A Practical Surgery Simulator

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Abstract—Surgery simulators are becoming practical with new frameworks that includes core components such as: enhanced medical imaging, rapid medical data modeling, realistic visualization procedures, and believable animation techniques. Surgery simulation requirements of cinematic quality rendering has also gained importance with the wide spread availability of affordable high end graphics on desktop computers. The limiting challenge however is the computation of man-machine interaction with the deformable tissue/organs. In this research we outline some of the challenges and propose possible solutions to improve the quality of the components in the framework for surgery simulation.

I. INTRODUCTION

Noninvasive imaging techniques such as Computed Tomography (CT) scans and Magnetic Resonance Imaging (MRI), Positron Emission Tomography (PET), Ultra Sound Radiography have been revolutionary in medical imaging visualization for diagnostic and surgical applications. As the technology is advancing, it has become practically possible to visualize the change in the geometry, appearance and texture of deformable tissues. Visualization of dynamics in the medical data leads to enormous applications in the area of Virtual Reality based Surgical Simulations in assisting surgical training, surgical planning, pre-operative rehearsal, intra-operative execution.

To attain a cinematic quality visualization of deformable tissue, one should achieve 30 frames/sec that will give a flicker free movement and will require very high computational power and memory. Challenge is to find optimized visualization algorithms to achieve the cinematic quality visualization of deformable tissue in a reduced computing intensive environment. Mass-Spring models and Finite Element Methods are some of the approaches used to model the deformation of tissues. This study will discuss various visualization algorithms for achieving cinematic quality visualization of body parts and deformable tissue.

II. SURGERY SIMULATION

Simulators [1] have been used in the area of training medical institutions or in preoperative procedures to predict an outcome of an operation. In such an application, visualization is tightly integrated with interaction, haptics, as well as volume deformation. First we present the design issues in a simulator for liver surgery and then discuss the realistic rendering and deformation of organs in such a simulator.

A. Need for a Liver Surgery Simulator

Herve Delingette and Nicholas Ayache [2] discusses about creation of a hepatic surgery simulator for training the physicians. This is helpful in performing invasive surgical procedures thereby reduce surgeon’s learning curve. The authors’ primary motivators were the importance of liver pathologies and the inherent complexity of hepatic surgery. The authors realized that modeling the interaction with the deformable organs of the abdomen was a very challenging research problem which they wanted to study thoroughly. Our goal is to add visual realism to the rendered geometry as discussed in Section III.

B. The Procedure

In the case of laparoscopic surgery, abdominal operations such as hepatic (liver) resections are accomplished through small incisions. The abdomen of the patient is inflated with gas to create open space inside and a video camera is inserted into the abdomen through one of the small incisions. The video image is magnified and transmitted to a high-resolution monitor, allowing the surgeon to see the abdominal anatomy with great clarity. The surgery is performed using special instruments introduced.

C. Possible Interactions

Deformable Interaction: The physical modeling of a simulator includes the modeling of contacts between virtual instruments and soft tissues as well as the biomechanical deformation of soft tissues. When a collision between an anatomical structure and a surgical instrument is detected, the boundary constraints on soft tissue models are updated and, depending on the nature of the instrument, a piece of tissue is removed. The soft tissue is then deformed according to a given biomechanical behavior. The paper shows designing of a combination of image-processing techniques to extract the principal hepatic structures of interest from the clinical CT images taken before surgery (preoperative images).

Cutting Interaction: By restricting the regions where cutting is allowed, it is therefore possible to include in the simulator deformable models of a large size. In the hepatic surgery context, the authors decomposed their model into eight regions, corresponding to the detected segments, and restricted the cutting regions to a number of 3D bands at the interfaces between these segments. These bands are described by tensor-mass models, while the rest of the mesh is described by pre-computed models.

Background Structures for Better Interaction Cues: For more realistic representation of the operative field, other elements are introduced. Ribs are added for more realistic
representation of the operative field, ie. the ribs are introduced for more visual feedback.

III. RENDERING FOR SURGERY SIMULATION

A. Cinematic Quality Rendering

Rendering scenes that simulate realistic surgery depends on several factors. These include lighting, choice of tissue and organ material properties. Apart from this the system should create photorealistic renderings in realtime. These functions should not only be for static organs or models, but also include complete deformable shape modeling and animation. The renderer to achieve the best quality computes, (i) reflection, (ii) refraction, (iii) high quality shading effects, and (iv) anti-aliasing.

