A Remote Interactive Master Class in Surgery

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Abstract

This paper describes a concept demonstration of a remotely conducted, virtual surgical training master class. A networked immersive virtual environment was used to link instructor and selected students, while the remaining audience of health professionals observed both the contents of the instruction and the instructor-student interactions. The demonstration illustrated the multiple levels of computer-human interaction involved in this large-scale scenario. The focus of the interactions between the computer systems and the participants was at the level of the problem domain, so that the participants, both the specific students involved and the wider auditorium audience, would feel that their experience was in some way akin to the instructor being present in person and conducting demonstration surgery. The actual demonstration was conducted at a simulation technologies conference held in Canberra, Australia. The medical and surgical instructors were at Stanford University in the USA. The responses of the audience and participants were collected in a questionnaire and the results are presented.

Keywords

Haptics. 3D visualization. Collaborative virtual environment. Remote instruction. Surgical simulation. Surgical training. Presence. Distance learning.

INTRODUCTION

Application motivation

Virtual Reality technology is emerging as an important component of modern surgical training. Cosman et al. describe the limitations of the current apprenticeship model of training, including reduced exposure to an adequate spectrum of operating procedures and the need for a modern adult-education model of training with "continual high-quality feedback on performance" (Cosman et al., 2002). They discuss the advantages and disadvantages of current work in this area and conclude that "There is no doubt that simulators will play a role in the training of future generations of surgeons". Powerful evidence that virtual reality technology does significantly improve the operating performance of resident surgeons was recently demonstrated in a randomised double-blinded study carried out at Yale University (Seymour et al., 2002).

In countries like Australia, where the population is small and unevenly distributed, access to specialist surgical expertise for training can be difficult. Surgical residents commonly travel long distances to attend specialist training courses, at significant expense and disruption to their professional and personal lives. The demonstration described in this paper explores the concept of combining remote interaction with an experienced surgeon instructor and the best attributes of virtual reality technology for this class of training.

Networked virtual environments

Collaborative (networked) virtual environments are expected to have many benefits for training at a distance (Singhal and Zyda, 2000), especially for skills training in the context of surgical procedures and supported by appropriate simulation capability. Others have shown (Basdogan et al., 2000 and Sallnas et al., 2000) that haptic feedback enhances performance in a collaborative virtual environment, but it is known that haptic feedback makes the issue of network quality, especially latency, a problem of prime importance (Matsumoto et al., 2000). The basic architecture for the collaborative virtual environment used in this demonstration was developed in Australia within the Commonwealth Scientific and Industrial Research Organisation (CSIRO) over the period 2000-2002, and was presented at the ACM SIGGRAPH conference (Gunn et al, 2003). It deals specifically with network quality and the issues of latency in the haptic interactions involved, between the two collaborating virtual environments.

This demonstration extends that work significantly in the directions of the quality and usability, and to include wider audience involvement. For this demonstration a temporary broad-band internet connection was established between the two venues, a conference auditorium in Canberra, Australia and the Stanford University School of Medicine in the USA. This event was jointly presented by teams from the CSIRO Information & Communications Technologies Centre (CSIRO ICTC, 2004) project and from the Stanford University Medical Media and Information Technologies project in the USA (SUMMIT, 2002).

The computer-human interfaces

Three pairs of computer-human interfaces were involved in this demonstration. Firstly, the anatomy instructor presented his lecture to the whole audience who observed live video of the instructor with his real-time, pointer-based commentary on a large-format, stereo display of images of cadaver dissections. Secondly, the surgical instructor and student worked with an immersive virtual environment system containing a rich set of multi-modal display and interaction components. The body organs were represented by simulations with attributes roughly approximating real tissue, having the ability to be compressed and stretched by the participants' instruments. These components formed the interface for each of them to their own virtual environment and, through the network, linked them to each other. Finally, the audience also viewed the surgical instructor and student at work, live at one end and through streaming video from the other, together with a real-time large-format stereo display of the 3D surgical model and their interactions with it.

The intention for each of these three computer-human interfaces was that the participants would be able to engage directly with the teaching content being presented, that they would also feel a sense of engagement with each other, and a sense of each other's presence. The success of the demonstration would be measured by the extent to which the participants felt a significant level of engagement and presence, and by the audience's perception that this goal was achieved. This measurement was conducted using two questionnaires, one for the audience as a whole and one specifically for those audience members who volunteered to take an active role in the surgical training scenario.

