

Using Collaborative Haptics in Remote Surgical Training

Chris Gunn* Matthew Hutchins* Duncan Stevenson* Matt Adcock*
Patricia Youngblood*[†]
(*) CSIRO, ICT Centre, Australia
(*[†]) Stanford University School of Medicine
E-mail: Chris.Gunn@csiro.au

Abstract

We describe the design and trial of a remotely conducted surgical master class, using a haptic virtual environment as an integral part of the learning process. In the trial, we linked a haptic virtual environment in Canberra, Australia with a second installation at Stanford University, California. We were testing several haptic components of the system, and whether collaborative haptics could be useful in teaching surgery at a distance. We were also interested to see if an audience could be engaged in the instruction. The participants used features such as manipulating body organs, diathermy and clipping and cutting of ducts. The audience followed each student's performance on a large 3D screen while waiting their turn at the interface.

A key aim of the application was to produce a shared sense of presence in the virtual environment. The responses of the audience and participants in this regard were collected and results are presented.

1. Background

Collaborative (networked) virtual environments (CVEs) have been found to have several benefits when groups or individuals need to share information or skills. Singhal and Zyada [19] list some of these as “a shared sense of space, a shared sense of presence, a shared sense of time, a way to communicate and a way to share data”. It has also been shown [2] [17] that haptic (force) feedback significantly improves perceived virtual presence in a CVE, and that it also enhances performance considerably in a shared, dexterous 3D task. Salilinas, Rasmus-Grohn and Sjoström [17] found that force feedback improved performance and a sense of presence in a cube

manipulation task.

However, this field presents several challenges. These include communication delay (latency) and logical consistency between separate representations of the environment. When haptic feedback is used as an interface mechanism, solving these issues becomes more critical, due to the direct and immediate user input at each end. Kammermeier et al [10] state that as well as providing information about the environment, haptic interaction also implies a bilateral exchange of energy between the human operator and that environment. This produces a feedback loop that is susceptible to instability.

To use collaborative haptics in a real world application, over a real network, we needed to overcome the stability problem. Kim et al [11] were able to achieve usable haptic collaboration across the Atlantic Ocean by introducing a predictive algorithm for collision detection, as well as three layers of damping. Our work [5] has shown that in certain circumstances, for example highly damped environments with soft objects, we can use a specialized physics model to withstand latencies of around 200 milliseconds. This allows such haptic environments to be shared by points on the opposite sides of the globe. We cover how this algorithm was applied in this trial in section 3.2.

Hespanha et al [6] discuss methods of resolving the problem of simultaneous access to the same object, by using object ownership and locking. In surgery, we are simulating real world activities and are therefore able to circumvent this complexity by allowing the combination of all applied forces to resolve the conflict as would happen in the real world. This is also covered in section 3.2.

Virtual Reality technology is increasingly becoming an important component in modern surgical training. Cosman et al describe the limitations of the current apprenticeship model of training, including limited

exposure to a variety of operating procedures and the need for “continual high-quality feedback on performance” [4]. They conclude that “There is no doubt that simulators will play a role in the training of future generations of surgeons”.

At SIGGRAPH 2003 we presented a pseudo-physics model, which can be used to help control the tendency to dynamic instability and allow long distance haptic collaboration [5]. This experiment extends that work 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 holding a simulation technologies conference (SimTect 2004) in Canberra, Australia and the Stanford University School of Medicine in California in the USA. The class was located at the conference in Canberra and the instructor was located in an office environment at Stanford University.

2. Hardware

The conference presentation environment used an immersive, hands-in, networked haptic environment, high quality, multi-screen video, echo-free audio and a large scale 3D projection screen. The entire system made use of a high bandwidth connection between the two sites, made possible through three academic and research networks; CeNTIE [3], within Australia, AARNet [1] for the trans-Pacific connection and Internet2 [8] within the United States.

For the immersive haptic interaction we used two CSIRO Haptic Workbenches [20] (figure 1). One was installed on the stage at the conference centre in Canberra and another at Stanford University School of Medicine, where the surgical instructor would be based. The workbench contains a SensAble Technologies’ Phantom 1.5 [12][18] as a 3D haptic input device and active stereo shutter glasses [9] to view the model in three dimensions.

The application at each end was running on a Dell dual processor 2.8Ghz PC running Windows 2000, fitted with 3DLabs Wildcat 3 7110 graphics cards, with active stereo output. For the class, the graphics output was also directed to an active-to-passive converter box and then to the two passive stereo projectors for the audience view. The projected 3D scene was displayed on a 3m square reflective screen on stage and the audience were issued with passive stereo glasses.

