Cataract Surgery Simulator for Medical Education & Finite Element/3D Human Eye Model

J.F. Perez[1], R. Barea[1], L. Boquete[1], M.A. Hidalgo[2], M. Dapena[3], G. Vilar[1], I. Dapena[3]

[1] University of Alcala/Department of Electronics, Alcala de Henares, Spain
[2] University of Alcala/Department of Physics, Alcala de Henares, Spain
[3] University of Alcala/Department of Medicine, Alcala de Henares, Spain

Abstract — **This work shows the results obtained in the development of a cataract surgery simulator for education and medical training. A Finite Element 3D human eye model has been developed with haptic feedback and the necessary surgical equipment to carry out the cataract surgery. The developed system provides the students and surgeons a tool for interactive learning that can be used for the anatomy study and physiology of the eye, diagnoses training or planning of ocular surgery.**

Keywords — **Virtual reality, Finite Elements, Haptic feedback, Surgical simulator, Phacoemulsification.**

I. Introduction

The Continuous Medical Education (CME) consists on an educational group activities that allow to maintain, to develop and to improve the basic medical knowledge and the necessary clinical practice for the professionals or people that provide services in the health sector. On the other hand, the surgical training consists of the knowledge acquisition supplemented with the practical observation during the surgery, and later on, the realization of surgical procedures under supervision. In a similar way, the surgeons also need training to improve their knowledge or to maintain these in procedures or non routine operations.

One of the areas in those virtual reality (VR) and Finite Elements models, has made more important taxes it is in the training and medical education. Those technologies combinated with themselves allows the users to interact with three-dimensional environments (3D) and with on-line generated objects. This way, the surgical simulator that combine visual information (graphics 3D), tactile (feedback force), and physics responses (Finite Elements) can be a great tool for the training and medical education.

In the last years the necessity of surgical simulator is increasing considerably since it avoids has to train with "models of plastic", with "patient" or even with cadavers. Diverse applications have been developed in neurosurgery [1], insertion of catheters [2], lumbar punction [3], acupuncture [4], cricotiroideostomia [5], surgery of cataract [6] [7] or even later capsulotomía [8], etc.

In this work the preliminary results are presented obtained in the casting of the human eye and in the development of a surgical simulator of the cataract surgery. Section II shows the cataract surgery procedure. In section III the system architecture is commented and section IV shows the results obtained with the software developed. Finally, section V and VI presents the finite elements research and conclusions.

II. Cataract surgery

The cataract is the transparency loss of the crystalline lens and it affects at 75% of the population older than 75 years old. The crystalline lens is a transparent lens located behind the pupil and that it is used to focus the objects clearly. Due to different circumstances, illnesses or more frequently due natural transparency and to become in an opaque lens. For a series of circumstances, illnesses or more frequently due to the step of the years, the crystalline lens can go losing its natural transparency and to become an opaque lens.

The treatment of the cataract is surgical fundamentally. The cataract surgical operation consists on the extraction of the crystalline lens, that is opaque and its substitution for an artificial lens that is placed in the same place that the original crystalline lens (intraocular lens), restoring the vision that had gotten lost as a consequence of the cataract. One of the most modern techniques to operate the cataract is the phacoemulsification. This procedure allows the extraction of the crystalline lens through an incision of only 3mm. The phacoemulsificator ("phaco") it usually uses an ultrasound probe or laser to fraction the crystalline one mechanically and then to aspire it. Finally a lens intraocular is implanted that replaces the crystalline lens. In most of the cases suture is not required the incision since it is the sufficiently small thing to be sealed by itself.

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III. SYSTEM ARCHITECTURE

A. Hardware

The developed system is based on a immersive system of virtual reality in 3D with tactile feedback - Reachin Display 2A [9]. This system has a typical PC monitor (TFT) that generates virtual images in 3D of the virtual organ patient, in this case, the human eye and its structures. The systems user, by means of a three-dimensional glass with shutter – CrystalEyes- perceives a threedimensional image (Fig. 1).

The tactile sensation is perceived through a two Phantom Omni device [10] located inside the visual space. Therefore, a user working in this environment can feel and to see virtual objects. The information process is carried out in a computer with double nucleus at least 3 GHz, 2 GB of memory and a 3DLabs Wildcat graphics card. This system obtains a 20 Hz visual refresh and 1 KHz haptic refresh.

B. Software

The utilized software is the Reachin API. These API´s allows carrying out a visual and tactile "rendering" in the hardware described previously. This way, models can be designed in 3D and later on to export them to the simulator.