THE MASTER CLASS DEMONSTRATION

The demonstration used two scenarios. The first was an anatomy instructor describing anatomic structures relevant to the surgical exercise that followed, and the second was a surgical instructor, also located remotely from the venue, teaching a surgical trainee or student about conducting a related surgical procedure. Both the surgeons and the audience observe the anatomy lesson, and the audience watch the interactions between the surgical instructor and each student, and also observes the data, models or objects that were used as part of the teaching, in the style of an audience watching a master-class. The concepts being explored included:

- An anatomy instructor, located remotely, displaying unique stereo images to inform in an engaging manner the surgical instructor, the student, and the audience about the anatomic region of surgical interest;
- The student and surgical instructor engaging in a meaningful dialogue both with words and with actions, mediated by virtual tools, objects and interaction interfaces;
- The audience being able to observe the dialogue and the subjects of the dialogue in a comfortable and natural manner;
- The geographical distance between instructor and student/audience (actually approximately 12,000 km) being no barrier to successful interaction.

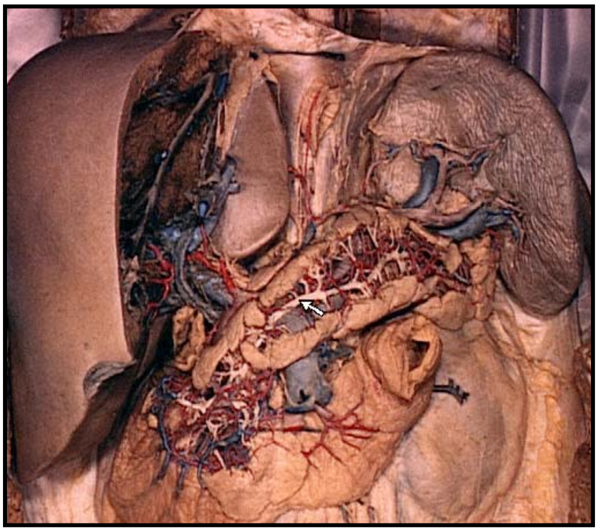
The first part of the demonstration involved an anatomist at Stanford (Dr Srivastava) presenting the relevant surgical anatomy using large-format 3D (stereo) images of cadaver dissections. He controlled the display from Stanford and used pointers to features in the images to support his narrative.

The second part involved a surgical scenario — the removal of the gall bladder (cholecystectomy). This scenario had many attributes that were appropriate to this concept. The anatomy of the abdomen is complex but structured (organs are in front, behind, under, connected to other organs) and well suited to the spatial teaching capabilities of the virtual environment being used. The sequence of surgical steps is well-defined (identify, lift, grasp, pull, hold, diathermy, clamp, cut, remove) and can be taught with reference to an anatomical model. There is scope for responses between instructor and student (find this organ, what is that organ, what is connected to this organ). Several of the steps are collaborative, with one person holding and stabilizing while the other cuts or clamps.

Remote anatomy lesson

The juxtaposition of anatomy images and corresponding surgery video clips or simulations has been used very effectively in remote teaching situations. In October 2002 the California Orthopaedic Research Network (CORN) presented an interactive demonstration containing real-time streaming video from the operating theatre, stereo anatomical images of the relevant anatomy, real-time commentary from observing surgeons and real-time questions from students, all located at a number of separate sites across the USA. An audience of approximately 200 attendees at the Internet2 Fall Workshop watched the various data streams under moderation by a panel of clinical and networking specialists. (Dev et al., 2004). The inclusion of a remote presentation of anatomy in this concept demonstration draws on the experience of this earlier work.

The image set used for the anatomical part of the demonstration was taken from the famous Bassett collection (Bassett, 1962). The Bassett collection is a unique set of more than 1500 stereo images that consists of detailed anatomical dissection of human cadavers in all anatomical regions (from head to toe). David Bassett conducted the painstaking dissections over a period of several years in the 1950s and 1960s. William Gruber, the inventor of the 3D View-Master meticulously photographed these dissections (figure 1). The high quality of these images was an important feature in selecting them as a part of this multi-component session.



Eight images relating to the particular surgical procedure were chosen and an anatomy lesson plan was prepared to complement the virtual environment component. From the audience's point of view there was no indication, in the way it was presented, that the anatomy lesson was coming live from the other side of the world. Tight timing of the overall timeslot within the host conference prevented a question-and-answer dialogue between the audience and Dr Srivastava but in other circumstances this would have been the natural way to conclude this component. The anatomy lesson was presented using a networked application called the Remote Stereo Viewer which can act as a client, retrieving the images from a remotely located database. (Dev et al. 2002). It was tailored to meet specific security requirements for the temporary broadband network connection between Canberra and Stanford.

Figure 1: 3D Anatomy screen.

The Remote Stereo Viewer was developed by Dr. Steven Senger at the University of Wisconsin, LaCrosse. (Remote Stereo Viewer 2003). Important collaborative features that require multicast could not be used due to network limitations across the Pacific.

