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REFINEMENTS TO PROOF-OF-CONCEPT EYE SURGERY SIMULATION MODEL

GEORGIA INSTITUTE OF TECHNOLOGY
INTERACTIVE MEDIA TECHNOLOGY CENTER
BIOMEDICAL INTERACTIVE TECHNOLOGY CENTER

GA TECH PROJECT B-16-626

FINAL REPORT

Prepared for:

The Medical College of Georgia
Department of Ophthalmology
Augusta, Georgia 30912

Prepared by:

Michael J. Sinclair and John W. Peifer

The Georgia Institute of Technology
Interactive Media Technology Center
Biomedical Interactive Technology Center
Atlanta, Georgia 30332

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REFINEMENTS TO PROOF-OF-CONCEPT EYE SURGERY SIMULATION MODEL

The Georgia Institute of Technology submits this final report to summarize the research collaboration with the Medical College of Georgia to refine the GIT/MCG Eye Surgery Simulation under Georgia Tech Project B-16-626 during the performance period of September 1, 1995 through June 30, 1997.

Background

The Georgia Institute of Technology and the Medical College of Georgia have developed an eye surgery simulation system that provides both visual and force feedback while a surgeon operates on a computer model of the eye in a virtual environment. A hand held tracking stylus controls virtual surgical instruments. The simulation includes options to change instruments, as well as record and playback training sessions. A cataract extraction procedure is simulated in which a knife makes an initial incision, and a phacoemulsifier breaks up and removes the lens. The system also permits the simulated grasping of tissue with forceps and cutting tissue with scissors. This simulation system can be used in a variety of teaching scenarios ranging from residents to experienced surgeons. It offers the possibility of providing surgical practice as well as the development of new techniques. In the virtual environment, the eye and the surgical instruments exist only as computer models. The eye is represented by a collection of deformable three-dimensional models that are texture mapped with photographic images. Interaction between the instruments and the eye is dependent upon the currently selected tool, the location of the instrument in the anatomy, and the kind of action requested by the surgeon.

Simulation Refinements

During the performance period, new simulation capabilities were added to create a second incision, to rotate the lens with a second instrument, and to expand the wound with scissors. Tools were also developed to quantify depth of incision and to alert the user when the instruments violate predefined limits.

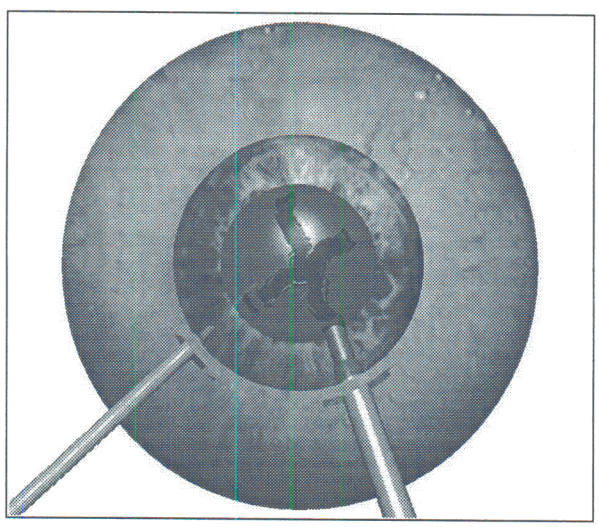
A second instrument is often used to stabilize or hold portions of the anatomy during surgery, and this capability has been added to the simulation. This also required a separate tracking stylus to update the position and orientation of the second instrument. Eventually, the second instrument should be incorporated into the simulator's tactile feedback system, but under this project the second instrument did not provide tactile feedback. Surgeons often use a second instrument to spin the cataract around so that the phacoemulsifier can continue to remove more of the cataract. This procedure is sometimes called "divide and conquer", and it now can be approximated in simulation with the second instrument. The second instrument can push and rotate the lens into a new position.

A second instrument was introduced in the simulation, and the program was restructured to allow the second tool to interact with the anatomy. A first step in this upgrade was to allow a second incision in the sclera. The program was modified to store the initial incision and keep track of the knife as it made a second cut. The second incision is constrained to be non-

overlapping with the first incision, and the wounds are still reshaped to follow the circular contours of the sclera grid. However, the program was modified to immediately present the wound as soon as the knife leaves the surface (before, the wound would only appear after the phaco or forceps were selected). The second incision supports all of the properties of the first incision. Either tool can be inserted into either wound, and the scleral deformations are represented the same way for both. The refined simulation divides the eye into two wound regions. Wound one is always on the patient's right side, and wound 2 is always on the patients left side. This eliminated confusion where the second wound could overlap the first. Other refinements included allowing the instrument in the wound to rotate the globe. In addition, the knife rotates the globe if lifting instead of cutting.

A distracting feature of the original simulation occurred when the instrument would pop out of the wound. This occurred because the graphics software allowed the instrument to move beyond the surface of the modeled globe when the stylus was moved out of range. The refined simulation forces the surface of the sclera to deform above and below the wound for small up/down deviations and to rotate the entire globe if the instrument is moved sideways, to the left or the right, beyond the wound limits. In addition, the force feedback system holds the stylus much more firmly in the wound than in the previous force feedback system.