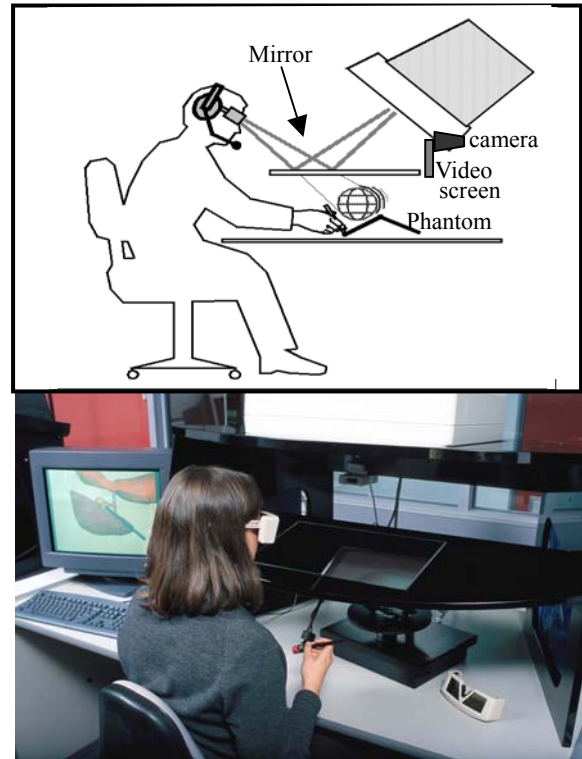


Fig. 1. The CSIRO haptic workbench

A camera, miniature screen and microphone were installed within the haptic workbench, giving users a close-up view of their collaborator. A broadcast quality video conferencing system enabled all participants (including the audience) to converse in a natural way. At the conference hall we installed two large plasma screens, each with a camera and echo cancelling microphone attached, allowing face to face conversations at several points on the stage. A high bandwidth connection allowed the use of Digital Video (DV) over IP transmission, providing broadcast-quality video and audio with no jerkiness or flicker and very little latency.

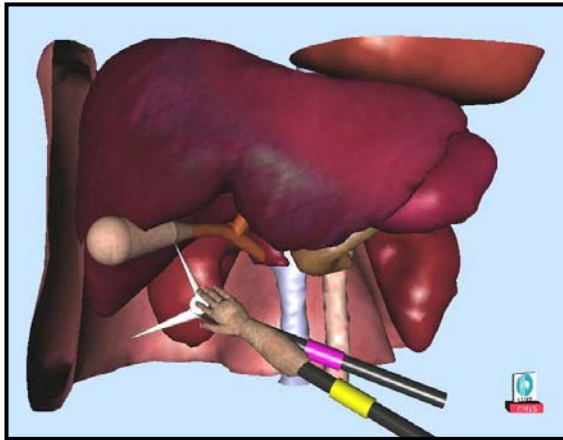
3. The application

The surgical training application has the scenario of a cholecystectomy (gall bladder removal), with an instructor and remote student working in the same virtual space. The training system has several views, which can be visited by users individually or in unison. The primary view is of a 3D model of body organs such as liver, stomach and kidneys, which was obtained by segmenting data from CT scans.

The training system has been designed with the philosophy of supporting discussion between the instructor and student about the anatomy and key steps involved in the procedure. It is not intended to be a

high fidelity simulation. Instead, the goal was to include indicative representations of objects and actions that can serve as a starting point of teaching discussions and aids to memorization. These indicative representations are augmented with the other views, as discussed in Section 4.

3.1. Haptic guiding hand



Within any view, the instructor can remotely grasp the student's tool, to haptically guide it (along with the student's hand) to any point in the scene (figure 2). The student can feel the force of the instructor's guiding hand and the instructor can feel any resistance by the student. This enables the instructor to quickly move a student to the correct position at any time or to help the student apply the correct force to organs such as the cystic duct. The guiding hand is implemented by providing an attractive force on each machine. The position of the attractive force is detected from the tool position on the remote machine at the haptics frame rate (1000hz) but we found that it is only necessary to transmit it across the network at 400 Hz. The strength of the force felt by the remote user, towards this point

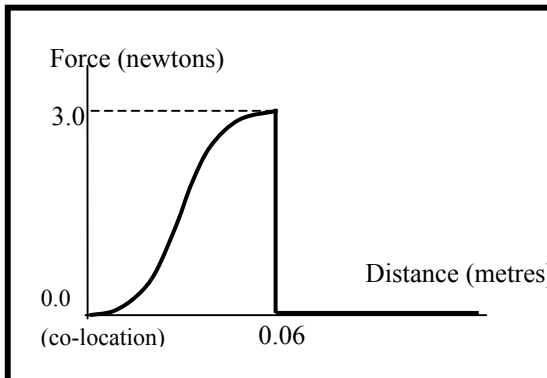


Fig. 3. The guiding hand force function

is calculated at the haptics frame rate with a sinusoidal force function shown in figure 3.