Remote interactive explanation of surgical procedure

The surgical procedure instruction used a collaborative simulated surgical training environment developed at CSIRO and described by Gunn et al (Gunn et al., 2003). It is based on the CSIRO Haptic Workbench (figure 2), a desktop immersive haptic virtual reality system that is well-suited to simulated tasks that are contained within a person's arm's reach (Stevenson et al., 1999).

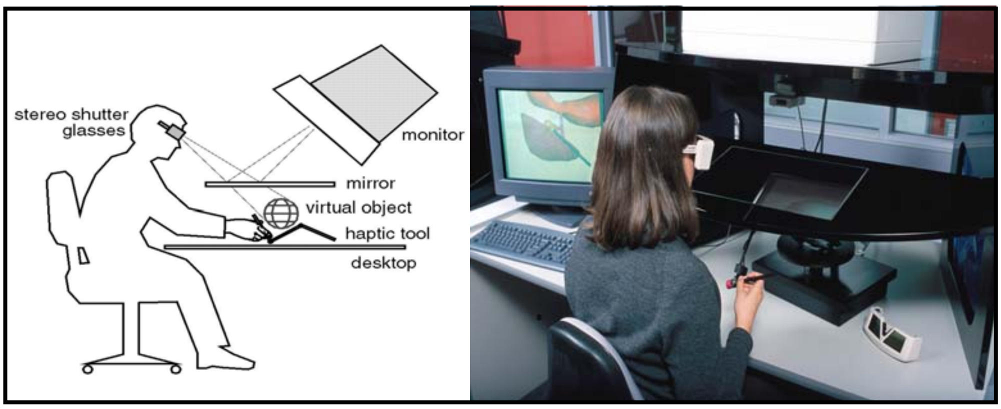


Figure 2: The CSIRO Haptic Workbench.

The surgical instructor led students through the simulated procedure, while experiencing a 3D scene comprising liver, stomach gall bladder, kidneys and other abdominal organs, all of which could be manipulated by the participants. The system continuously transmitted incremental changes in the 3D model (anatomy, instruments, pointers and annotation) between Canberra and Stanford, keeping all movable components, as well as the users' instruments, synchronized with each other. It allowed both participants to simultaneously draw within the 3D scene while discussing the anatomy, and co-operatively grasp pliable body organs (figure 3). They could also cut tissue, clip and cut ducts (figure 4) whilst feeling the actions and forces provided by each other across the Pacific Ocean. Using the haptic capability of the system, the instructor could grasp the student's instrument (figure 5a), and guide it to the correct part of the anatomy, helping them to grip and extend the attached ducts, so as to apply the required tension for clipping, or to retract the instrument to avoid potential injury. It was possible for them to independently zoom and pan their viewpoints, as well as lock their views together to jointly study the scene from the same viewpoint.

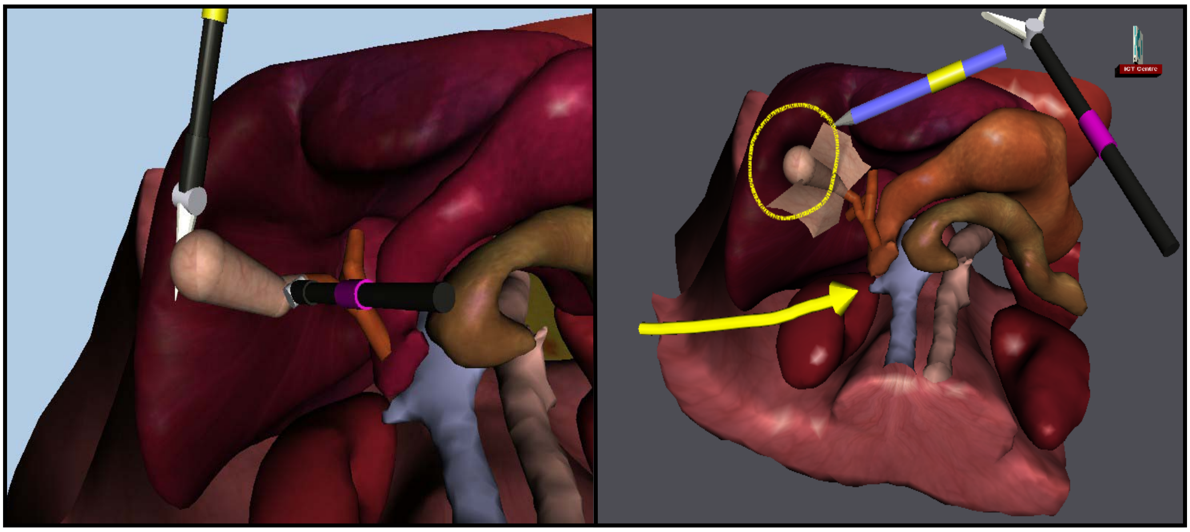


Figure 3: a) Manipulating a simulated gall bladder. b) Annotating in 3D.

