The Varioscope AR – A Head-Mounted Operating Microscope for Augmented Reality

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Abstract. Inherent to the field of computer-aided surgery (CAS) is the necessity to handle sophisticated equipment in the operating room; an undesired side-effect of this development is the fact that the surgeon's attention is drawn from the operating field since surgical progress is partially monitored on the computer's screen. The overlay of computer-generated graphics over a real-world scene, also referred to as augmented reality (AR), provides a possibility to solve this problem. The considerable technical problems associated with this approach such as viewing of the scenery within a common focal range on the head-mounted display (HMD) or latency in display on the HMD have, however, kept AR from widespread usage in CAS. In this paper, the concept of the Varioscope AR, a lightweight head-mounted operating microscope used as a HMD, is introduced. The registration of the patient to the preoperative image data as well as preoperative planning take place on VISIT, a surgical navigation system developed at our hospital. Tracking of the HMD and stereoscopic visualisation take place on a separate POSIX.4 compliant realtime operating system running on PC hardware. While being in a very early stage of laboratory testing, we were able to overcome the technical problems described above; our work resulted in an AR visualisation system with an update rate of 6 Hz and a latency below 130 ms. First tests with 2D/3D registration have shown a match between 3D world coordinates and 2D HMD display coordinates in the range of 1.7 pixels. It integrates seamlessly into a surgical navigation system and provides a common focus for both virtual and real world objects. On the basis of our current results, we conclude that the Varioscope AR with the realtime visualisation unit is a major step towards the introduction of AR into clinical routine.

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1 Introduction

Augmented reality (AR), the overlay of computer-generated graphics over a real world scene, has a tantalising potential for visualisation in computer-aided surgery (CAS). Several groups have tried to achieve this goal. One of the earliest approaches was the integration of the computer's monitor into the operating microscope for neuronavigation [8,10,11,13,16]. While this appears to be the most promising technology for clinical applications where an operating microscope is used (such as in neuro- or skull base surgery), the vast majority of surgical specialties does not utilise such a device, and the introduction of such an expensive system for the purpose of AR-visualisation alone appears problematic. Others have tried to use commercial head-mounted displays (HMD) [9,18] or semi-transparent panels [7] for displaying monitor information. The major problem of this approach is the fact that a common focus of the real world scene and the computer-generated graphics cannot be achieved by the viewer's eye. A possibility to overcome this problem is the usage of miniature video cameras [12] and monitors [9]. The image from the video cameras can be merged with the computer-generated scene and displayed on the video monitors. The obvious drawback of this approach is, however, the fact that in addition to the HMD the surgeon also has to wear the miniature video cameras on the headset, and that a video generated view cannot compete with the view of a scenery as provided by an optical system alone in terms of image quality.

From our clinical experience, a number of requirements was defined for AR visualisation in CAS:

- Surgical instruments such as operating microscopes are preferrable for AR visualisation since clinical acceptance is easier to be achieved.
- Common focus for both the real-world scene and the computer-generated graphics has to be provided.
- Display latency due to lags in position measurement and rendering time requirements have to be minimised to avoid simulator sickness [2].
- The AR visualisation has to be an add-on to a normal navigation system. Sophisticated image processing such as multiplanar reformatting and volume rendering still have to be available during surgery while not overloading the scenery displayed in the HMD.
- Economic and intraoperative time expenses due to AR have to be kept to a reasonable amount.

These considerations led to the development of the Varioscope AR, a miniature head mounted operating microscope for surgical navigation; it features display of additional computer generated sceneries and communication to a surgical navigation system.

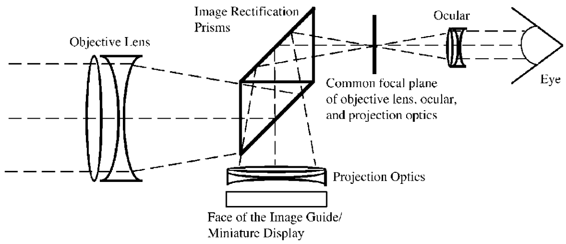

Fig. 1. The principle of image overlay in the Varioscope AR. An additional image from a miniature computer display is being projected into the focal plane of the Varioscope's objective lens. Both images can be viewed through the ocular of the Varioscope.

