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THE UNIVERSITY OF QUEENSLAND

QPSF Pilot Project Final Report

Project Title: Development of a Virtual Reality-based Laparoscopic Surgery Simulator
Project Status: Completed
Period: November 2004 – February 2005
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A. Introduction

Surgical simulators are becoming an integral part of surgical training as healthcare is becoming increasingly complex and subject to greater legal scrutiny. It is therefore essential that training systems are constructed that will develop surgeon's skills in a cost-effective, ethical and demonstrable manner. It is now widely accepted that Virtual Reality-based surgical simulators are going to become an essential component in surgical training programs.

The pilot project aimed to construct a prototype simulator that could be used to demonstrate the feasibility of constructing a complete simulator that would overcome the limitations of commercially available systems. The principal limitations are: (i) realism; and (ii) the relatively small number of surgical procedures that are simulated. The limitations arise because organ deformation is typically not simulated using physics-based methods. Methods such as Finite Element Modelling (FEM) can realistically simulate organ deformation that occurs in a wide variety of surgical procedures. FEM methods have not been used in commercial systems as they have traditionally been too computationally expensive to compute in real-time. The pilot project sought to determine if this limitation could be overcome.

The prototype simulator was to consist of an anatomical dataset, a haptic input device and a computer. The simulator would enable the user to manipulate graphical models of organs and tissue using a haptic device. Organ deformation would be computed using FEM and the physical appearance of the organs updated accordingly. The forces arising from the user intervention would then be sent back to the haptic device, to provide force feedback to the user.

B. Project Outcomes

A prototype simulator with basic functionality has been developed. The simulation framework consists of three core components:

1. <u>User input</u>

   Most user interaction will be via the haptic device that enables the user to manipulate the virtual anatomy. A Laparoscopic Surgical Workstation (Immersion Corporation) was purchased using funds provided by the Pilot Project grant and is shown in Figure 1. The device cost $37235.10.

   Communications software was developed to provide a high performance communication channel between a Unix client and a Microsoft Windows server. The software provides an interface between the Microsoft Windows machine that is hosting the haptic device and the Unix machine running the simulation. The haptic device must be connected to a Microsoft Windows machine as drivers are not available for any other platform. The simulation application is platform independent, however the graphics component is currently tied to the Unix Xwindows environment. The software uses Unix and Microsoft Windows sockets for network communication.

Figure 1. The input device is a Laparoscopic Surgical Workstation

The communications software provides a logical separation between the simulation and haptic input device. The separation is significant, as the simulation is not synchronised with the haptic device. Specifically, the haptic device must be updated at a much higher frequency than the simulation. The complexity of the simulation algorithm will determine the update frequency of the simulation, which should be no less than 25Hz. To provide continuous and realistic force feedback, the haptic device must be updated at a frequency no less than 300Hz. To interface these two loops, the simulation loop executes as fast as possible. It requests position and orientation data from the interface application every iteration. It processes that data and computes the forces that should be exerted on the user by the haptic device. Those forces are then sent to the interface application. The interface application receives new force information at the same rate that the simulation loop runs at (approximately 25 Hz). To update the haptic device at an acceptable rate (approximately 300Hz), the interface application extrapolates the force data (received from the simulation application) and updates the haptic device using the extrapolated data. The extrapolation/update loop runs as fast as possible, and continues until a new set of force data is received from the simulation. When new force data arrives, the extrapolation/update loop restarts, using the new data. The architecture of the software is shown in Figure 2.

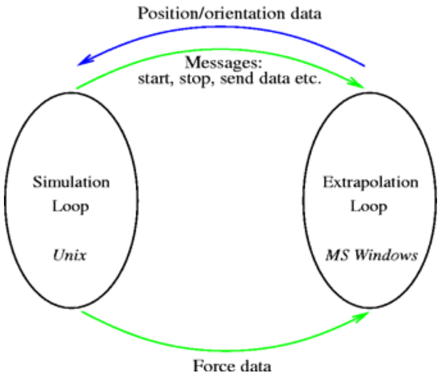

Figure 2. Architecture of the communication channels

As at the time of writing, the haptic device had not been interfaced with the simulation application as there was a considerable delay in delivery of the device. The device was ordered in April 2004, but was not delivered until October 25, 2004. The interface software has been written (as far as possible) and interfacing the device should be a minor task.

2. <u>Simulation</u>

A literature search was conducted to determine the most appropriate algorithm to use for simulating the deformation of organs and tissue. An adaptive algorithm based upon non-linear anisotropic elasticity was selected. The algorithm was implemented but found to be unsuitable as the structure being modelled could be contorted into stable configurations which would prevent it returning to its original shape. This was clearly unacceptable. However it should be noted that there are situations where this behaviour is required. For example, if the structure has been partially folded over onto itself, the weight of the portion that is folded over may exceed the restorative force that would tend to return the structure to its original form.

To overcome the aforementioned problem, we developed another formulation which is invariant to rigid translations and rotations. This formulation does not appear to suffer from the problem of remaining in local energy minima which prevents the contorted structure from returning to its original shape. Both non-linear isotropic and non-linear anisotropic forms have been implemented. The anisotropic extension is available at almost negligible additional computational cost.

The simulation algorithm was found to be highly efficient and capable of simulating the deformation of complex structures in real-time. Volumes containing approximately 10000 tetrahedra can be manipulated in real-time, while retaining a refresh rate exceeding 100 Hz. The algorithm is sufficiently fast to support the modelling requirements of a fully-featured surgical simulator.

3. <u>User Feedback</u>

A comprehensive virtual anatomy has not been created as we do not have sufficient funds to purchase a segmented data set. To demonstrate the simulator, a 3D heart model was adapted from a tetrahedral mesh that was developed at the Center for Computational Visualization at the University of Texas. The rendered model is shown in Figure 3.

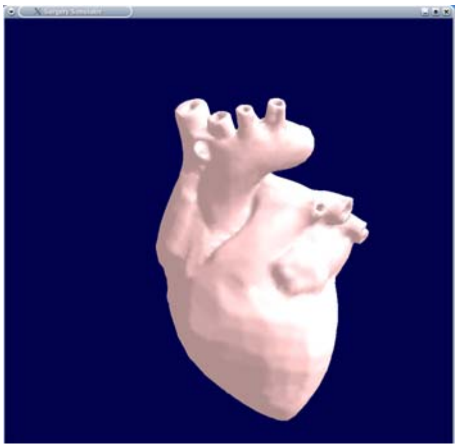

Figure 3. The prototype simulator was tested using a 3D model of a human heart

The virtual anatomy is rendered using OpenGL. The combination of force feedback and remote visual display will accurately recreate the inherent challenges involved in manipulating a delicate organ with surgical instruments that lack an intuitive feel.

The prototype has sufficient functionality to demonstrate the principles involved. The underlying simulation algorithm is capable of modelling organ deformation in real time, which is the critical factor that limits the realism and scope of existing commercial simulators.

C. Publications

- A poster describing the project was displayed at the QPSF Strategic Planning Day (3 November 2004).
- A paper describing the simulator and underlying simulation algorithm has been written and will be submitted to *Graphical Models* in late March of 2005.

D. Project Status

The pilot project is finished and has achieved its objective. It has determined that physics-based modelling can be used to build a fully functional surgical simulator. Additional funds are now being sought to continue development of the prototype.