

CAMPAR: a software framework guaranteeing quality for medical augmented reality

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Abstract. In-situ visualization is the projection of imaging data into the doctor's field of view in real time for medical procedures. This kind of augmented reality (AR) needs other requirements in terms of quality of service, reliability, and accuracy than its counterparts in industry and entertainment. We aim at in-situ visualization during medical procedures such as minimally invasive surgery. For any system based on augmented reality visualization we need the three essential requirements: Reliability, usability, and interoperability. Since the persuasive power of this kind of visualization is very high, visualization software must guarantee certain accuracy constraints by monitoring it during run time. This paper describes a general approach for a software architecture needed for in-situ visualization.

Keywords: Medical augmented reality, In-situ visualization, Reliability

1. Introduction

The increasingly amount of data provided by medical 3D imaging devices to surgeons makes new visualization technology necessary that reveal more information at a glance than a stack of 2D slices and that is less cumbersome than browsing through these stacks. Augmented reality (AR) is an emerging technology that meets these requirements. There are several valuable systems proposed in the literature [1–3, 6]. However, there is still the need of a general framework for medical augmented reality systems, in particular one that integrates synchronization issues.

This kind of visualization has a high persuasive power. Therefore the software must guarantee certain accuracy constraints by monitoring it while running. This must be deeply integrated into a software framework. At least as important as reliability of technology is its usability.

The aim of in-situ visualization is supporting doctors in their work. Therefore common user interfaces must be used that are well known and accepted by doctors. Last but not least interoperability plays an important role for medical visualization. There are different manufacturers of imaging and navigation hardware that usually come with their own display. For combining data of different hardware and bringing it to a single display the software framework must be prepared to communicate with various hardware devices.

This paper describes a general software approach to meet these requirements and presents our running implementation that realises such theoretical considerations. This is the base for research on next generation visualization in operating rooms.

2. Methods

The three essential requirements are met by the following means:

2.1 Reliability

The reliability of a visualization system is maintained by real time checking whether the desired accuracy can be provided. In situ visualization depends strongly on the measurements of tracking systems. The point of time when the measurement has been taken is as important as the value of a measurement. Unfortunately, computers of different tracking systems or image sources have different clocks and they perform at different speed. Therefore a synchronization mechanism based on NTP is integrated into the core of CAMPAR. This offers the possibility to visualize only data from the same point of time and eliminates the lag between the systems as a source of error. This feature is also crucial for redundant position tracking. It is important to note that this synchronization is not a compromise that slows down the system. Since the software offers awareness over its own performance it uses this information to render the visualization at the earliest possible point of time, where all essential data is available.

2.2 Usability

The overall aim is to ease up the work with computer-aided hardware in the operating room in order to enable the surgeons to concentrate on their actual work while taking advantage of newest imaging and navigation hardware. A software framework that is supposed to visualize complex data intraoperatively has to be easy to use. This design goal has to be deeply integrated into the process of software framework development. Only visualization algorithms have been selected that do not need manual interaction by physicians.

Furthermore, the usability of a visualization system should no longer be regarded without its environment. With this philosophy an advanced visualization system would be only considered as another system in the operating room with some functionality. For a smooth integration into operating room and intuitive usability for the surgeon and other personnel, the system must operate together with the other computer-aided systems in the operating room and access their data and functionality.

2.3 Interoperability

A visualization system must interact with various hardware devices of different vendors. Current operating room hardware does not have a common user interface. We have the vision of a unified user interface with a single visualization system per operating room but not per imaging or navigation hardware. This ideal visualization system has access to all computerized procedures in the operating room and provides a single user interface to the surgeon instead of a display and a user interface for each piece of hardware. Therefore the software framework is designed to operate with differing hardware. This means on one hand the integration of imaging standards as DICOM or networking standards as TCP/UDP and on the other hand special data handling routines. A software framework must take care of synchronization of the data. Therefore the software collects the data and marks it with a time stamp. The time stamp must be from the point of time, when the data has been measured. This point of time should not be mistaken with the point of time when the data arrived at the visualization system. We have developed sophisticated algorithms for this synchronization of data from differing hardware.

As important as the temporally correct collection and processing of data is an abstract programming interface for similar hardware, e.g. the infrared tracking systems Optotrak and Polaris. CAMPAR allows for interaction with similar hardware of different vendors

in exactly the same way. This idea appears to be obvious; however the existing solutions in the operating room do not usually support this kind of collaboration.

2.4. Choice of language and libraries

We decided to implement our framework in C++ to fulfil its high real-time requirements and possibility to address hardware as directly as possible while keeping a clear object oriented design. To guarantee a high visualization quality and performance the core of the graphics routines are based on OpenGL, a reliable and stable industry standard for computer graphics. We also use scene graph engines such as OpenInventor based on OpenGL. To further speed up the visualization of huge medical imaging data, for instance during direct volume rendering, we utilize the graphic card's processing unit (GPU) by the integration of shaders, as provided by the Cg language.

