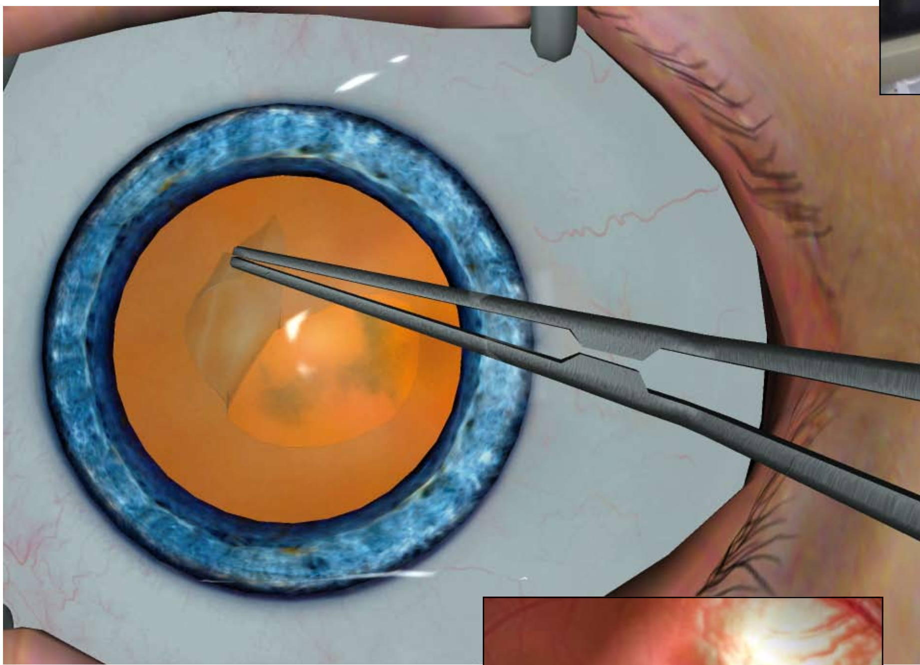
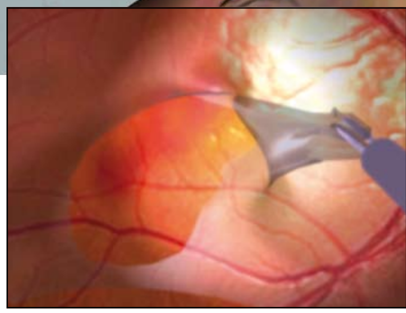
It´s Magic

FPGA-based Tracking Enables Highly Realistic Eye Surgery Simulation



"We are magic!" – this was the slogan printed on the t-shirts of the three young men who carried a large black box into the exhibition hall at the annual conference of the German Society of Ophthalmology (DOG) in Berlin in 2001 and caused quite a stir as a result. What the specialists at the conference saw afterwards did indeed have something magical about it: for the first time ever, three young scientists from the Universities of Mannheim and Heidelberg demonstrated how eye surgery could be trained in a highly realistic way using a computer-based simulator – without a patient or animal eyes.

Previously, students of ophthalmology had practiced their first attempts at surgery on pig eyes before they were allowed into the operating theatre under the guidance of a professor. The possibilities for gaining actual surgical experience were therefore limited and always involved a certain residual risk for the patient. The new system with the name "EYESi" had been developed by an interdisciplinary team of computer scientists, physicists and medical specialists as part of a research project on "Virtual reality technology and medical simulations". The goal of this project was to develop a VR simulator that would allow doctors to practice surgical operations without any risk to patients – similar to the principle employed in training pilots using a flight simulator.



The surgical scenario is computer graphically generated and then rendered to the microscope, views are calculated for left and right eye giving an excellent stereoscopic insight into the eye

Surgery in Cyberspace

Surgery inside the eye is one of the greatest challenges in the field of microsurgery. The specialist training of eye surgeons takes two years. "We integrated all the important aspects of a real operation into the simulation environment when developing Eyesi," explains Dr. Markus Schill, who led the working group at the university and is now CEO of VRmagic Holding AG. "When working with the simulator, the surgeon sits in the usual position at an operating microscope and inserts original surgical instruments into a model eye."

The model head of the simulator contains an optical tracking system that follows the movements of the instruments with three cameras and supplies corresponding position information to a computer. The system simulates in real time how the tissue reacts when it comes into contact with the instrument.

