compensation middleware that we will implement as a part of this project.

The educational objectives will be measured according to quantitative and qualitative metrics, such as the user feedback after a simulation session, the degree of involvement of students in a simulation-based activity, and the health care outcome of simulation training. Further details are described in Section 4.2.

2 Background and Innovation

The project is innovative in that it seeks to transfer academic contributions in the areas of distributed simulations, surgical simulations, and medical curriculum development into an operational platform for surgical training.

2.1 Surgical Simulations

Currently, surgeons are trained through apprenticeship or through learning predicated on occasional exposure. The basic techniques are taught with simple training equipment, but the rest of the training is either with books describing surgical procedures and techniques, or in the operating room by watching and participating in actual operations, and rarely in animal laboratories. Although actual operating room training is essential and invaluable, it does not provide the optimal environment to try or practice new techniques and procedures due to the risks to the patient and the prohibitive cost (estimated at $60 per minute). This method of training also limits the diffusion of knowledge since only a limited number of people can be trained by one experienced surgeon.

Virtual environments present an alternative to the established training scheme. Virtual environments create an interactive 3D simulation, where the surgeons use a haptic interface to manipulate, cut, or suture dynamically and geometrically correct models of organs and tissues simulated on a computer (Figure 1). The idea is similar to flight simulators for training airplane pilots. Virtual environments provide an environment where there is no risk to a patient, teacher, or the trainee, and is therefore less stressful. They are interactive and 3D in contrast to books, and they are relatively inexpensive compared to training in the operating room or animal labs. Virtual environments also give a unique advantage, as it is possible to generate arbitrary anatomies and pathologies with which the surgeons can be trained for cases that they will encounter only a few times during their whole career but for which they must nonetheless be trained. Simulation allows for repetitive and standardized training tailored to the needs of all learners. In the longer run, it might even be possible to standardize the training and accreditation in surgery.

2.2 Developments in Simulation

A variety of simulation approaches and tools have proliferated in the past ten years. These include the increasing sophistication of Advanced Cardiac Life Support training systems, complex task trainers for endoscopic and catheter based procedures, ultrasound simulators, full length mannequin computer controlled simulators, and surgical devices incorporating touch, audio, and visual simulation. Recent advances in miniaturization of computerized mannequin simulators has begun to stimulate much more widespread adoption through cost reduction and enhanced device mobility [48]. A review of surgical simulation is given in Appendix A. Virtual reality devices are also under intense development, and are rapidly reaching an early stage of implementation. These tools have enabled the exploration of new frontiers in training and performance assessment at the level of individual skills, knowledge and attitudes as well as similar investigations at the level of teams and even systems (teams and technologies). Our project is innovative in that it translate research contributions in virtual environments into an operational approach for health care training.

The existing successful surgical simulators are for applications where there are not large deformations, and mostly manipulation of hard objects. However, for other applications, deformable models are required. The deformable tissue models have to be interactive, efficient enough to be simulated in real time, visually and haptically realistic, and able to be cut and sutured. The state of the art for interactive deformable object simulation is not sufficiently

advanced to build realistic real-time simulations on consumer level computer systems, and requires supercomputer level computational power and networked simulation technologies to access remotely these simulations.

Dev *et al.* have demonstrated networked Anatomy Workbench and Surgery Workbench for training of anatomy and surgery, respectively, which features rich graphics and visualization and haptic interaction with biomechanical models over the network [12]. However, these types of systems rely on a network infrastructure with very high bandwidth and guaranteed QoS, which is not available in most of the current Internet (including Internet2) due to fundamental architectural reasons and continuing economic factors [24].

2.3 Remote Interactive Simulations

A *remote interactive simulation* allows a user to access and interact with an environment that is simulated on a remote host computer. Remote interactive simulations have included military simulations [44], networked virtual environments (e.g., [31]), and multi-player computer games (e.g., [40]). The extension of interactive simulations to the network setting poses several non-trivial problems because the physical communication platform introduces constraints in terms of delays and bandwidth. Moreover, the network layer can specify a best-effort model, whereby no type of traffic receives any preferential treatment. The best-effort model lacks any explicit QoS provisioning and is pervasive in today's Internet for fundamental economic reasons (e.g., [25]). As a consequence, the simulation traffic cannot expect any special handling within the network, and can be subject to delays or packet losses due to congestion. Further details are given in Appendix B. An innovative aspect of this project is the implementation of middleware methods to recover from poor network QoS in the area of distributed surgical simulations.