Working distance	300 - 600 mm
Magnification	3.6 × −7.2×
Parallax correction	Automatic
Weight	297 grams
Physical dimensions	120 mm width, 73 mm length

Table 1. Optical data of the Varioscope.

2 Materials and Methods

2.1 Visualisation Optics

The Varioscope is a head-mounted operating microscope developed and marketed by Life Optics, Vienna/Austria (*http://www.lifeoptics.com*). A list of the Varioscope's optical data can be found in Table 1. A beamsplitter together with a projection lens was inserted into the optical path by Docter Optics, Vienna/Austria. Both the image from the Varioscope's objective lens and the projection optics merge in the focal plane of the objective lens. Thus both the real world scene and the computer graphics can be viewed through the Varioscope's ocular and appear focused to the the viewer's eye (Fig. 1).

2.2 Display System

Two miniature VGA displays (AMEL HiBrite, Planar Systems, Munich/Germany, *http://www.planar.com*) with 640*480 pixel resolution and 0.75 inch display diameter were connected to a miniaturisation lens system which reduces the image from the display by a factor of 0.67. This image is being transferred to the projection optics of the Varioscope AR by means of a flexible, high resolution image guide with a resolution of 800*1000 pixels and an active area of 8*10 mm (Schott Fiber Optics, Southbridge/MA, *http://www.schottfiberoptics.com*).

2.3 HMD Tracking and Calibration

The HMD is being tracked by an optical tracking system (Flashpoint 5000, Image Guided Technologies, Boulder/CO, *http://www.imageguided.com*). A LED assembly was mounted to the Varioscope AR; a triaxial gyroscope (ATA ARS-09) and three accelerometers (Endevco 7290 A) are rigidly connected to the LED

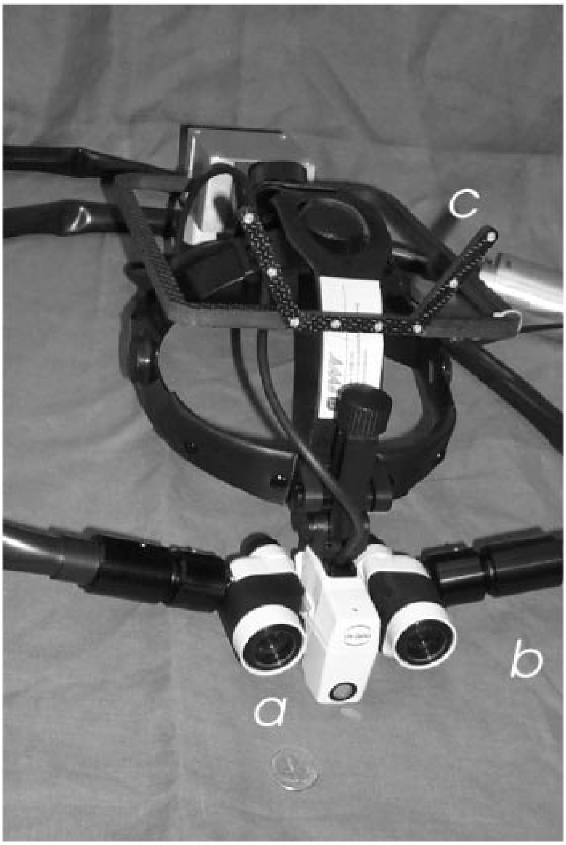

Fig. 2. The first prototype of the Varioscope AR. In addition to the normal Varioscope (a), two image guides (b) injecting a scene generated by the realtime control unit of the Varioscope are attached. Furthermore, a LED assembly (c) rigidly connected to a triaxial gyroscope and accelerometer assembly can be seen.

assembly (Fig. 2). The readings from the kinematic sensors are to be used for predictive filtering of the HMD's position through a Kalman filter [1,14]. At the very moment, the HMD is, however, only tracked by the optical tracker.

Photogrammetric registration of the readings from the optical tracker to the actual scene to be viewed is achieved by Tsai's algorithm [17]. While this is work in progress, we have achieved first results by using a variant of Tsai's algorithm which uses a coplanar 3D world coordinate data set. These data were retrieved by aiming a crosshair displayed in th HMD at a calibration grid. From these data, six extrinsic calibration parameters (a rotation and a translation which transfers the world coordinates to the HMD's coordinate system) and two intrinsic parameters (the effective focal length of the HMD's optics and the radial distortion coeficient) are determined. Three more parameters (the center of the display relative to the optical axis and an uncertainty factor which is of no interest for this application) were either determined manually or omitted.

