Virtual Reality Based Surgical Assistance and Training System For Long Duration Space Missions

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Abstract. Access to medical care during long duration space missions is extremely important. Numerous unanticipated medical problems will need to be addressed promptly and efficiently. Although telemedicine provides a convenient tool for remote diagnosis and treatment, it is impractical due to the long delay between data transmission and reception to Earth.

While a well-trained surgeon-internist-astronaut would be an essential addition to the crew, the vast number of potential medical problems necessitate instant access to computerized, skill-enhancing and diagnostic tools. A functional prototype of a virtual reality based surgical training and assistance tool was created at our center, using low-power, small, lightweight components that would be easy to transport on a space mission. The system consists of a tracked, head-mounted display, a computer system, and a number of tracked surgical instruments. The software provides a real-time surgical simulation system with integrated monitoring and information retrieval and a voice input/output subsystem.

Initial medical content for the system has been created, comprising craniofacial, hand, inner ear, and general anatomy, as well as information on a number of surgical procedures and techniques. One surgical specialty in particular, microsurgery, was provided as a full simulation due to its long training requirements, significant impact on result due to experience, and likelihood for need. However, the system is easily adapted to realistically simulate a large number of other surgical procedures. By providing a general system for surgical simulation and assistance, the astronaut-surgeon can maintain their skills, acquire new specialty skills, and use tools for computer-based surgical planning and assistance to minimize overall crew and mission risk.

1 INTRODUCTION

NASA's current plans for a manned mission to Mars in 2025 involve a journey between 120-180 days to reach the planet, between 200-600 days on the surface, followed by a 120-180 return trip[9,10,24]. The crew size would be between 4-6 crewmembers, of which one would be designated as a Chief Medical Officer (CMO). This surgeon-internist-astronaut would be responsible for the well-being of the other crewmembers and, in the case of a medical emergency, the entire mission may be their responsibility.

In order to perform their job, the CMO on such a long-duration mission will need to maintain surgical skills in absence of real cases and, when an accident occurs, may need to acquire new, specialized surgical skills, plan a surgery, and have assistance performing surgery. Moreover, should the CMO be the injured party, a crewmember with limited medical training may need to perform advanced medical care, perhaps involving surgery.

Specific problems that are anticipated include intra-abdominal emergencies, fractures (due to trauma exacerbated by bone demineralization), radiation effects (Immuno-suppression/infection and cancer). The risks associated with these conditions include decreased performance of crewmember, loss of crewmember, and/or mission failure.

In light of these challenges, a number of alternatives to having a single trained surgeon have been discussed. Telemedicine is largely ineffective due to the long distance between the Earth and Mars. It takes from 7 to 22 minutes for light to reach Earth and return to Mars. Moreover, blackout periods of up to 30 days are anticipated when the two planets are on opposite sides of the Sun. Due to these drawbacks, it is clear that an autonomous crew on such a mission will be a requirement. Another alternative would be to have many crewmembers trained for surgery, but therein lies a tradeoff with the size of the crew- on such a mission, there may be many tasks to perform beyond maintaining crew health. Finally, robotic surgery, although promising for longer-term exploration, will be unavailable for some time due to the complexities in replicating a surgeon’s skill.

The skills required of the CMO will include those in general medicine, intensive care, and surgery. Basic surgical skills include aseptic techniques, dissection, suturing, among others. Advanced skills include speed, optimal exposure, anatomy knowledge, and knowledge of procedures (indications, approach, complications and management, and postoperative care). However, some specialized skills will require extensive preflight training and in-flight maintenance.

One example of a specialized surgical skill, microsurgery, involves the reconstruction of tissues, such as reattaching a severed or crushed finger, under a microscope. This often requires the surgeon to suture blood vessels and nerves that are less than 1mm in size. While the loss of one or more fingers could clearly limit performance of the affected crewmember, the procedure requires a great deal of training and this level of training directly impacts outcome (The average rate of successful microsurgical procedures increases from 79% to 96% as surgeons gain clinical experience). In order to develop this specialized surgical skill, the surgeon must dedicate 6 months of time toward learning the technique and also continually practice their skills over time to maintain proficiency. While this is one example of a specialized skill, the time commitment for skills acquisition and maintenance, multiplied by many unique specialty surgical skills, demonstrates that the CMO will not be able to be an expert in everything.