"The use of simulators offers a number of advantages for medical training: all human pathologies – even rare cases – can be simulated, the permanent availability of the simulator saves both time and costs, and the training units can be repeated any number of times. In addition, the data provided permits objective assessment of surgical performance," explains Schill.

Eyesis' precise optical tracking system and optimized simulation algorithms for tissues reaction enable a stunning degree of realism

Award Winning Success

The positive feedback on the simulator when the prototype was presented in 2001 was sufficient encouragement for the research team to develop the product to series maturity. The company VRmagic GmbH was founded when Eyesi received

Eyesi in operation in Da Nang, Vietnam (Credit: PJ Saine/ORBIS International)

the Innovation Prize of the Rhine-Neckar Foundation of the Manfred Lautenschläger Foundation in the same year.

In 2004, the simulator received the award for the "Most Innovative Product" from the British Royal College of Ophthalmologists in Manchester, England. This was followed in 2007 by the "European ICT Prize" of the European Union.

Eyesi has been in use on all continents since 2006. In the U.S., the use of simulators was included last year in the new guidelines for ophthalmological training. The international non-profit organization Orbis, which fights blindness all over the world, has equipped its "flying hospital" and various national programs with Eyesi simulators in order to train eye surgeons in developing countries on the surgical techniques for removal of cataracts.

"We still often get enquiries from doctors asking us how frequently it is necessary to change the pig eyes in the system," smiles Schill, and his evident enthusiasm for the subject matter shows the amount of passion that has been incorporated in development of the simulator. Highly sophisticated hardware and software are needed so that the user actually has the impression that he is really performing the simulated operation. The time delay of visual imaging must be below the human perception threshold of 50 to 100 milliseconds. Powerful algorithms were developed for Eyesi that calculate in real time the behavior of fluids and tissue upon collision with the instruments and after tearing or deformation. Visualization of the space inside the eye is extremely realistic thanks to special effects such as shadows, selective focus and spotlighting.

Highly Precise Tracking in a Tiny Space

The demands on optical tracking of the surgical instruments inside the eye are very high, particularly because the instruments and lights should be freely movable. The relatively small volume of the eye must be scanned with high resolution in order to permit realistic simulation. The update rate must be higher than 30 Hz,

During simulated surgery, the surgeon manipulates realistic handheld instruments which are inserted into an artificial eye

even with minimum latency, so that the computer graphics can produce a delay-free representation of the operation.

Movement of the instruments is followed by FPGA-based tracking: the swivel-mounted, mechanical model eye has color markers. The tips of the instruments also have a color marking. This makes it possible to determine both the position and the alignment of the eye and instruments. The markers on the model eye and instrument tips are projected onto the sensors of three calibrated FPGA cameras. After image processing in the FPGA, the 2D images are forwarded to a PC via a USB connection. 3D reconstruction takes place here. The image data of the three calibrated cameras is fusioned and triangulated in order to determine the precise spatial position of the instruments.

The camera system has become smaller and smaller over the course of the years. "On the first prototype, there was still an enormous box under the unit to accommodate the cameras, wiring harness and FPGA technology," remembers Thomas Ruf, who developed the FPGA-based tracking system for Eyesi and is today the head of Research and Development at VRmagic. The complete tracking system has been incorporated in the model head of the simulator since 2004. As a result, it is possible to easily replace the head in order to train different operations. USB compatibility was a prerequisite for simple interchange of the peripheral devices.

Simulator Cameras Branching out

Since there were no USB cameras offering sufficient performance on the market at the time, the developers at VRmagic started to build their own components.

Advanced optical 3D tracking technology for realtime eye surgery simulation

This led to the presentation of the first certified USB 2.0 camera in Mannheim in March 2003. Inquiries from industrial and scientific customers provided VRmagic with the encouragement needed to further expand the range of functions offered by the cameras. A second field of business therefore developed. Since 2003, the Stemmer Imaging Group has been the sales partner responsible for selling VRmagic cameras throughout Europe. The product portfolio now includes over 70 components – ranging from simple streaming components that forward image data to a host system and smart FPGA components for data pre-processing through to intelligent cameras that have a separate operating system and take decisions autonomously.

"We are our Own Most Critical Customer"

Often, VRmagic first develops new image processing components for its own needs. "We work with our SDK ourselves, so we know what features are important for developers," explains Thomas Ruf. Recently, a pixel-synchronous multi-sensor camera was developed for a medical training system with augmented reality. VRmagic will present this new camera with up to four remote and freely positionable sensors at the Vision 2008.

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