B. Experiments for Cinematic Quality Liver Rendering

Experiments were conducted to achieve cinematic quality rendering of human liver for use in surgery simulation. 3D mesh model of liver was used in 3D studio max 8 software tool to render high quality liver images shown in Fig. 1. Multi layer textures are applied to obtain realistic effects. 3ds tool has advanced raytracing mechanism that has been implemented for cinematic quality visualization. Blinn shading and refraction map are introduced to achieve a realistic liver surface.

Fig. 1. Cinematic quality rendering of the liver

C. Surgery Simulation of Deformable Organs

There exist a number of approaches to model the deformation [3] of the organ, including free form deformation (FFD), mass-spring models, and finite element methods (FEM).

Computer simulation provides a virtual training environment for surgeons to practice.

- Human Soft Tissue Simulation: The appearance of the tissue is obtained from real textures or images of organs. This texture is mapped onto a polygonal mesh of the organ that is being examined. The deformation of the mesh is generally done using a range of techniques from free form deformation, mass-spring models or even realistic FEM models. To create flicker free movement and collision detection, we need to compute 30 frames/sec for which the computational requirements are high.

- Tissue Tool Interaction: The interaction between the tool and organ is a challenge to compute. The position of the tool has to be estimated in relation to the organ first. The behavior of the tissue has to be simulated in real-time when the tool interacts with it (eg. cut, prodded or punctured).

D. Parametric Organ Deformation

A parameterized representation of virtual organs for surgery simulation takes a 3D input mesh that is parameterized and re-sampled into a regular 2D parameterized model. With this parameterized representation, a high resolution 3D organ mesh can be reconstructed and deformed interactively with a simple and fast free-form deformation method. The amount of deformation and force feed-back can be calculated rapidly. Therefore, haptic rendering can be achieved. In addition, the parameterized mesh can be used to handle collision detection and the contact between multi-objects in an efficient way for interactive surgery simulation.

Interaction of a tool with parameterized and re-sampled organ models, one stomach model and one liver model are shown in Fig. 2 and Fig. 3. A more realistic rendering is shown in Fig. 4. Both re-sampled meshes can be simulated in real time with user interaction. Texture and bump map are used to add realism to the model. The textures of the organs are obtained from real laparoscopic surgery.

IV. SURGERY SIMULATORS - MORE EXAMPLES

A. Orthopedic Surgery Simulation

Modeling 3D shapes for orthopedic surgery simulation [4] has gained lot of attention. This is of interest for the the design of biomedical implants and prosthetic devices. One possible approach is to obtain the 3D model by using a 3D digitizer. Fig. 9.2 shows the digitized surface of a tibia. Another area of interest is to model geometric implants and embed them in medical data, which will help in orthopedic surgery simulation.

In our research for caricature scanning, most of the raw data (point-cloud) are done using the Minolta 3D Scanner, a static non-contact 3D digitizer. This is so far the most popular device being used in this field. A number of software and
process were developed and used to transform the point-cloud, to construct 3D surfaces.

VIVID digitizer cannot produce a see-through image like what CT or MRI do to obtain the internal anatomical structure, for instance a knee joint, of a patient. But it provides an alternative to obtain the 3D caricature of bones, in vitro, for the purpose to carry out any studies such as implant design. Fig. 5 shows the digitized surface of a tibia.

B. Volume Haptic Deformation

In Haptic deformation, the sense of touch is added to accomplish realistic interaction with the organs or models. Fig. 6 shows the architecture for a haptics simulation system, called Haptic Browser. The concept is same as the web browser (that can display a web page), but the haptic browser can display and enable interaction with haptic enabled organs. Fig. 7 shows the haptic needle interacting with various organs. Fig.

8 shows the same tool used to assemble/disassemble parts from a complex organ, and the human ear.

V. CONCLUSION

We feel that the time is ripe for building a high quality surgery simulator. We have designed a frame work and several components have been evaluated for both rigid as well as deformable organs. Immediate application of the virtual surgery system can be for training medical students, with long term applications in everyday planning of pre-surgery, post-surgery and also use during live-surgery.

ACKNOWLEDGEMENTS

We would like to thank Dr. M. A. Srinivasan, Director of Touch lab, MIT, who provided access to the Touch Lab at MIT, which helped this research immensely.

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