Stereoscopic Augmented Reality System for Computer Assisted Surgery

Marc Liévin and Erwin Keeve

Research center c a e s a r,
Center of Advanced European Studies and Research,
Surgical Simulation and Navigation Group,
Friedensplatz 16, 53111 Bonn, Germany.

A first architecture for an augmented reality system in computer-assisted surgery is presented in this paper. Like in ”X-ray vision” systems, a stereoscopic overlay is visually superimposed on the patient. The main purpose of our approach is user-friendliness for the surgeon: no additive wearing equipment is required. Registration, rigid bodies location and 3D volume computation are proved to respect real-time processing, thanks to an optical navigation system and our integrated software framework. Studies are undertaken to replace our actual monitor display by an upcoming holographic screen.

1. Introduction

Computer assisted surgery aims at providing user-friendly interfaces to the surgeon in the operating room. In surgical navigation systems, multiple corresponding views of preoperative data, CT and MRI, are aligned and manipulated by positioning surgical tools in the real world. One of the main drawbacks of such a method is the repetitive look away of the surgeon from the patient to an ordinary computer screen. For years, people have been looking for ”X-ray vision” systems, allowing a stereoscopic overlay of hidden anatomical structures [7]. In this paper, we present an architecture for an augmented reality system with stereoscopic image data visually superimposed on a human subject. This system will include display, navigation and registration devices.

Augmented reality establishes the link between real environment and virtual environment, where 3D images generated by computers are merged to the real scene. Since the surgeons environment is much more real than virtual, the display system should be the only source of virtual information (e.g. the surgeon and the patient should not wear additional apparatus in the operating room). Finally, augmented reality offers friendliness and complete immersion in a stereoscopic world. Nonetheless, two major key points must be solved to achieve good results. First, the whole system must work in real time. As a standard rule, 20 Hz is the minimum rate required. Ideal systems should present 30 Hz refresh rate for an optimal immersion. The second requirement is a very good accuracy in positioning. For surgical purpose, but also for credibility, millimeter accuracy must be achieved in locating all the actors of the system.

2. Methods

Before all, a navigation system has to be defined. Mechanical devices have been prohibited, due to their moving constrains. Magnetic systems offers unconstrained movements at the expense of a dramatic fall in accuracy [6]. We use here an optical system with sub-millimeter accuracy and real-time capabilities (FlashPoint 5000 system from IGT Inc., Boulder, CO, USA). This system uses 3 CCD cameras to triangulate the location of active LEDs. Surgical instruments are equipped with 2 LEDs that may be tracked during the surgical procedure. Other rigid objects in the operating room, like patient or display devices, are also located using 3-LEDs dynamic reference frames.

Registration between the patient and the data is currently achieved by rigid body transform using an optical probe and corresponding landmarks extracted from the data sets. The transformation matrix is computed by classic least squares minimisation method. In forthcoming procedures, looking through the overlay screen will increase interactivity and accuracy in probe positionning and patient registration. In neurosurgery, cranio- and maxillofacial surgery, an optical reference frame may be attached to a clamp allowing dynamic tracking of the patient. Works are also planned to include calibrated camera systems, combining information between data sets and body surface properties.

The real time 3D computation is accomplished by our software application framework - called Julius [5]. The volume data set is resampled in real-time according to the position of the optical probe and transmitted to the display system. Included in a common pipeline, all real or virtual objects are related to Julius. Therefore, the Julius coordinate system (data coordinates) defines the reference of the whole system. This definition respects the surgeon own thought process orienting himself in the data sets.

Several stereoscopic display devices are now available in virtual applications. New autostereoscopic LCD screens afford the user to see 3D images without shutter glasses, according to dedicated tracking system. In augmented reality, we need a see-through overlay with stereoscopic properties. HUD (Head Up Display, see-trough helmets) is the most popular solution, often used in military applications, unfortunately with too many constraints. A first enhanced reality system for neurosurgery proposes to overlay a live video of 3D anatomical structures onto the patient [4]. The main difficulty of the method is the accuracy in 3D to 2D projective registration. Moreover, no object - surgical tools or surgeon hands - may appear between the beamer and the projecting surface. In computer assisted interventions, microscope-based augmented reality system provides surgeons with 3D visualisation of hidden structures during surgery [3]. Accuracy and 3D perception are proved to be efficient in this restricted research area. One related project uses overlay see-through merging with half silvered mirror [1]. The surgeon still needs to wear polarised glasses, tracked by an additional system. True 3D displays are also affordable using holography and internal photography [2]. In our application, we are now experimenting such holographic displays with no specific wearing equipment, thanks to new projection technologies. Computer vision techniques are still required to track the surgeon gaze, while projecting a stereoscopic overlay.