For these reasons, the CMO astronaut/surgeon requires a system for skill maintenance and acquisition, as well as for surgical planning and assistance. Additional benefits of such surgical simulators[1-8,12,13,15-18,20,22-23,25] would be the ability to present the surgeon with different scenarios (anatomical variations such as gender, size, etc, diseases/trauma and conditions, and gravity/operating environmental differences), quantify performance and simulate the surgical result, and provide for faster training[11,14,19,21] both preflight and during the mission. Additional benefits of this generalized sensor input and display system include eliminating the need for separate monitors, displays and lightboxes, as well as providing a generally useful platform for augmented reality display and interaction. For example, such a system would also be useful for overlay of wiring diagrams on equipment, intercrew communication, telepresence for inspection of hazardous locations, as well as countermeasures for depression and other psychological affects of long-duration spaceflight. The requirements of such a system are that it have low power consumption, small size, and low weight (mass).

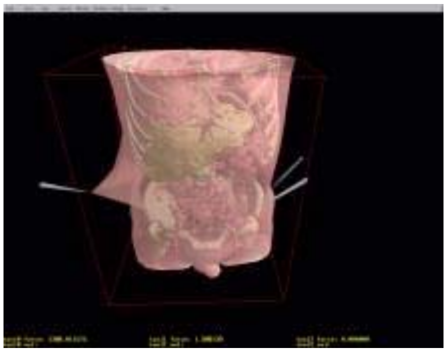
2 MATERIALS AND METHODS

A functional, usable prototype of an augmented reality surgical training tool was created at our center, using small, lightweight, low-power computer components that would be easy to transport on a space mission. The system consists of a see-through head-mounted computer display (HMD, Sony Glasstron PLM-S700), a tracking device (Ascension Technologies pcBird electromagnetic tracker), computer system (Sony Vaio or desktop system), and tracked surgical instruments (microsurgical forceps, Osteomed Corp, etc). Interaction with the system is provided through voice input (DragonSystems NaturallySpeaking) and speech synthesis (Microsoft Speech).

The system produces computer-generated imagery overlaid onto the real world, including virtual “hanging windows” for information display (CT/MR scans, vital signs, live endoscopic video, step-by-step instructions, dictation/communication screens), 3-D models of anatomy, and other information (for example, the projected trajectory of a drill) to assist the surgeon during a procedure. In addition, virtual patient models can be brought up within the environment for surgical skills training.

This system uses common off-the-shelf hardware and can be easily modified to use improved head-mounted displays, trackers, and computer systems as they become available. Instead, we have sought to provide a hardware/platform independent application and are focusing on refining the user interface and functionality for surgical assistance. The system component cost of this prototype is roughly $15,000, it’s weight under 15 lbs., and power consumption under 60 watts.

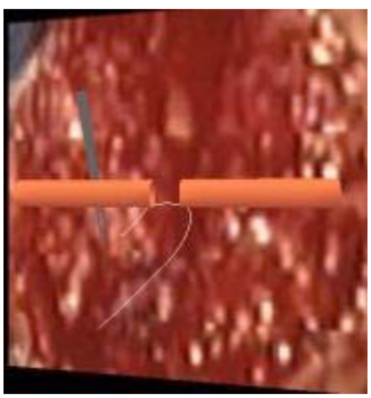
2.1 Software



Custom software was developed using C++ and the OpenGL, GLUT, and GLUI graphics libraries. This software provides for rapid information access and display, as well as a full surgical simulation engine capable of soft-tissue modeling supporting haptic interactions. It communicates with the tracking devices mounted on the HMD and surgical instruments and with networked haptic devices, captures live video sources from a framegrabber (FlashBus MV Pro, Integral Technologies) for endoscopic video acquisition, and displays this information within the environment. When in training mode, the user can also bring up patient-specific anatomical models and interact with them using the tracked surgical instruments and/or haptic devices and our soft-tissue modeling engine.

