Haptics-based Cataract Surgery Simulator

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1. Narrative

Introduction

Surgical training using computer-based simulators are being adopted by many medical specialties, mainly because they offer several advantages to traditional training methods involving animals or cadavers. My research focuses on the design and implementation of a haptics-based cataract surgery simulator. Cataract is very common in older people, and remains the leading cause of blindness and low vision (WHO, 2015). The treatment of cataract is surgical and very successful in restoring sight. Phacoemulsification is the most commonly used technique of cataract surgery. With only constructing small, self-healing incisions on the cornea, the cataract lens can be removed and replaced. Due to its popularity, phacoemulsification is a basic while essential technique for ophthalmologists.

The objectives of my projects are as follows:

- Enhance the current haptics- based cataract surgery simulations
- Design and implement a simulation for phacoemulsification
- Improve the assessment method for residents' performance on the simulator

Results

1. During this academic year supported by the Link Foundation Fellowship, several advances have been made on the current simulations for several procedures in cataract surgery.

    - To increase the realism of the simulation, several human interface devices such as pressure sensor and phaco foot pedals (which are actually used in the operation room) have been added to the simulator. To establish the connection between these interface devices and the simulation applications, a hub device has been designed. All the electronics for this hub device has been assembled.

    - Besides, the simulator has been reviewed from the ergonomic perspective. To improve the hand stability of the users, a head mannequin has been added in the simulator. When performing virtual operations on the simulator, users may now rest their wrists on the forehead of the mannequin, just like how surgeons do on the actual patient. The deck for haptic devices has been redesigned for proper alignment between the mannequin and the haptic devices.

    - To expand the number of scenarios encountered by cataract surgeons and residents, we have designed 2-3 cases for simulation of three surgical procedures - capsulorrhexis, corneal incision, and dexterity (previously we had only one case per procedure).

    - An eyeball balancing training module has been developed. In the virtual scene, the eyeball is controlled by a customized joint which limits its motion and rotation. A spring damper model is applied to the joint to mimic the eye muscles. Trainees are asked to use two virtual instruments to balance the eyeball while completing some specific tasks in the eye.

2. As the main portion of my work supported by the Link Foundation Fellowship, a simulation for phacoemulsification has been designed and implemented.

    - To simulate the deformation and removal of human lens, a soft body simulation algorithm using position based dynamics (Muller et al, 2006) is introduced. The lens is modeled as volumetric meshes made up of tetrahedrons. Vertices of all tetrahedrons are simulated as particles, and each tetrahedron defines two constraints on the particle positions.

- A tetrahedral mesh defines the resting state of the human lens model. The lens is first described by continuous asymmetric bi-elliptical model (Rama et al., 2005). A triangular mesh of the lens surface is then constructed according to this equation. After that, the tetrahedral meshes are built based on the surface mesh. A variety of tetrahedron models have been developed with different levels of complexity.

- To simulate lens emulsification, an algorithm has been implemented to remove the individual tetrahedrons and modify the shape of the whole mesh. A small rigid shape attached to the virtual instrument serves as a “drainer” for the soft body mesh. It periodically removes tetrahedrons that collide with it. Additionally, an optimized graphics rendering algorithms has been implemented to effectively update and render the changing surface of the lens soft body mesh.

3. Several improvements has been made on the assessment method for residents’ performance on the simulator.

    - An algorithm that tracks the virtual instruments during simulation has been implemented. The position and orientation of the instrument can be recorded with a frequency up to 50 times per second. The recorded data can be used for performance evaluation as well as animation reproduction for comparison with the actual surgical operation.

    - Aiming at the details and complications of each surgical procedure, the simulator is designed to monitor the performance and identify the problems. Haptics rendering algorithm may report any collision between virtual instruments and objects in the scene. Any unexpected contacts or punctures are recorded and eventually affect the assessment.

Significance and impact

Compared with ordinary training platforms, our haptic-based cataract surgery simulator has several advantages. Practice on the simulator allows trainees to perform the same surgical procedures multiple times without incurring extra costs of resources. Also, the haptic-based simulator can provide an immersive environment with realism and life-like interaction. Finally, our simulator provides an objective assessment of the trainees’ skills to measure their performance and track their progress during a series of training sessions.

Haptics is our most important feature compared with many existing cataract surgery simulators. Haptics rendering enables trainees interacting with the virtual patient realistically. Several haptics effects have been carefully designed to emulate tactile sensations in the actual cataract surgery. By incorporating tactile feedback, the quality of simulation is greatly enhanced.

Where might this lead?

A series of enhancement can be done to improve our haptic-based cataract surgery simulator. More advanced algorithms will be introduced in both haptics and graphics rendering, as well as physical simulation. For instance, we may incorporate fluid simulation to reproduce irrigation and aspiration of liquid inside the eye. And particle based simulation may also lead to better interaction between the liquid and tissues in the virtual eye.

Besides, we are aiming at deeper collaboration with ophthalmologists and tailor our cataract surgery simulator to better fulfill their resident training program. We are in a process of creating a curriculum for training on the simulator. The performance will be saved in the database and the training progress can be tracked and visualized. In addition, we are expanding our case library to simulate various scenarios of cataract surgery with different level of difficulty or rarity.

Reference

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2. How did the fellowship make a difference?

Receiving a Link Foundation Fellowship means a lot to me. First of all the Link Foundation Fellowship has greatly supported me economically. The fellowship has dramatically accelerated the progress of my thesis, as I could be able to spend full time on my research project. Besides, the Link Foundation Fellowship has strengthened my connections to the society of simulation, and I now have a better understanding of the frontier of this industry. More importantly, from the initial application to this final report, the Link Foundation Fellowship has awarded me a perfect opportunity to practice working in academia. I feel deeply honored and grateful to be a Link Fellow.

3. Future Plans

After graduating from UIC, I will be looking for opportunities in academia and/or industry in my area of expertise. I am seeking post-doctoral positions in universities or research institutions. And I am also open to opportunities in the industry of simulation.

4. Publications, Presentations, and Other Outputs.

We are currently working on a paper for eyeball balancing training using the haptic-based cataract surgery simulator. We are in the process of conducting experiments and collecting data. We will also write more papers acknowledging the Link Foundation in the future.