They were both able to draw diagrams on a virtual white board as well as annotate a virtual medical scan-viewer. This permitted detailed discussion about the techniques required in the gall bladder removal operation. Each was able to point and sketch questions and answers, adding to the flow of information between instructor and surgeon.

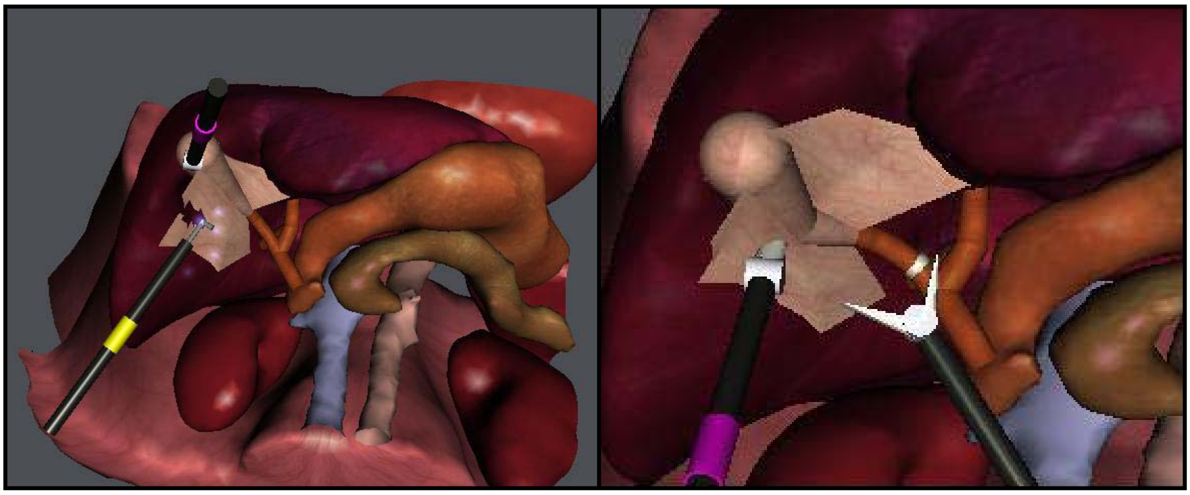


Figure 4: a) Diathermy. b) Clipping of the cystic duct.

A virtual video player (figure 5b) embedded in a separate part of the scene, allowed the participants to remain immersed in the virtual environment while they viewed a pre-recorded video of real surgery. Each participant could operate the video and draw on the virtual screen while discussing the operation depicted. The virtual video players at each end of the network connection were synchronized so that each participant saw, and was commenting on, the same video frames. This video feature helped to bridge the gap between the diagrammatic, abstract presentation of the surgical procedure delivered using the virtual anatomical models, and the reality of actual surgery. Its role parallels the blend of streaming surgical video, static anatomical images and off-line discussion that was presented at the CORN demonstration mentioned above (Dev et al., 2002).

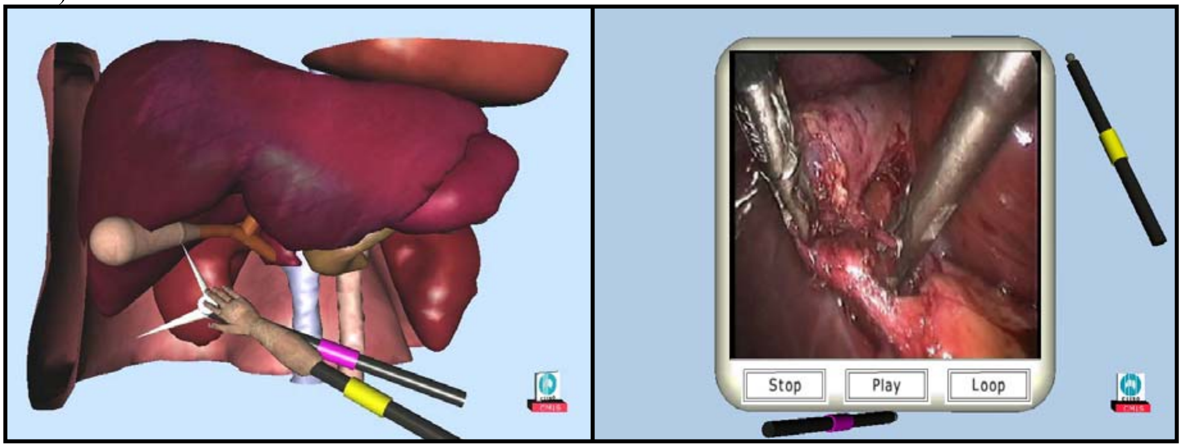


Figure 5: a) Haptic hand guiding. b) Virtual video player.