Phacoemulsification was coarsely approximated in the original proof-of-concept simulator. A more realistic tool-tissue interaction for this procedure created with a new representation for the deformable lens. A modified representation of the lens now includes multiple layers that approximate the sculpting process. Several variations of this approach for sculpting the lens were explored, but this is a difficult procedure to approximate with simple algorithms. A more detailed representation of the sculpting process leads to real-time performance degradation. Methods were implemented to simulate the directional behavior of the vacuum path in advance of the instrument, and the ability to spin and crack the lens into separate pieces before the phaco-aspiration.



Another detail that was addressed involved the deformation of the sclera with the forceps. In previous demonstrations, the simulation would allow the user to grasp the wound with the forceps and stretch the sclera up to 200% of the globe's diameter. This, of course, is not a standard procedure, and it was only allowed to demonstrate the concept of surgical interaction.

The refined version imposes a greatly reduced threshold for stretching the sclera. If the user attempts to pull beyond 0.1 of an inch the simulation forces the wound to break free and resume its undistorted shape.

The refined simulation includes a more realistic function of the scissors to extend the wound. A proportional open-closed sensor has been added to the instrument stylus that tracks how hard the button is pressed. By partially depressing the button, the user can now partially close the scissors. The simulation locates the cutting point between the two blades and displays an expanding wound as this cutting point makes contact with the wound.

Tools were implemented to measure performance and to demonstrate the credentialling potential in surgery simulation. The hypothesis is that surgical skills can be improved more rapidly through computer simulation. The simulation software was upgraded to measure and record time-to-complete, the amount of cataract left in the eye, how often the surgeon deviated from "safe regions" of the anatomy and proper instrument positioning.

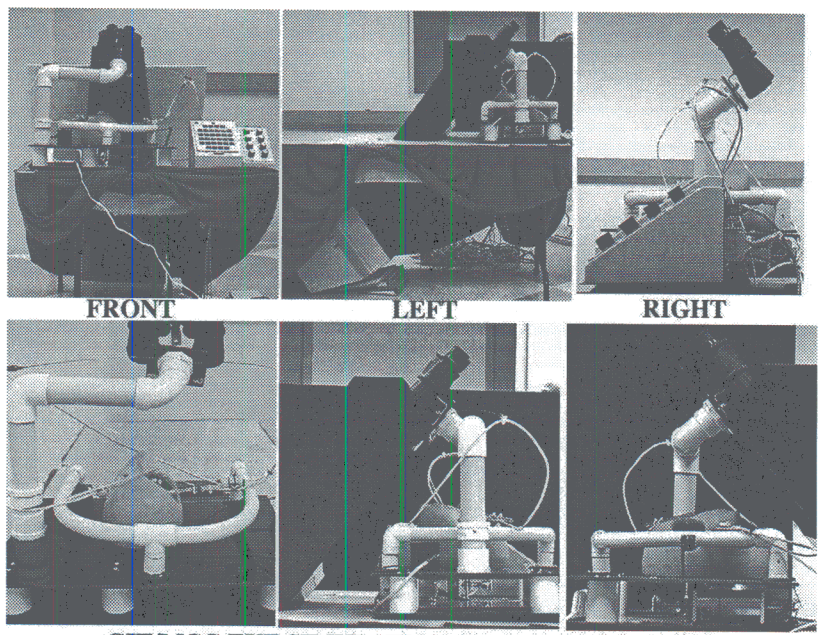
Force Feedback

The force feedback system produces a compliant resistance as the sclera deforms and then allows the blade to slice through the sclera with a small viscous resistance in the cutting direction after penetration. As the blade is cutting, a strong compliant resistance is generated at the stylus tip in the direction orthogonal to the cutting direction to produce the type of resistance that would be experienced if the surgeon tried to lift the incision with the flat portion of the blade. Using the forceps to grasp and open the wound also produces a compliant force feedback.

A series of eye force measurements have been conducted on eye bank eyes at the Medical College of Georgia in an attempt to characterize some of the forces experienced by the surgeon. Researchers at Georgia Tech developed a special handle for the surgical instruments that measures instrument position, orientation, and force/torque values in six degrees of freedom. An experienced ophthalmic surgeon then operated on eye bank eyes with this modified instrument. The position, force and orientation data are captured by this measurement system and can be displayed in real-time or written to disk.

Simulation Station Upgrade

A new simulation station was also created during this project. The top shelf and wrist rest for the workstation were replaced with clear Plexiglas components. In addition, a foot pedal was added to activate the phaco. The stylus handle for the primary instrument was redesigned, and a new stylus switch was added to support proportional scissors tracking. The new station design included the new force feedback motors control system housed directly below the operating area.



GIT/MCG EYE SIMULATION OPERATING STATION

Exhibit at the American Academy of Ophthalmology

In October 1996, the updated Eye Surgery Simulation was exhibited at the Centennial Meeting of the American Academy of Ophthalmology in Chicago. The simulation was included as part of the "Office of the Future" showcase. This exhibit section was a special presentation associated with the 100th year commemoration of the American Academy meetings. The Eye Surgery simulation was set up for demonstrations and hands-on operation for the physicians attending the meeting. In another section of the GIT/MCG exhibit area, Georgia Tech demonstrated the Electronic House Call connecting back to the Medical College in Augusta over ISDN communications link. Live videoconferences were established at scheduled times, and remote ophthalmic examinations were conducted using a specially adapted ophthalmoscope.

Summary

During the performance period, Georgia Tech worked with the Medical College of Georgia to upgrade the Eye Surgery Simulation. These efforts included a force feedback experiment, new software development, a redesign of the force feedback system, and a presentation of the new simulation prototype at the Centennial Annual Meeting of the American Academy of Ophthalmology.