3 Community Involvement

Partnership. Since its founding more than 80 years ago, the Jackson Memorial Hospital (JMH) has grown to become one of the largest, most comprehensive medical centers in the nation. With more than 1,500 beds on a 57-acre campus centrally located near two major freeways in Miami-Dade County, Jackson is this area's only public hospital. The University of Miami/Jackson Memorial Medical Center (UM/Jackson) forms the only academic medical center within 300 miles, educating 1000 house staff, and caring for the sickest patients with unusual complications not only from southern and central Florida but from the Caribbean, Central and South America. As a private institution, the University of Miami brings its resources and excellent clinical, research, teaching, and community service commitment to the county-owned Jackson Memorial Hospital to form a public-private partnership found nowhere else in the nation. It serves the indigent population of Miami-Dade County and is the dominant Medicaid provider in the state of Florida. In 2000, the JMH Health Plan was ranked first in satisfaction in the State of Florida's HMO Report Card, "Choosing A Quality Health Plan." Presently, there are 17 Primary Care Centers within a 40 miles radius under the Jackson Health System umbrella. Twelve sites are UM/Jackson clinics and four

are federally funded clinics. In addition, there are small community private clinics whose patients deliver at UM/JMH.

The Jackson Health System will be the primary recipient of this project. The virtual environment will run on a cluster computer at Case Western Reserve University in Cleveland, Ohio. Medical training, continuing education, and advanced training will be able to access the simulation from JMH and the other hospitals in the Jackson Health System through broadband network connectivity.

User Support. User support will be available in two form. First, the Center for Patient Safety at the University of Miami will assist users with software installation and with training in the use of the simulation. Center technicians will travel to the various clinics to install the software, give seminars and talks, and generally advertise the availability of this resource. Second, support will be available on-line with respondents both at Case Western Reserve University and at the University of Miami. The project will use Voice-over-IP and videoconferencing facilities whenever available.

Stakeholder Involvement. The supporting personnel at the Center for Patient Safety will regularly tour the participating hospitals in the Jackson Health System to conduct training sessions, open meetings, and to collect feedback from the on-going training program. In turn, the user feedback will be used to continuously improve the quality of the training program and of the virtual environment. We will strive to empower users and to make sure that users will have an opportunity to give their input on the general direction of the project.

Sustained Commitment. The Center for Patient Safety (Barach) at the University of Miami, the Network Research Lab (Liberatore) and the Medical Robotics and Computer-Integrated Surgery Lab (Çavuşoğlu) have been interacting and planning the proposed activity for almost one year. Our intense level of participation includes a workshop on "Patient Safety Curriculum" (January 9-10, 2004) organized by the Center for Patient Safety and attended by representatives from both institutions. We expect our collaboration to continue and intensify as the result of this project.

4 Evaluation

4.1 Simulation Realism

It is our conviction that the quality of virtual environments will ultimately affect (or hinder) their adoption by practitioners, instructors, researchers, and trainees. Appendix D described modules meant to enhance the user-perceived quality of a networked simulation even in the presence of low network QoS. A broad objective of the evaluation phase will be to ascertain the effectiveness of these methods and to improve upon them in critical scenarios. The first step in this direction is to develop a framework for the semi-automatic evaluation of networked surgical simulation. The framework will be used to evaluate the effectiveness of surgical simulations over various network configurations and then to improve simulation

performance in problematic network configurations. The framework consists of hardware, software, and preliminary quantitative results that will enable and steer the performance evaluation of GiPSiNet. Our approach is to run GiPSi on a real and emulated networks with a set of benchmark tasks and to introduce causes for deviation from the ideal behavior, such as network-induced delays, packet losses, or congestion. The details of the approach are given in Appendix C.

4.2 Educational Outcomes

The educational objectives will be measured according to two metrics. First, we will collect subjective feedback from the participant in the simulation training programs. The evaluation will be conducted early and continuously so as to use the trainees' feedback to improve the quality, accuracy, and effectiveness of networked simulations. Second, we will examine the medical outcomes of selected procedures and compare a control group with the programs that implement simulation training. In the longer term, we expect that networked surgical simulations will significantly contribute to a substantial decrease in mishaps caused by medical management.