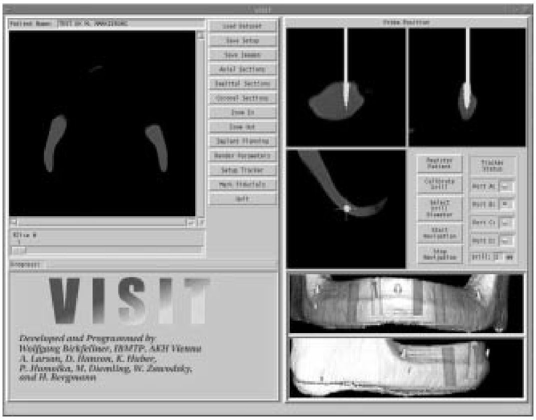

Fig. 3. A screenshot of VISIT, the non-realtime navigation system for additional visualisation on multiplanar reformatted slices and volume renderings. VISIT acquires data from the RT-control system for tool position visualisation, and delivers the data for generating the OpenGL model in the coordinate frame of the patient to the RT-control system. This OpenGL model is then visualised on the Varioscope AR (see Fig. 4).

2.4 HMD Control and Communication with a Navigation System

The visualisation of the preoperative scene takes place on a POSIX.4 compliant real-time operating system (Lynx OS 3.0.1, *http://www.lynx.com*) running on a standard PC (Intel Pentium II Processor, 450 MHz, 128 MB RAM) with a standard Ethernet controller (3com 509B), a SCSI controller (Adaptec 2940UW), two graphics controllers (Matrox Millenium II), and an 8 channel ADC board with 200 kHz sampling rate (Pentland Systems LM1, *http://www.pentland.co.uk*). Two independent X-servers are driven by the Lynx OS. OpenGL programming was done using the Mesa 3.0 API (*http://www.mesa3d.org*) and the GLUT-toolkit [15].

The realtime system polls data from the optical tracker at an update rate of approximately 10 Hz. These data are used to render two perspective scenes on the VGA displays according to the actual position of the HMD, the patient and the surgical tool (Fig. 4). Furthermore, a navigation system is connected to the real-time system. VISIT, the system used for these experiments, was developed at our hospital (Fig. 3); it's first application is the computer aided insertion of endosteal implants in the field of cranio- and maxillofacial surgery [3,4,5,6]. The navigation system acquires data at a lower priority (approx. 1 Hz). It visualises the drill's position on obliquely reformatted slices and volume renderings. The accuracy of the system was found to be 0.9 ± 0.4 mm [4]. The preoperative planning data are sent to the realtime system after patient-to-image registration; the real-time system derives the OpenGL scene from these data (Fig. 5). Communication between the CAS-workstation and the realtime system takes place by means of POSIX.1 conformant non-canonical serial communication via the RS232 interface. The system waits for 0.1 s for a request from the CAS system; if the CAS-system does not send a request, the next position dataset is polled from the optical tracker, and the next request handler is being invoked.

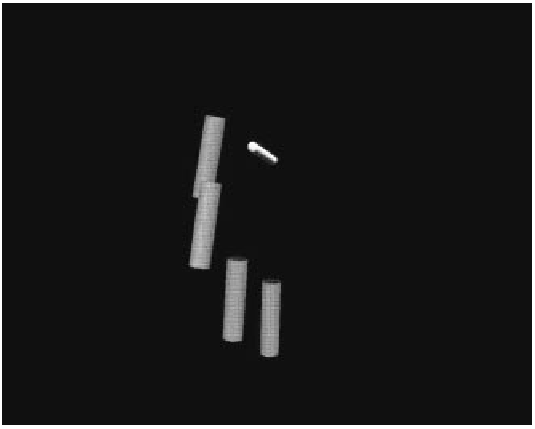

Fig. 4. The OpenGL scene as visualised on one channel of the HMD. Visible are four implants derived from the preoperative planning on the preoperative CT scan, and the drill. This scene is updated at a rate of approximately 10 Hz.