The initial demonstration of the surgical procedure had an Australian surgeon, Dr Patrick Cregan, role-playing a surgical trainee. The instructor, located at Stanford University was Dr Sherry Wren. Following this, several members of the Australian audience participated in the surgical procedure lesson, one at a time, under remote direction from Dr Wren at Stanford.

Audience involvement

The audience played two roles. At the local level they watched and listened, observing the clinical teaching points being made and observing the way a student might respond to an instructor in such a situation. Their feedback would point the way towards an environment that might maximise the value to be gained from a highly expert but very busy surgical instructor.

Their other role was perhaps more important. Most of them were health professionals or worked in health and medical education. They could, therefore, comment with considerable authority on the value and relevance of the concepts being presented. At the end of the demonstration the audience was handed a questionnaire to gather their impressions and personal responses to what they had experienced.

THE PRESENTATION ENVIRONMENT

In Canberra the conference presentation environment, shown in Figure 6, used high quality video, echo-free audio, graphical 3D interactive models of human body organs shared over the network, bi-directional haptic interaction and 3D stereo visualization. This involved several discrete sub-systems – each of which was achieved in both Canberra and Stanford by different combinations of hardware and software. The entire system made use of a high bandwidth connection between the two sites, via a link involving three academic and research networks; CeNTIE (CeNTIE, 2003), AARNet (AARNet, 2004) and Internet2.

To ensure that all views were continuously visible from the audience and that all conversations by participants could be easily heard we mounted a camera and microphone above two of the display screens. This had the effect of allowing face-to-face conversations while the audience looked on.

At Stanford a single camera and screen were used to record and display the video. A single microphone was used to record audio and headphones were used to play audio. The use of headphones meant that an echo canceller was not required at the Stanford end to prevent any echo being heard in Canberra.

A single video/audio stream was sent in both directions between Canberra and Stanford. A high bandwidth connection allowed the use of Digital Video (DV) over IP transmission, providing broadcast quality video and audio. There was no jerkiness or flicker in the video and very little latency – allowing a natural flow of discussion between the participants.

In Canberra two cameras were used, one giving a close-up view of the surgeon and the other a wider view of the auditorium. An operator controlled which video streams were sent to the local display screens and to Stanford. In addition to the two large plasma displays for the audience there was a miniature video screen built into the workbench to provide a more intimate face-to-face communication between the instructor and the local surgeon.

Audio capture was achieved by two microphones, one on the haptic workbench and the other at a podium for the speaker. The local audio was mixed and the resulting output transmitted to Stanford. The local audio mix and the audio stream from Stanford were then broadcast locally on loud speakers for the benefit of the audience. An echo canceller was used in the lecture theatre in Canberra to allow the use of microphones in conjunction with loud speakers without an echo being heard in Stanford.

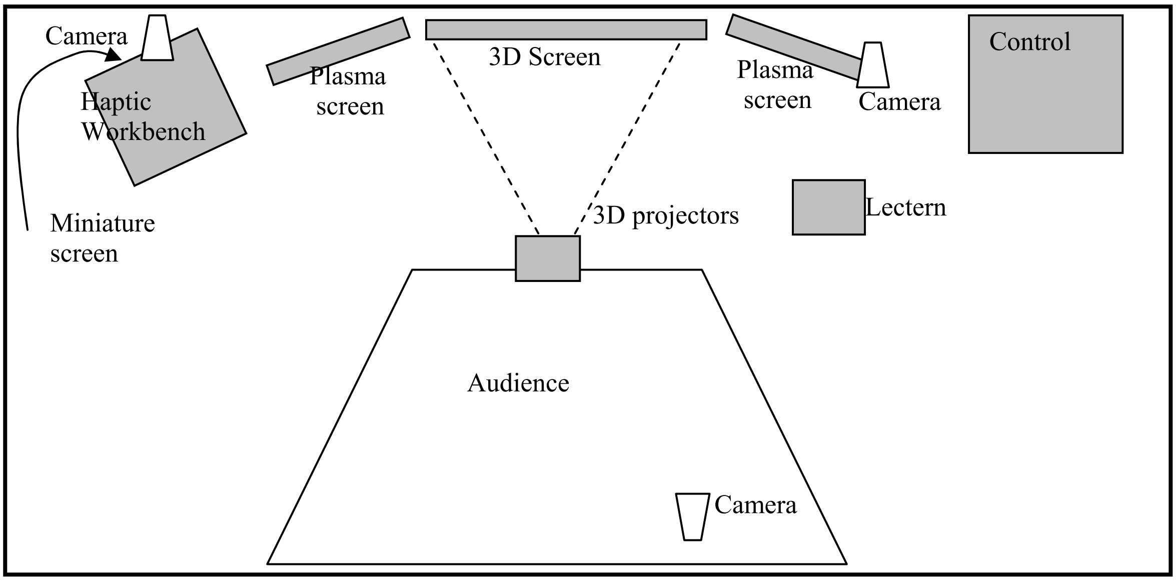


Figure 6: The auditorium layout.