5 Project Feasibility

Technical Approach. The specific objectives of the project are

Develop a simulation middleware for networked surgical simulation. A preliminary objective of this project is to adapt the GiPSi simulation architecture to a network environment by adding an appropriate middleware component (*GiPSiNet*, Figure 2) between the simulation kernel and the Input/Output components. The resulting framework is generalizable and extensible to various surgical simulations and middleware technologies. GiPSiNet is the software foundation upon which the rest of the project will be developed.

Develop middleware components to reduce the incidence of data unit losses. We will implement methods, such as adaptive playout, forward error correction, and compression, that attempt to enforce a predictable data delivery timeline. These methods are a first step to improve the realism and effectiveness of simulations on typical networks.

Develop a framework for the semi-automatic evaluation of networked surgical simulations. The framework will include a benchmark suite of representative surgical tasks and the infrastructure for network emulations of GiPSiNet. The framework will be used to evaluate the effectiveness of surgical simulations over various network configurations.

The details on the specific aims are given in Appendix D.

Applicant Qualifications. The project benefits from the multi-disciplinary background of the investigators, who have been involved in the design and implementation of surgical virtual environments, in supporting networked interactions with physical systems, and in

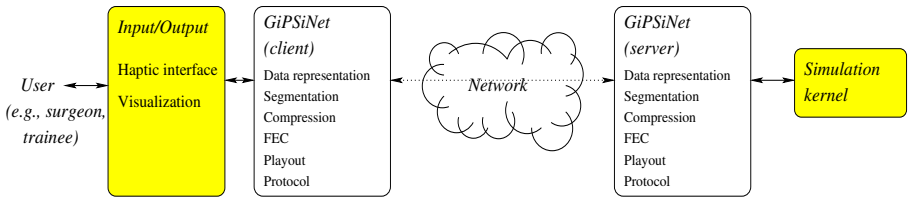
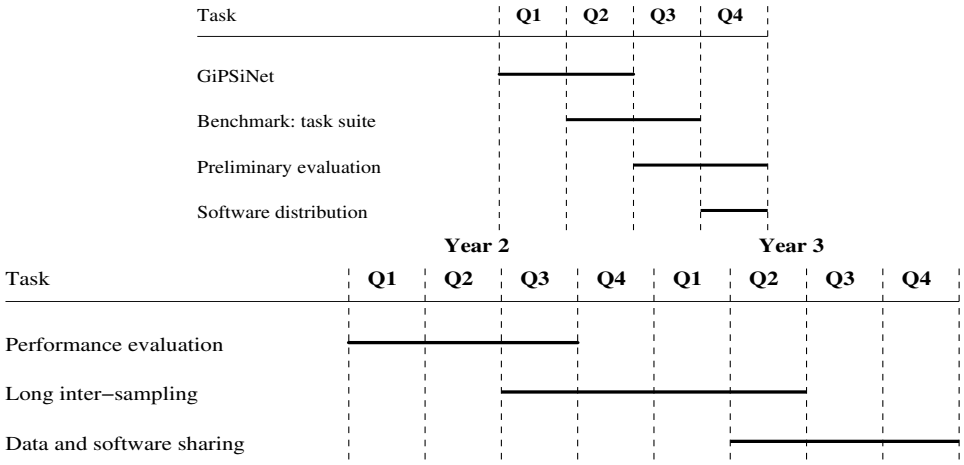


Figure 2: The GiPSiNet software architecture. Shaded module are part of the existing GiPSi platform, clear modules are part of the proposed GiPSiNet middleware.

patient safety and organizational learning. The biographies of the applicants are included in the appendix.

Project Implementation and Completion. The project will follow the following tentative timeline, organized on a quarterly basis:



Privacy and Security. The performance of individual users on simulated surgery can be used to establish their level of competence at the given task. As a result, user performance data will only collected for project evaluation purposes, users identifiers will be scrambled whenever possible, and performance data for individual users will never be released to external entities.

Sustainability. Upon successful completion, the project should become a regular component of the curriculum of study at the University of Miami and of continuing education programs in the Jackson Health System.

Dissemination. The GiPSiNet middleware will be made publicly available on the Web. Software dissemination from the early stages should increase the impact of this project among potential developers and users of surgical virtual environments. A project Web site will be created and it will contain the source code for GiPSi and GiPSiNet, installation

instructions, software dependencies, executables for the most common architectures, source code documentation, a manual of use, and a contact address to send comments or report problems. The GiPSiNet distribution will follow the Mozilla license, which is the same model as in the current GiPSi software.