Surgical Training Using Haptics Over Long Internet Distances

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Abstract This paper describes a collaborative surgical training prototype using haptics, which has been able to operate across the world. It allows two users to collaboratively manipulate a simulation of pliable human body organs, as well as guide each other's 'hands' over 22,000 km of internet connection. It uses a force impulse collection mechanism feeding haptics data to a single physics server program. The server runs a 'pseudo' physics model that is resilient to latency.

1. Introduction

Collaborative (networked) virtual environments (CVEs) have many potential benefits for training at a distance [7]. It has been shown [1] [5] that haptic (force) feedback enhances performance in a CVE. However, real-world CVEs experience the problem of communication delay (latency). Haptic feedback makes this issue more critical, due to the direct user input at each end. Matsumoto et al [3] argues that latencies of greater than 60 ms prevent the effective use of haptics across a network, limiting collaborating networks to 4000 km or less. However, our work has shown that in the field of surgical training, using specialized physics, we can accommodate latencies of around 190 milliseconds each way.

2. Experimental Environment

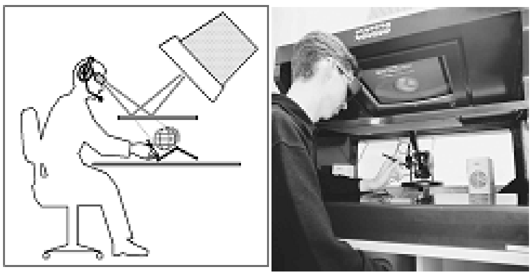

Figure 1. The CSIRO Haptic Workbench

The CSIRO haptic workbench (Figure 1) [8] uses a SensAble Technologies' Phantom [6] as a 3D input device and stereo shutter glasses for 3D viewing. It uses a mirror to co-locate the haptic interaction with the virtual objects, so that the body's proprioception adds to the reality of the experience. It is a desktop system suitable for arm-scale immersion.

3. Surgery Simulation

We have developed a surgical training prototype for a cholecystectomy (gall bladder removal), which enables an instructor and remote student to work in the same virtual space. Communicating via a headset/microphone, they simultaneously view and manipulate a 3D scene consisting of pliable body organs. The instructor can grasp and guide the student's tool in the scene and both users feel each other's movements. They can also simultaneously

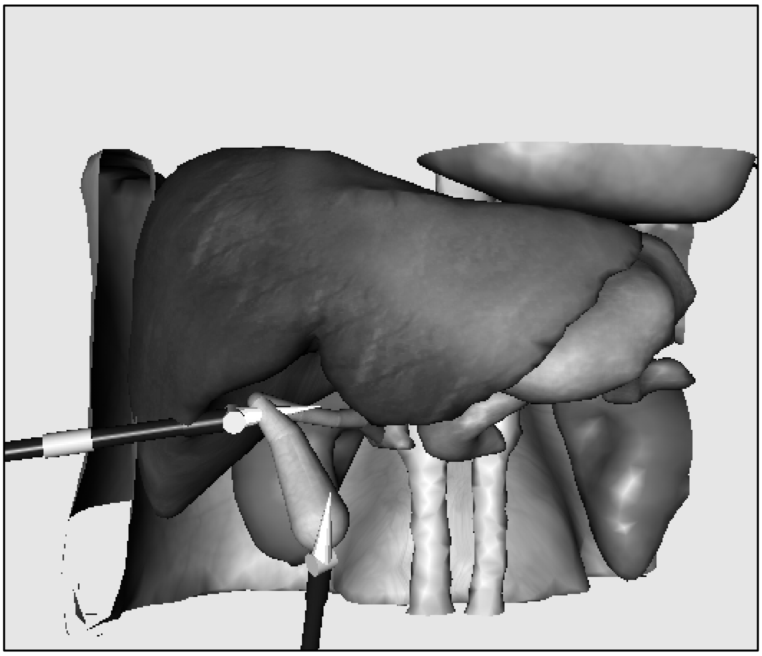

Figure. 2. Screen shot (note 2 grasping tools)

move, stretch and pull the gall bladder, with its attached bile duct trailing behind (Figure 2). It is possible to independently zoom and pan their viewpoints, as well as lock their views together to co-operatively fly through the scene. There is also the ability to jump to a virtual ‘video player’ showing the real procedure, as well as to a ‘light box’ where a medical scan can be analyzed. The users can annotate any view with lines and arrows, creating a rich environment for discussion. Dexterous techniques are demonstrated with the ‘vapor trail’ facility, which provides a trail of fading tool images following the instructor’s motions. The software is built upon the Reachin API [4]. It has been demonstrated at the 2003 Scientific Congress of the Australian College of Surgeons and related clinical trials are planned.

4. Haptics in Collaboration

Since a haptic tool exchanges energy directly with the user’s hand, connecting it across a network can cause it to become unstable, due to a complex feedback mechanism which involves the physiology of the human user at each end as well as the network, software and hardware. The system is susceptible to oscillations when used with any significant network latency. In addition, if the data is received in bursts, it can cause the human at each end to over-react and send the system into chaos.

One way to try to overcome these oscillations is to apply damping to the dynamic objects that are being moved by the haptic tool. Our trials found that damping adjustments could not always overcome the problem, probably because we are dealing with a discrete, sampled system, and the user’s reactions were variable. However, since our goal was to create a system that could be used for surgical training, we could take advantage of the fact that the body organs are typically very highly damped by their environment. This meant that it was not unreasonable to assume that they have zero momentum, since it is not likely that body organs are sent off on a trajectory of their own. Once we make this assumption, we can develop a false physics of object movement, which determines an object’s change in position purely from the instantaneous forces acting upon it. The body stops moving as soon as the forces are removed, or in equilibrium. Using this approximation, we have been able achieve stable haptic collaboration over global networks.

In a CVE, attempts to simultaneously access the same object are often solved by object ownership and locking [2]. We have been able to circumvent this issue by allowing the haptic forces to resolve the conflict in a real-world manner. All forces on each object are collected and combined in a single ‘pseudo-physics engine’ running on one of the collaborating machines. The physics engine calculates the object’s new position and returns this information to both scene renderers. The object moves in the same way that a real world object would move if several people (and other forces, such as gravity and elastic tissue) were to try to move it simultaneously. We no longer need to have an object owned by any one user, and do not need to gain permission across the network before pushing or pulling on an object. This is an example where the addition of haptics simplifies other aspects of a system.

5. Communication Mechanism

Scene graphs, such as VRML and Reachin API, typically route data fields together to transmit changes amongst 3D objects. We have extended this concept to provide 'remote routes' across a network, connecting corresponding objects on different machines. This ensures that data is only sent when it changes. The remote routes are multiplexed over a single TCP/IP connection at 30Hz. Time critical, hand-guiding haptic information is sent at 400 Hz via UDP/IP for improved speed.

6. Results

We were able to run the collaborative surgical simulation between two immersive virtual environments running across the Internet between Canberra, Australia and Stockholm in Sweden. Since the connection went via the Pacific, the U.S.A., the Atlantic and Europe, the total distance was about 22,000 km (13,670mi). We found that the behaviour was smooth and stable with both users simultaneously manipulating the body organs and guiding each other's instruments.

Our trials have shown that for some suitable applications, such as a surgical training system, it is possible for users to simultaneously hold, pull and stretch pliable objects from opposite sides of the world. Not only that, they can guide each other haptically around the scene, opening up the possibility to teach dexterous tasks by example, as well as to simply drag another user's tool to an interesting spot.

7. References

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