Information flow between the "surgical trainee" in Canberra and the surgical instructor in Stanford

This link between the trainee, or student, in Canberra and the instructor in Stanford demonstrates the purpose and intent behind the architecture of the CSIRO Collaborative Haptic Workbench upon which this system was built. The intention was to provide a variety of ways for the two people to communicate about the data in front of them and about the tasks to be performed, and to provide it in such a way that the actions of each are natural in the context of the scenario at hand. The real-time two-way flow of information (voice, gestures and actions upon objects) is intended to support a natural dialogue that combines references in 3D space and time with actual spatial operations (here, that, under there, like this, let me show you) where the individuals physically move their hands and the virtual instruments that they are holding as an integral part of the dialogue.

The system designers expected that people coming fresh to this system would find it quick and easy to understand what they needed to do. This expectation was met at this event. The members of the audience who took part in the latter stage of this event were all able to use the components under remote instruction with a minimum of explanation.

IMPLEMENTING THE DEMONSTRATION

This demonstration required access to capabilities that are still very much in the research domain. Creating the required network capacity and reliability half-way around the world involved three network research entities (CeNTIE, GrangeNet and Internet2) as well as significant "last mile" implementation. The Haptic Workbench is still a research tool which needed to be installed and tailored at both ends. The collaborative haptic software required significant modification and extension to support the surgeons' requirements for a meaningful demonstration lesson. The ability to clip the cystic duct and use diathermy to dissect the membranes was added at the suggestion of the Stanford surgeons. They also suggested that it would greatly benefit the teaching utility of the system if error conditions could be represented. Accordingly, the cystic duct and gall bladder were modified to leak bile fluid if they were mistakenly cauterized. Also the cystic duct would rupture, leak fluid and eventually break if it was put under too much tension. This allowed the students to learn the limits of safe practice through error and repetition. The surgical simulation system ran on a dual processor 2.4Ghz PC running Windows 2000.

The Digital Video (DV) format which was used in this demonstration offers broadcast quality audio and video. While its compression ratio is not as high as other common formats such as MPEG2 it is suitable for real-time compression on a commodity computer. Software developed within CSIRO, based on work by Ogawa et al. (Ogawa et al., 2000) provided both video compression and conversion of the compressed video into network packets for transmission over the broadband connection between Canberra and Stanford. The video/audio system ran on its own PC.

It was felt that audio and video quality of this level was important. The demonstration team felt that artifacts attributable to a low-quality link, such as frame freeze, lack of synchronisation between video and audio and poor quality audio, would seriously interfere with the participants' experience of the content of the demonstration.

Firewall access also needed to be opened up between the collaborating machines to allow an unhindered flow of data packets between them. This required the cooperation of the various network administrators.

ASSESSMENT OF THE EVENT

General assessment

A major aim of the demonstration at the Health and Medical Simulation Symposium was to provide a knowledgeable audience with direct experience of remotely-conducted surgical training supported by high-quality broadband connectivity, complex multi-modal interaction and large-scale modern stereo display and then to seek their feedback. Members of the audience observed very closely the interactions between the surgical instructor and student in a role-play that contained genuine surgical teaching content and demonstrated in real time the content-rich dialogue between the surgeon and student, knowing that the two were actually physically separated by intercontinental distances. Some members of the audience also took their turn to experience, at first-hand, the remote training session. A one-page questionnaire with structured and free-form responses was used to gather audience feedback. The demonstration team also made informal observations of the audience's response.

The audience consisted of about 70 delegates to the Health and Medical Simulation Symposium and the associated Simulation Technologies Conference. Most of the audience were clinical practitioners (doctors, medical specialists, nurses and medical educators) who already had extensive experience in using simulation technologies in their professional work. They were, therefore, an ideal group to critique our work.

The conditions of the demonstration were designed to maximise the interaction between the participants and the networked computer systems. There were large, high-quality visual displays, both of the anatomical data under discussion and of the remote instructor. The audio quality was excellent and the stereo display was achieved through light-weight comfortable glasses and high-quality projector and screen. The contents of both the surgical anatomy lesson and the surgical procedural lesson were relevant and meaningful to the audience.

The first informal observation, made by both our project team and the conference organisers, was that the audience was strongly focussed on the event. Throughout the 20 minutes of the actual teaching demonstrations the audience was still and silent and their body language indicated a strong level of attention. At the end of the session we received 39 completed questionnaires. We also received responses to additional questions from the eight people who volunteered to personally experience the surgical procedural lesson under remote mentoring from the surgeon at Stanford.