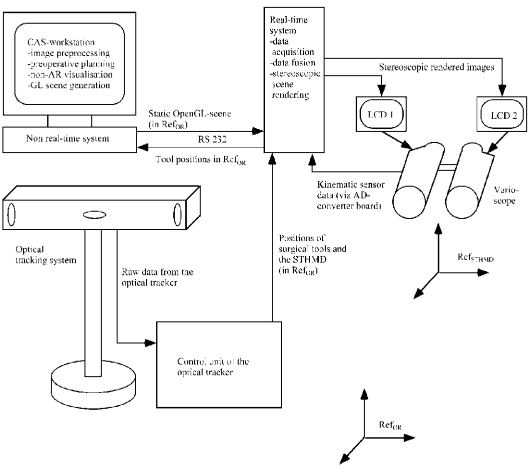

Fig. 5. The realtime control unit of the Varioscope polls data from the optical tracker at an update rate of approximately 10 Hz. The realtime system also acquires additional data from the eight channel ADC board. Two stereoscopic scenes are rendered and displayed on two miniature VGA displays connected to two independent X-servers. The navigation system (CAS workstation) acquires data at an update rate of approximately 1 Hz from the RT-system; the navigation system uses these position data to display the tool's actual position on the preoperative datasets.

2.5 First Laboratory Assessments

The latency in image display is a crucial problem in AR. In order to get a figure of the performance of the realtime control system of the Varioscope AR, we have analysed the single factors contributing to the overall display lag; furthermore these measurements were repeated to see whether the time lags in communication can be expected to be constant. If this is the case, predictive tracking [1] can be expected to be able to reduce the lag in display due to rapid head movements of the surgeon significantly. Measurements were taken by calling the internal timers of the Lynx OS (timer resolution: 0.01 s).

Table 2. Time requirements for data acquisition from the optical tracker and the ADC-board of the real-time workstation and the time needed for rendering the two OpenGL-scenes.

Run No.	Data Acquisition Time [s]	Rendering Time [s]
1	0.146 ± 0.02	0.04 ± 0.01
2	0.147 ± 0.02	0.04 ± 0.01
3	0.147 ± 0.02	0.04 ± 0.01
4	0.145 ± 0.02	0.04 ± 0.01
5	0.146 ± 0.02	0.04 ± 0.01
Average	0.146 ± 0.02	0.04 ± 0.01

3 Results

First of all, it turned out that common focus is easily achieved in the prototype. The HiBrite displays have turned out to be bright enough to show the OpenGL graphics in a sufficient manner without additional light sources.

The data acquisition time's repeatability was found to be in the range of the timer's resolution. Overall time requirements for accessing data from the tracker and the CAS-workstation over the serial ports was found to be 0.15 ± 0.02 s. The time needed for rendering the OpenGL scenes remained constant at 0.04 ± 0.01 s. While evaluation of the photogrammetric registration is still under progress, first experiments at a fixed focal length of 35 mm resulted in a match between measured 2D display coordinates and 3D coordinates transformed back to the HMD's display of 1.7 pixel (maximum error: 3.0 pixel).

4 Discussion

Our current results show that a head-mounted operating microscope with the capabilities of the Varioscope AR provides a very promising approach towards introduction of AR in the operating theatre. The system can handle the problems adressed in the introduction; furthermore it can easily be connected to other navigation systems since the CAS-workstation and the realtime control unit are separated. Currently, both image update rate and latency are within reasonable limits. Since the visualisation hardware can still be improved in a cost efficient manner (by usage of OpenGL accelerated graphics boards and one or more CPUs with higher computing power) we believe that the next months will bring even increased performance. Another bottleneck is the request handler for communication with the CAS-workstation; it consumes 0.1 s of computing time in the realtime control system's main event loop. This is due to the use of POSIX.1 conformant serial communication between the navigation system and the realtime-unit. A faster method using Ethernet and POSIX.4 conformant timers is currently under development.

This is a paper on work-in-progress. Therefore, the most important part of evaluation, the clinical assessment, was not yet performed. Since the basic visualisation task currently is the matching of planned implant position and actual drill position, both static and dynamic errors in photogrammetric matching of the real world view and the computer generated view are not yet crucial. The next steps include assessment of the Kalman filter's performance for improving dynamic registration, and the accuracy of the static photogrammetric registration has to be assessed. Our current work shows, however, that our approach has the potential to bring AR to a wide acceptance among surgeons in a wide variety of specialties.

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