The programming language is X3D and H3D for the virtual world models and Phyton to configure certain stocks. The H3D API libraries allow to add physical properties to the objects designed in X3D like stiffness, elasticity, texture, etc. It is also possible to design the instruments used in the surgical operation, this way, the pointer can adopt the form of the instrument used in each step of the process. Also we use any structure analisys software for the Finite Element analisys.

Fig. 1 System Architecture

IV. RESULTS

A. Human Eye Model

To develop the cataract surgery simulator is necessary to have a model of the eye and the surgical. For it, we have acquired a commercial model "exchange3D" [11] and modified to obtain a definitive model with the most realistic as possible detail, shape, size, colour, texture, etc. (Fig. 2) Shows the program developed for training cataract surgery.

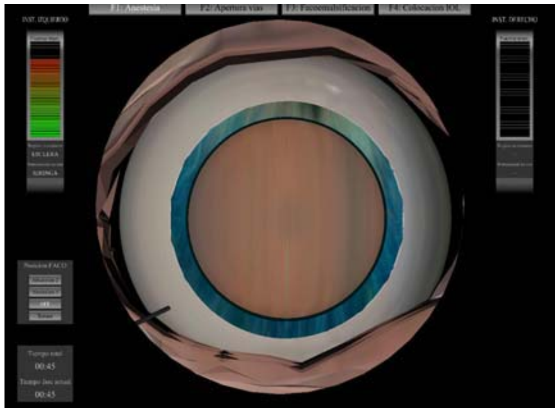

Fig. 2 Human Eye Model

The haptics attributes of each one structure that compose the ocular globe have been implemented by a finite elements study pocess and wide clinical experience. The necessary surgical instruments in the operation have been modeled by any comercial 3D design software (for example 3D Studio Max, Maya, etc.) For the instruments design (shape, size, texture and operation), has worked in collaboration the faculty of medicine of the University of Alcalá.

B. Incisions and Phacoemulsification

To carry out the cataract surgery, two small incisions are made in the edges of the cornea. The first one it is known as “main incision” (Fig. 3), its carried out by the Keratome, this incision is greater than the other one, and it will serve to introduce througth it the Phacoemulsificator. On the other hand, the second incision is called “auxiliary incision” and it is used to introduce througth it anothers surgicals instruments, for example a cannula or another instrument into the Anterior chamber of the eye with the objetive to help the surgeon. The above mentioned incisions are minimal and they do not provoke changes inside the IOP (Intraocular pressure) of the human eye.

Due to the action of the facoemulsificador, see Figure 4, the crystalline structure it is destroyed in micro fragments

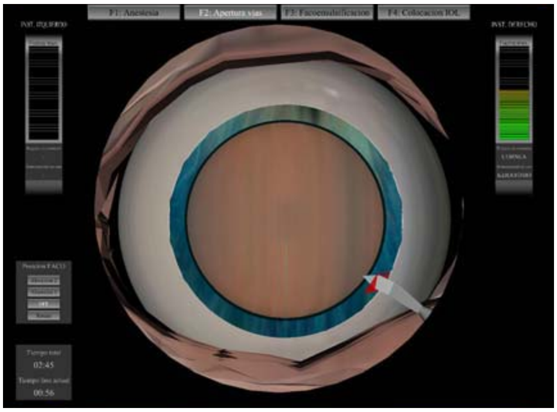

Fig. 3 Main Incision on the edge of cornea

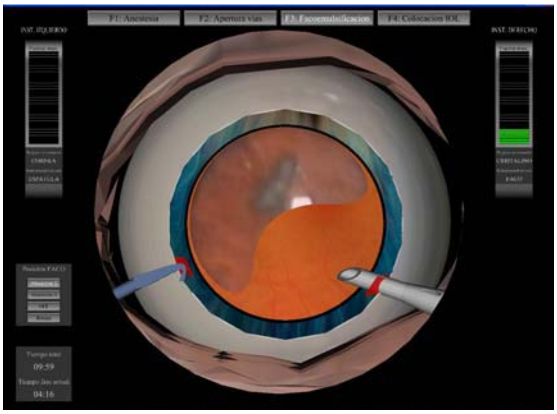

Fig. 4 Phacoemulsification Action

that the Phacoemulsificator absorbs later, leaving the Anterior chamber of the eye ready to implant the artificial lens (IOL). The above mentioned division in microstructures of the crystalline lens, allows to the surgeon simulates surgical skills as the erosion of the crystalline lens and the absorption of every dispersed fragment inside the Anterior chamber. H3D allows to us design deformable structures with Gaussians properties. We get these Gaussian characteristics to the crystalline surface, with the objective to simulate the erosion and the absorption of the lens. On the other hand, with these Gaussian properties is possible to graduate the erosion power of the phacoemulsificator, controlling this way the size of crystalline lens destroyed and absorbed by the Phacoemulsificator during the erosion procedure.