Results of participants' questionnaires

Technical Performance Ratings

The first three items of the questionnaire addressed the quality of the technical performance of the systems used in the demonstration. Audience members were asked to rate the following features on a five-point scale (1=Unacceptable, 5=Excellent):

1. Interaction between the surgeon and the student (rapport, dialog, etc.)
2. Display of 3D images of the anatomy during the Anatomy Lesson
3. Remote teaching of a surgical procedure

Thirty-nine members of the audience completed the one page questionnaire, which yields a response rate of 56%. The data in Table 1 show that 97 % of those who responded rated the interaction between the surgeons as either very good or excellent. 85 % rated the visual display of 3D anatomy as very good or excellent, and 87 % rated the remote teaching as either very good or excellent.

Table 1 shows the distribution of responses.

Technical Performance	Unacceptable		Poor		Acceptable		Very Good		Excellent	
	Score	%	Score	%	Score	%	Score	%	Score	%
Interaction between Surgeon & Student	0	0%	0	0%	1	3%	23	59%	15	38%
3D Images of Anatomy	0	0%	0	0%	6	15%	16	41%	17	44%
Remote Teaching	0	0%	1	3%	4	10%	23	59%	11	28%

Table 1: Audience's rating of technical performance.

Usefulness for Learning a Surgical Procedure

The next three items on the questionnaire addressed the effectiveness of the unique components of the demonstration in terms of usefulness for learning a surgical technique or procedure. The audience members rated their perception of the following on a 5-point scale [1=Not at all useful, 5=extremely useful]:

1. Viewing 3D stereo images of the relevant anatomy
2. Interacting with a master surgeon as she manipulates the virtual structures and uses the 3D drawing tool to explain concepts
3. Being guided by an expert surgeon as the student manipulates the virtual anatomical structures

The data from this set of questions show that 88 % of those who responded rated viewing 3D stereo images of the relevant anatomy as very useful or extremely useful. 89 % rated the ability to interact with the master surgeon as she manipulated the virtual structures as very useful or extremely useful, and 89 % also rated the ability to be guided by an expert surgeon as either very useful or extremely useful.

Table 2 shows the distribution of the responses.

Usefulness for Learning	Not At All Useful		Not Very Useful		Useful		Very Useful		Extremely Useful	
	Score	%	Score	%	Score	%	Score	%	Score	%
Viewing 3D Images	0	0%	0	0%	5	13%	24	62%	10	26%
Interaction with Master Surgeon	0	0%	0	0%	4	10%	22	56%	13	33%
Guided by Master Surgeon	0	0%	0	0%	4	10%	22	56%	13	33%

Table 2: Audiences rating of "usefulness for learning".

Ratings of Presence and Engagement

Eight members of the audience accepted the invitation to try the immersive surgical training system for themselves. We asked each of them to respond to the following about their experience:

1. The extent to which they felt that the teacher was "present" with them
2. The extent to which they felt engaged with the teaching scenario

The data showed that 100% reported a high or very high sense of presence with their teacher and 87% engaged highly or above with the scenario.

	Very low		Low		Acceptable		High		Very high	
	Score	%	Score	%	Score	%	Score	%	Score	%
"Presence" of teacher	0	0%	0	0%	0	0%	5	62%	3	38%
Engagement with scenario	0	0%	0	0%	1	12%	3	38%	4	50%

Table 3: Audience participants' rating of their experience of the collaborative haptic workbench.

CONCLUSION

The concept demonstration of a remote surgical master class showed that it is possible to overcome the technical difficulties involved in presenting a hands-on teaching environment, in real-time, linking two institutions on either side of the world. It also showed the feasibility of providing education through demonstration to a knowledgeable audience and the ability to get structured feedback from the audience members.

In terms of the user interface support between surgeon and student, 97% of the audience assessed the interaction between surgeon and student as Very Good or Excellent and all eight audience volunteers rated the sense of presence of the surgeon (instructor) as High or Very High. Seven of the eight audience volunteers rated their engagement with the teaching scenario as High or Very High. While this does not represent a controlled trial this strongly positive response by a knowledgeable audience to a novel situation indicates that there is real value in pursuing this collaborative approach to support the rapport between student and instructor.

Eighty-five percent of the audience rated the remote teaching of anatomy using stereo images as Very Good or Excellent. Eighty-seven percent rated the remote teaching of the surgical procedure, using dialogue, interactive stereo models and shared supporting media as Very Good or Excellent. This indicates strong support for procedural teaching using shared virtual environments containing high-quality information but it also implies that there is some work to be done to reach the quality needed for actual teaching deployment.

Finally, although this demonstration was not intended to teach the audience explicit material (as would be expected in an actual master class) the audience engagement with the demonstration can be gauged by their responses to the three "usefulness for learning" questions, where 86% of them rated the three selected aspects as Very Useful or Extremely Useful. This set of responses, together with the informal observation of the high level of focus on the part of the audience during the demonstration, implies a high level of effectiveness of the overall interface between the audience and the multiple modes of information presentation that they experiences.