The graph shows a dead zone around the co-location point, a means of avoiding vibrations. The force is also smoothed between successive haptic cycles, resulting in the student feeling a gentle pulling force to the instructor's tool once within range. The attraction is activated with the button of the phantom device, and only comes into effect if the button is initially depressed whilst inside the active zone.

3.2. Deformation of body organs

Most organs in the model are deformable, simultaneously by both instructor and student (figure 4), allowing either participant to push, grasp and stretch the body organs. The pliability of each organ is set differently to demonstrate the variability possible, e.g. the liver is configured to be stiffer than the stomach.

Due to processing power limitations, we built all organs using a surface mesh. No volumetric calculations are performed. This concession was not perceived as a problem by the medical professionals who took part in the trial. The force feedback is proportional to the extent of deformation of the point of contact, while the deformation of the rest of the object is shown graphically. On the remote machine the deformed shape needs to be felt haptically, to give the remote user the ability to grasp the shape in its



Fig. 4. Deforming the stomach.

deformed state.

The deformation behaves in three different ways depending on the requirements of each organ. Some organs, such as the liver, are considered to be basically fixed in place but elastic. Some organs are set to be permanently moveable to some degree. These are set to have some plasticity. This means that the longer that they are held in their deformed shape, the closer to that

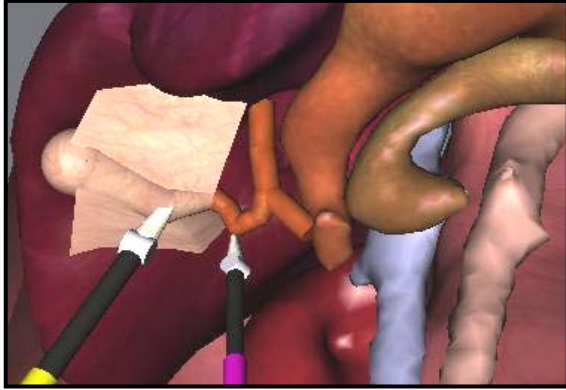


Fig. 5. Two instruments manipulating the gall bladder

shape they will be when released.

The ability to set an object's elasticity and plasticity is built into the surface model. For each organ, two sets of surface coordinates are stored: the *original coordinates*, and the *deformed coordinates*. The haptic feedback is determined by how far the haptic tool is moving a point in the *original coordinates*. As well as providing a force to the user, this movement is used to calculate an offset for each of the other coordinates of the surface, depending on stiffness parameters and distance from the contact. The *deformed coordinates* are each placed at these offsets from the *original coordinates* and are used for rendering the shape graphically. If an organ has some plasticity, the *original coordinates* are incrementally repositioned towards the *deformed coordinates* over time.

The third deformation type is needed to simulate the gall bladder and cystic duct system. The gall bladder is connected to ducts which branch and join both the liver and duodenum. A cholecystectomy typically involves one surgeon extending the cystic duct while another applies clips and cuts it. As the surgeon manipulates the ducts or gall bladder, these ducts stretch and slide according to axial linear forces (figure 5). To simulate this, we modeled the system as a series of segments with nodes at the junction points. Once a node is grasped, a virtual spring is put in place between the tool and the node. The spring extension forces are transferred to the node which transfers the forces to adjacent nodes, by extending virtual springs within the segments. In this way, each node has knowledge of all the forces acting on it and can reposition itself depending on those forces. The extension of the grasping virtual spring provides force back to the haptic tool.

Nodes can collide with other organs, and can be simultaneously grasped by the remote user. Since the design allows for any number of forces to be directed to each node, both collision forces and tool forces can

be accumulated with the spring forces into a resultant force used to reposition the node. A similar system is described in [21]. This mechanism allows us to incorporate the remote user's actions into the physics model. To avoid temporal inconsistencies, it is necessary to nominate one of the collaborating machines as a 'physics server' which collects all these forces, resolves them and calculates the resultant node positions.

Initial tests showed that latency of the network over global distances introduces instability into the system. We were able to overcome this by ignoring any momentum or acceleration. Objects either move under forces or stop when those forces are in balance. We found that, while this may not be suitable for all collaborative environments, for surgical simulation, where objects need to be moved and stretched, but not sent on trajectories, the behaviour was convincing enough to satisfy the participants of the trial.

We also found that this mechanism allowed us to avoid the need to lock objects for editing, such as described in [6]. Since all interaction with objects is based on real world actions (pushing, pulling etc), and the duration of these interactions is relatively long compared to the latency of the network, we can accumulate all the forces into a single resultant, and therefore allow both users to interact simultaneously at any time as they might do in the real world.