2.2 Content

Currently, a number of medical content modules have been produced for the system. These include craniofacial anatomy and surgical technique, hand anatomy, inner ear anatomy, dental anatomy, and simulators for surgical anastomosis and other simple procedures. An ongoing related project (the *iAnatomy* project) seeks to collect and collate information on every piece of human anatomy and every surgical technique and currently has access to ophthalmic anatomy, hand anatomy, and general anatomical dissection.



Microsurgery training was used as the first example, but the system has been adapted to realistically simulate a number of other surgical procedures. The user interacts with 3D computer generated soft tissues, in this case blood vessels, and virtual sutures that obey the laws of physics and deform like real vessels. Anatomical variations can be introduced (different sized vessels, different orientations, end-to-side anastomosis, etc) and can be performed over and over again at any magnification or operating conditions (Earth gravity, zero gravity, Mars gravity) and provides a number of metrics quantifying the surgeon's performance.

3 RESULTS

Functionally, the system provides a reasonable and useful system with fast response and adequate graphics refresh rate. The ability for the user to bring up important information (vital signs, CT data, etc) by voice command was found to be extremely intuitive. The use of real surgical instruments for training, as well as for intraoperative use, also contribute to ease of use and low learning curve

requirements of the system. Computer generated soft tissues deform and respond to instrument manipulation as real life tissues. In the specific case of microsurgical anastomosis, the lack of tactile feedback from the vessels does not significantly affect the overall experience. The program is easy to use since the interaction with the vessels happens through real microsurgery instruments, with the user looking at a stereo image of vessels as if viewed

through the microscope.

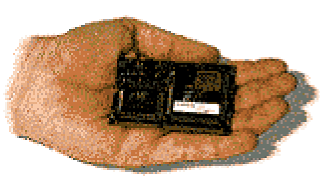
Real-time graphics performance of the system was found to be limited with the PC-based platform and especially challenging due to minimal hardware acceleration provided on small footprint portable computers (laptops). Despite this lack of hardware graphics acceleration, 6 frames per second were realized on the Sony Vaio platform and was found to be mainly limited to graphics fill-rate. A second development system (PentiumIII 550MHz with Oxygen GVX1) attains 15 frames per second, even when capturing live video off-screen and rendering it as a texture. Performance of the mass-spring simulation engine on this platform, while complex to analyze in detail, was also adequate at this display rate for 30,000-50,000 element geometries in this prototype system.

4 DISCUSSION

The effect of working in the virtual environment approximates that of working on real patients in the operating room and is comparable to existing methods of training. During long duration space flights, a system similar to the one we developed could provide the hands-on experience necessary to perform a complicated procedure.

While the current HMD is usable, we anticipate the need for higher resolution head-mounted displays in the near term and anxiously await new technologies such as retinal scanning displays, holographic optical elements, among others, which promise significantly improved resolution and dynamic range. In addition, improvements in tracking will also be welcome and we anticipate moving to more precise optical tracking methods before testing the system intraoperatively.

The graphics and computational performance of the current system is anticipated to continue to increase in accordance with Moore’s Law (performance doubling roughly every 18 months) and will yield a system easily capable of providing real-time imagery and simulation by the time of the first long-duration mission. In anticipation, continuing work on the system will produce a usable and highly integrated tool for medical officers in space or medical professionals on the ground.



In addition to computing and graphics performance, moving from a briefcase-sized unit to a handheld-sized computer unit worn on the belt would make the system even more usable. In initial discussions with palm-sized computing vendors (Tiqit), computation power appears tractable in the near term, while graphics power will take somewhat longer to develop. In either case however, computing and graphics performance in this form factor is projected to be adequate and commercially available within 10 years.

As for the simulation engine, the refinement of the physical properties and interactions between soft tissues such as skin, subcutaneous fat and muscles will lead to an even more realistic simulation environment. Simulation of blood and integration of on-line, interactive computational fluid dynamics will allow for comparison of different vascular interventions, should the be required. Similarly, adding more biomechanical modeling and simulation tools will also allow for predictive modeling of osteotomies and orthopedic interventions.

The content of the system is being increased as well. In addition to the anatomy and surgical technique content already underway, easy access to an electronic medical record of the patient will be required. Finally, as the content and functionality of the system increases, the need for improved and intelligent user interfaces will become more important.

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