Figure 1 presents the whole architecture of our system. The core of data loading, processing and pipeline visualization is located in the Julius framework. Navigation and video systems are connected to the core and establish the correspondance between data coordinates and actors in

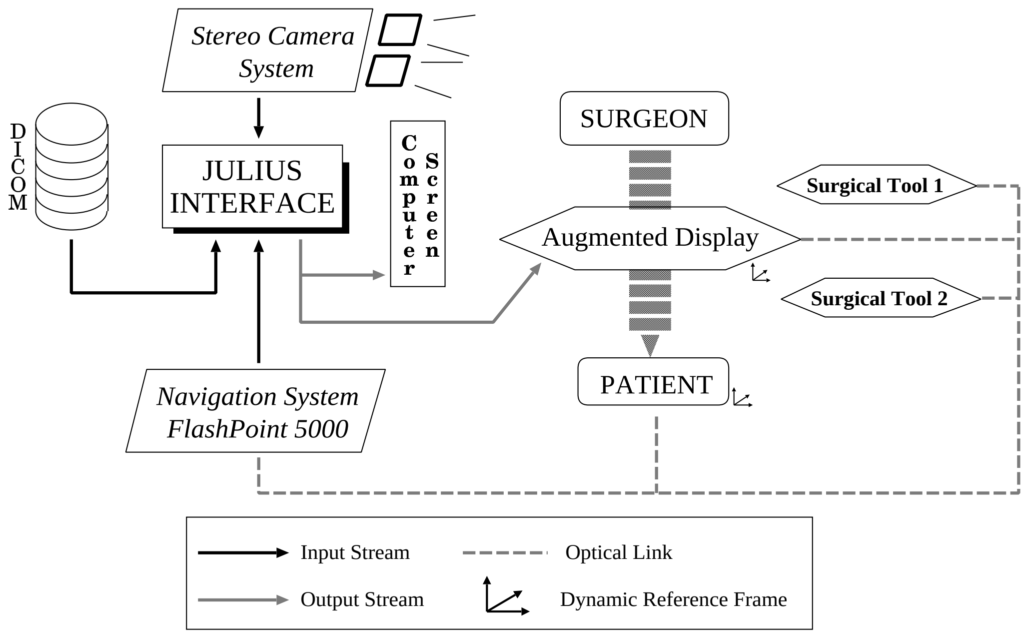

Figure 1. Augmented Reality System Architecture.

the operating room. Whereas camera systems are currently optional, the navigation system is required to locate the display device, patient and navigation tools.

3. Results

A navigation system, including tool location, reference frame correlation and 3D volume computation is actually implemented on an Octane 2 (SGI, Mountain View, CA). The combination of optical and computer vision systems should offer the accuracy of the millimeter in locating all the actors of the surgery room. 3D locations of 2 surgical tools (2 LEDs each) and 2 reference frames (3 LEDs each) are now updated at average rate of 30 Hz on a computer screen - see Figure 2. This real-time frame rate corresponds to the limit of our optical navigation system but is required for surgery purpose.

Thanks to the Julius pipeline, the prospected augmented display may present the real scene with interactive virtual information superimposed, like hidden structures, virtual tools and trajectories. Figure 3 shows virtual representations of surgical instruments within the 3D reconstruction of the patient anatomy. Navigation tools are here composed of 2 probes (painted in black and silver) and 1 star frame referenced to the patient, e.g. the skull. The extrapolated trajectories of the surgical tools inside the head are shown in grey. Registration landmarks are represented by spheres on the skull.

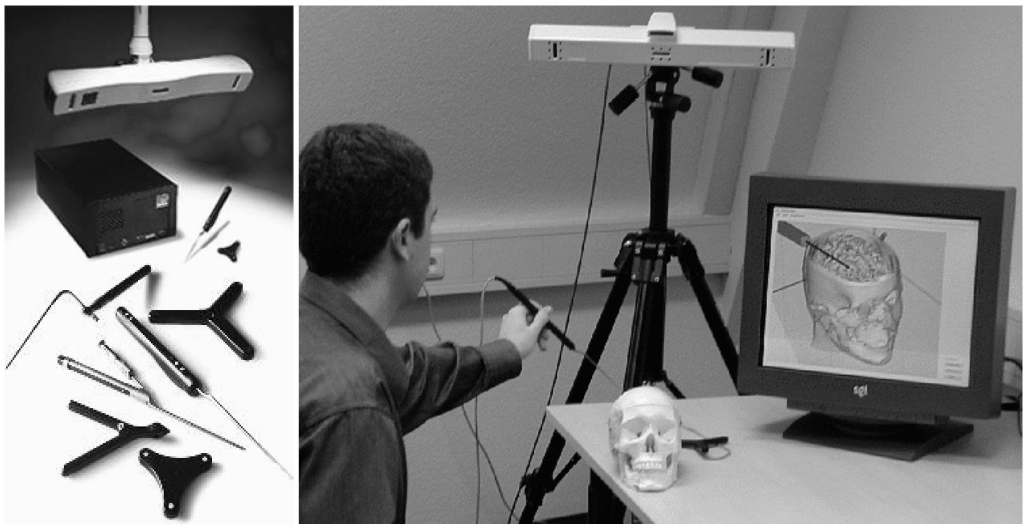

Figure 2. Navigation in real-time. *Left*: Optical navigation system and its associated tools. *Right*: The navigation system in use, registered to a phantom skull.