3.3. Diathermy of tissue

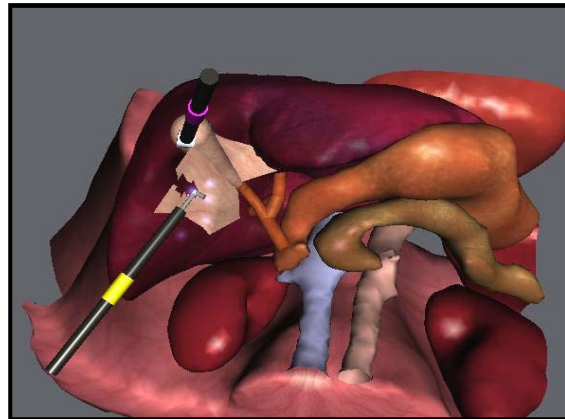


Fig. 6. One tool holds gall bladder, other uses diathermy to cut attached tissue.

The gall bladder is attached to the liver with a webbing of tissue. In the operation, this is cut with a diathermy tool, which uses a cauterizing action to separate it. We simulated the webbing as a polygonal elastic membrane as described above for organs such as the liver. This enables it to be haptically felt and

deformed. Points on the edges of the webbing are linked to specific points in the gall bladder and liver, so that deformations of these organs are also transferred to the webbing itself (figure 6).

The diathermy effect is created by removing individual polygons from the membrane if they are touched by the diathermy tool for longer than a specified time.

The diathermy tool also produces bleeding if it accidentally touches the gall bladder or any of the ducts. A touch-sensitive surface triggers this.

3.4. Clipping and cutting the duct

Having separated the gall bladder webbing, the next stage in the procedure is to clip the cystic duct ready for cutting (figure 7).

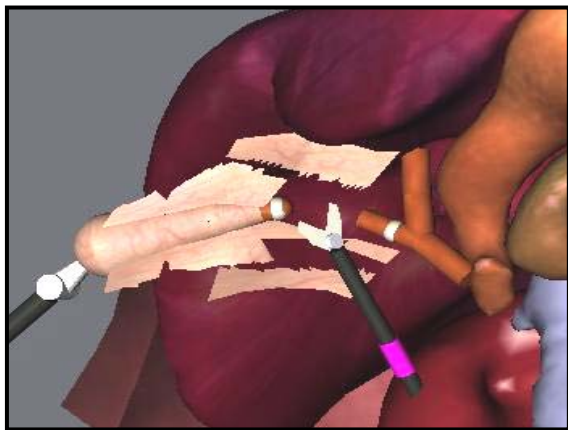


Fig. 7. Cutting the cystic duct

If the duct is cut correctly between two clips, the gall bladder and its attached duct segment is detached from surrounding objects and can be removed. If the cut is made in a place that is not bordered by clips 'upstream' and 'downstream' on the duct, either bile or blood droplets are released.

3.5. Breaking the duct

A common mistake is to apply too much tension to the duct before clipping and cutting. We added the capability for the duct to rupture, emit fluid and eventually break if the extension of any segment is too great.

4. Other scenes

We also provided a virtual white board, a virtual light box to view medical scans and a virtual video player which can show an actual operation recorded by a laparoscopic camera within the body. The haptic buttons and sliders which control these items can be used by both users. The users are also able to touch and draw on the screens of any of these. The haptic touch triggers the flow of 'virtual ink' from the tool, so that it can be used much like a ball-point pen or marker.

5. Communication

We developed this application using the Reachin Core Technology [16] API (formally Magma [20]) which provides haptic and graphic rendering of the scene. Reading and writing network sockets occurs through separate, dedicated threads.

We use replicated databases on each machine with update data being transferred between them when necessary using 'remote routes' that exist across a network and transfer data with TCP/IP for less time-critical data and UDP/IP for more time-critical data.

6. Results

The audience consisted of about 70 delegates attending the Health and Medical Simulation Symposium and associated Simulation Technologies Conference. At the end of the session we received 47 completed questionnaires. Ten of these also participated in the haptic interaction.

The interaction between the surgeons was rated as either very good or excellent by 97% of respondents. Eighty-seven percent rated the remote teaching as either very good or excellent. Eighty-nine percent 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. 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.

7. Further work

We are planning to extend the collaboration to allow the instructor to connect to one of a number of students, working alone or in pairs on a task. The concept is for the remote instructor to be able to join or leave a session at will. The students need not all be co-

located. We are also adapting this technology to other surgical scenarios.[22]

8. Conclusion

The demonstration showed that it is possible to overcome the technical difficulties involved in presenting a haptic teaching environment, linking two institutions across the world. The resulting feedback endorses the ideas behind this trial and provides encouragement for further exploration in these directions. It showed that remote demonstration and discussion can use a rich set of interface components and need not be limited to conventional video conferencing technology.

9. Acknowledgements

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