The overall feedback validates the ideas behind this concept demonstration and provides encouragement for the development teams to further explore these directions. It showed that remote teaching demonstration and discussion can be carried on using a rich set of interface components and need not be limited to conventional video conferencing technology.

REFERENCES

AARNet (2004) AARNet – Australia's Research and Education Network, http://www.aarnet.edu.au/, Accessed 9 June 2004.

Basdogen, C., Ho, C., Srinivasan, M. and Slater, M. (2000). *An Experimental Study of the Role of Touch in Shared Virtual Environments*. ACM Transactions on Computer-Human Interaction, Vol. 7(4), December 2000.

Bassett, D. (1962) *A Stereoscopic Atlas of Human Anatomy*, Sawyer, Portland, Oregan.

CeNTIE (2004) *Centre for Networking Technologies for the Information Economy*, http://www.centie.net/, accessed 9 June 2004.

CSIRO ICTC (2004) *CSIRO Information & Communications Technologies Centre*, www.ict.csiro.au, Accessed 9 June 2004.

Cosman, P., Cregan, P., Martin, C. and Cartmill, J. (2002) *Virtual Reality Simulators: Current Status in Acquisition and Assessment of Surgical Skills*, ANZ Journal of Surgery 2002;72, pp 30-34.

Dev P., Srivastava S., Gutierrez D., Senger S., Jones N.F., Steadman R.H., Relan A., Wilkerson L., Smith C.F., Akeson W.H., Johansen W.E.(2004) *Production of a Multisource, Real-time, Interactive Lesson in Anatomy and Surgery: CORN demonstration*. J. Educational Technology Systems, 33, pp. 3-10, 2003-2004.

Dev P., Montgomery K., Senger S., Heinrichs W. L., Srivastava S., Waldron K.(2002) *Simulated Medical Learning Environments on the Internet*. Journal of the American Informatics Association, Vol 9(5), pp 437-447, 2002.

Gunn C, Hutchins M, Adcock M and Hawkins R (2003) *Trans-World Haptic Collaboration*, ACM SIGGRAPH 2003 Sketches and Applications, San Diego, July 27-31, 2003.

Gunn, C., Hutchins, M., Adcock, M. Hawkins, R. (2004) *Surgical Training Using Haptics Over Long Internet Distances* in *Medicine Meets Virtual Reality 03/11*, Westwood, J., Hoffman, H., Robb, R. and Stredney, D., Editors, IOS Press, Amsterdam, 2004.

Matsumoto, S., Fukuda, I., Morino, H., Hikichi, K., Sezaki, K., and Yasuda, Y. (2000) *The Influences of Metwork Issues on Haptic Collaboration in Shared Virtual Environments*. Fifth Phantom Users' Group Workshop, 2000.

Ogawa, A.., Kobayashi, K., Sugiura, K., Nakamura, O. and Jun Murai, J. (2000) *Design and Implementation of DV Based Video over RTP*, Proceedings of the Packet Video Workshop 2000, Cagliari, Italy, May 2000.

Reachin Technologies AB (2003) *Reachin API*, http://www.reachin.se/products/reachinapi/ Accessed 9 June 2004.

Sallnas, E., Rassmus-Grohn, K. and Sjostrom, C. (2000) *Supporting Presence in Distributed Environments by Haptic Force Feedback*. ACM Transactions on Computer-Human Interaction, Vol. 7(4), December 2000.

Remote Stereo Viewer. (2003) http://www.visu.uwlax.edu/NGI/RSV.html.

Sensable Technologies Inc. (2004) *Haptic Devices and Toolkits*, http://www.sensable.com/products/phantom_ghost/index.asp Accessed 9 June 2004.

Seymour, N., Gallagher, A., Roman, S., O'Brien, M., Bansai, V., Andersen, D. and Satava, R. (2002). *Virtual Reality Training Improves Operating Room Performance*, Annals of Surgery, Vol 236, No. 4, pp 458-464.

Singhal, S. and Zyda, M. (2000) *Networked Virtual Environments*. ACM Press, SIGGRAPH Series. 2000.

SUMMIT (2002) *Stanford University Medical Media and Information Technologies*, http://summit.stanford.edu, Accessed 9 June 2004.

Stevenson, D., Smith, K., Veldkamp, P., McLaughlin, J., Gunn, C. and Dixon, M. Haptic Workbench (1999) *A Multisensory Virtual Environment* in *Stereoscopic Displays and Virtual Reality Systems VI*, Merrit, J., Bolas, M. and Fisher, S, Editors, Proceedings of SPIE Vol 3639, 356-366, January 1999.

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JumboVision International Pty Ltd provided the 3D projection system and stereo glasses which enabled the audience to fully experience the demonstrations.

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