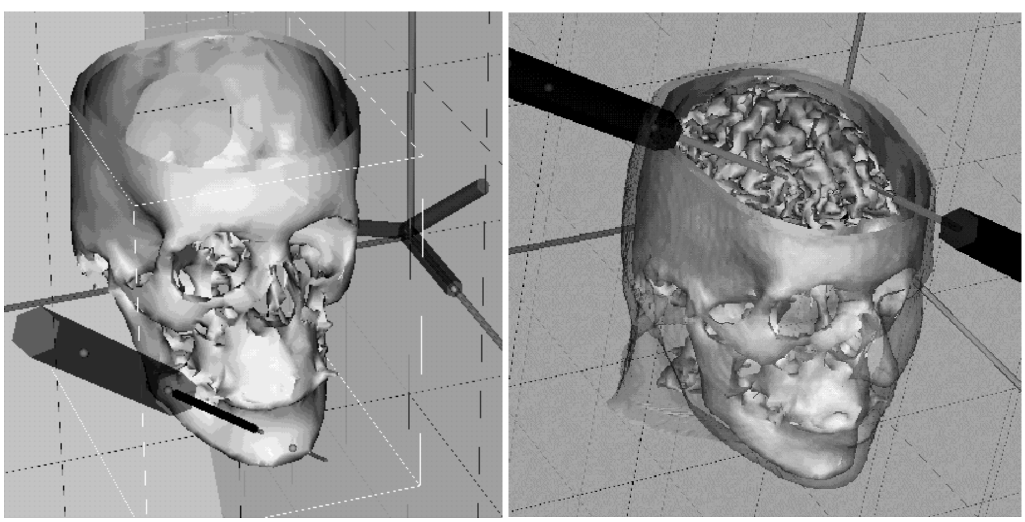

Figure 3. 3D virtual representations of surgical instruments within 3D head reconstruction. *Left*: Registration with anatomical landmarks on the skull; *Right*: Navigation using 2 tools within the patient anatomy (bone, skin and brain).

4. Discussion

A first architecture is presented for an augmented reality system in computer-assisted surgery. The registration, rigid bodies location and 3D volume computation are proved to be achieved in real-time. The navigation system and registration procedure respect currently a millimeter accuracy. We need now to replace our current display - computer screen - by a forthcoming stereoscopic display to validate the whole system accuracy and the clinical use error.

According to the challenging conditions, the main characteristic of our approach is the user-friendliness for the surgeon. No wearing equipment is required to achieve a real-time stereoscopic overlay display with dynamic location of patient and surgical devices. Registration and preoperative procedures will be fully interactive when overlayed on the patient. Studies are undertaken to include computer vision to handle optical orientation problems and to locate the surgeon. Adding camera systems will decrease this rate to a half video rate (15 Hz) but we are still confident in robustness and display improvements. This system is still in development and clinical evaluation in cranio- and maxillofacial surgery is under forthcoming study.

REFERENCES

1. M. Blackwell, C. Nikou, A.M. DiGioia and T. Kanade, "An Image Overlay system for medical visualization," *Transactions on Medical Image Analysis*, Vol. 4, pp. 67-72, 2000.
2. T. Dohi, "Surgical Robotics and Three Dimensional Display for Computer Aided Surgery," *in Proc. of Computer Aided Radiology and Surgery*, CARS 2000, pp. 715-719, San Francisco, U.S.A, June 2000.
3. P. Edwards, A.P. King, C.R. Maurer, D.A. deCunha, D.J. Hawkes, D.L.G. Hill, R.P. Gaston, M.R. Fenlon, S. Chandra, A.J. Strong, C.L. Chandler, A. Richards and M.J. Gleeson, "Design and Evaluation of a System for Microscope-Assisted Guided Interventions (MAGI)," *in Proc. of Medical Image Computing and Computer-Assisted Intervention*, MICCAI99, pp. 842-851, Cambridge, UK, September 1999.
4. E. Grimson, M. Leventon, G. Ettinger, A. Chabrerie, F. Ozlen, S. Nakajima, H. Atsumi, R. Kikinis and P. Black, "Clinical Experience with a High Precision Image-guided Neurosurgery System," *in Proc. of Medical Image Computing and Computer-Assisted Intervention*, MICCAI98, pp. 63-73, Cambridge MA, USA, October 11-13, 1998.
5. T. Jansen, B. Rymon-Lipinski, Z. Krol, L. Ritter and E. Keeve, "An Extendable Application Framework for Medical Visualization and Surgical Planning," *in Proc. of SPIE Medical Imaging*, MI'01, San Diego, CA, February 17-23, 2001.
6. D.A. Simon, "Intra-Operative Position Sensing and Tracking Devices," *in Proc. First joint CVRMed and MRCAS Conference*, pp. 62-64, June 1997.
7. R. Yamanaka, K. Yamamoto, N. Handa and H. Yoshikura, "A 3D Display with a Linearly Moving Mirror to Reflect a Series of 2D Cross Sections and Its Application to Noninvasive Angiography," *Transactions on Medical Imaging*, Vol. 7, No 3, pp. 193-197, September 1988.