The surgeons use a surgical instruments seemed to a spatula to help to the destruction of lens and the absorption of the same one, which they allow to rotate the lens and to displace the fragments suspended in the liquid of the Anterior chamber. This allows a minimal incision in both sides of the cornea to be able to realize this operation. For it, we

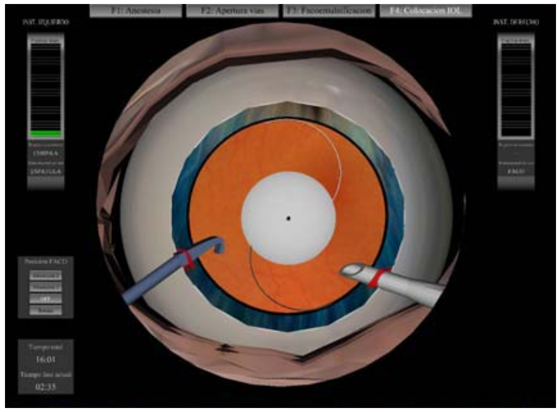

Fig. 5 IOL Allocation

have developed our operation providing the crystalline lens with rotational movements and inertia properties, which creates a real environment for the free displacement of the structures facilitating the surgical task.

Finally, once the Anterior chamber of the eye is empty thanks to the phacoemulsification, we can put on an artificial intraocular lens (IOL), ending this way with the procedure (Fig. 5).

V. Finite elements research

In parallel to design the virtual application, we are researching with models of finite elements that represent the Anterior chamber structures of the human eye. The above mentioned models are designed in CAD programs, those models can be exported and treated by finite elements programs, or if the structures are simples, to design them directly (Fig. 6).

This programs allows us to realize static and dynamics structural analisys on the distortions that suffers the eye on having applied to its courts or pressures, as well as to obtain response curves like for example: materials resistance, to see which might be the maximum pressure that would support the Anterior chamber of the eye without the membranes of separation between the Anterior and Posterior cavities of the eye were broken down. For the development of our finite elements model and his later study, we have taken the results as a base obtained by E. Uchio [12] and Neumman [13]. Thanks to this information, our finite elements model can estimate the maximum pressure that it is possible to apply in any point of the cornea. This information allows our simulator, thanks to the tactile feedback, to estimate the maximum pressure that the user can apply on any point of the virtual model without exceed the limits of rupture, and allow to develop this way a surgical training.

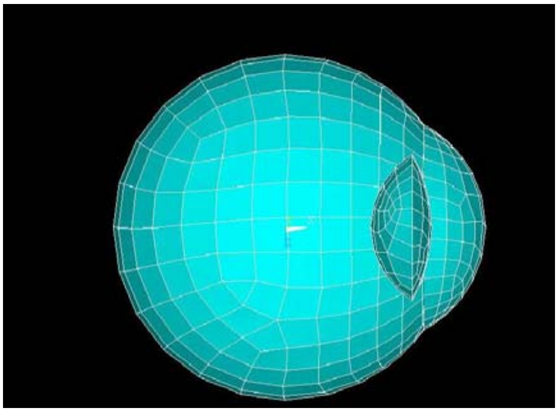

Fig. 6 Finite Elements Mesh Detail

VI. CONCLUSIONS

The initial results presents a virtual simulator of the human eye allows carrying out the cataract surgery. The developed system provides the students and surgeons a tool of interactive learning that includes a precise representation of the anatomy and physiology of the human eye with a real behavior based on physics responses. It can be used for anatomy study, training and planning of the cataract surgery.

In these moments we are studying a generic caucasian human eye with a Finite Element 3D model and how to include this results on our Virtual Simulator with the objetive to develop a Virtual Evaluator for the surgery, and in a near future try to include the possibility to record the virtual surgery by an expert ocular surgeon, and later in an automatic way, comparing the movements and skills of the expert with the virtual surgery of any user. All of these with a low cost hardware and software. On the other hand, use the Finite Elements analisys data response to provide our Virtual Simulator with surgical alarms to simulate and correct problems during the intervention, like for example: If the virtual surgeon applicates too much preassure during the phacoemulsification procedure, sporadical eye moves, IOP less, etc. It is also considered the possibility to adapt the realized program, to predict the effect of laser operations on the ocular system.

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Author: Juan Francisco Perez
Rafael Barea
Institute: Department of Electronics. University of Alcala
Street: 2885. Alcala de Henares.
City: Madrid
Country: Spain
Email: juanf.perez@depeca.uah.es
barea@depeca.uah.es