The most common format for all kinds of medical imaging data is DICOM, which is easily processed within our framework by the gdcM library. The graphical user interface can be easily swapped from OpenGLUT to Qt. All external libraries can be downloaded and used for free.

If the involved hardware requires a local distribution to several PCs, we can still keep our augmented reality architecture synchronized in time up to a few milliseconds by using the network time protocol (NTP), where one PC simply serves as an NTP server, which provides its local time to all other PCs.

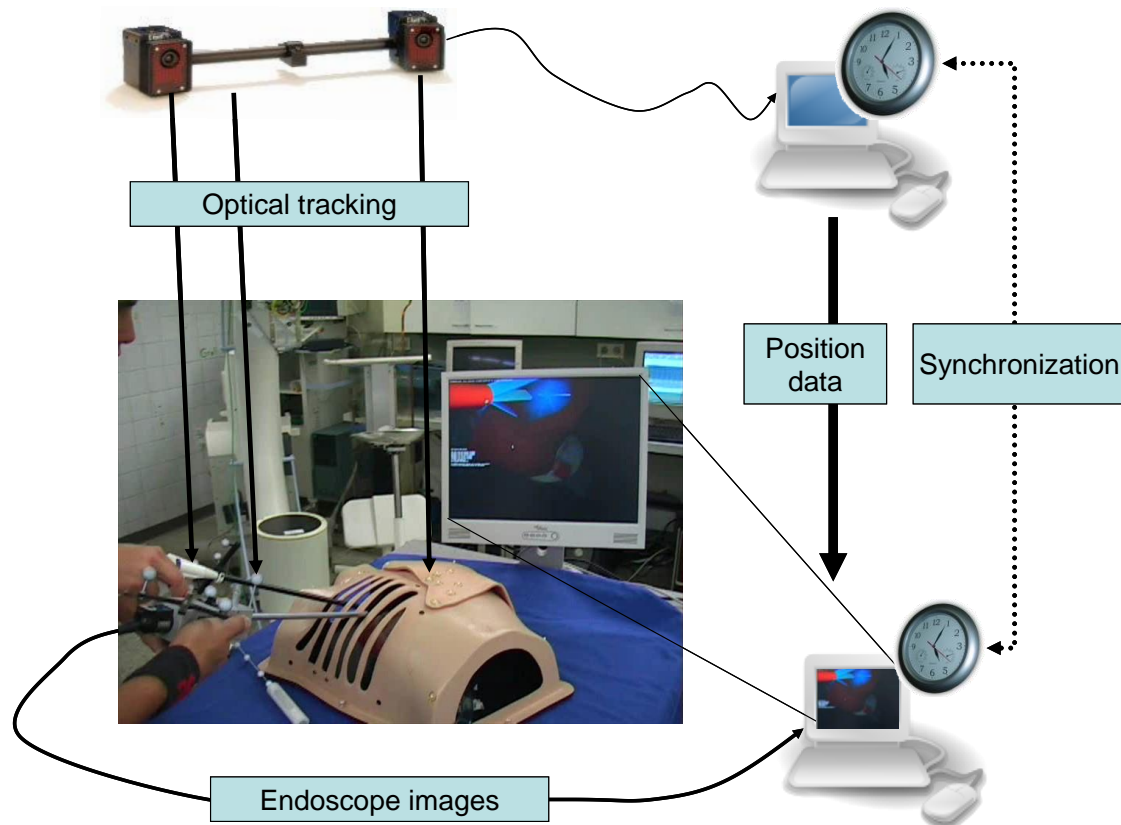


Fig. 1. Scheme of endoscope augmentation; the display in the image shows an augmented endoscope view: The CAMPAR framework guarantees the correct synchronization and smooth integration of multiple tracking and visualization systems.

3. Results

3.1 Reliability

Our system offers to monitor and control the data flow in the temporal accuracy below a millisecond. We can monitor the speed of the system and each of the remote components at run time.

3.2 Usability

The speed of the endoscope augmentation system based on our software framework is 30 Hz and the overall lag of the system is below 100 ms. The speed of our head mounted display (HMD) based stereoscopic system with video see-through augmentation has also a frame rate of 30 Hz and an overall lag of less than 100 ms. In both cases the color camera technology is the limiting factor. Psychological research and our own evaluation suggest that this speed offers an efficient interaction with a visualization system.

Common visualization paradigms such as orthoview slices, arbitrary 3D slices, volume rendering, and instrument based navigation provide an intuitive start to any new system, since they are well known among surgeons and do not require prior segmentation by a doctor.

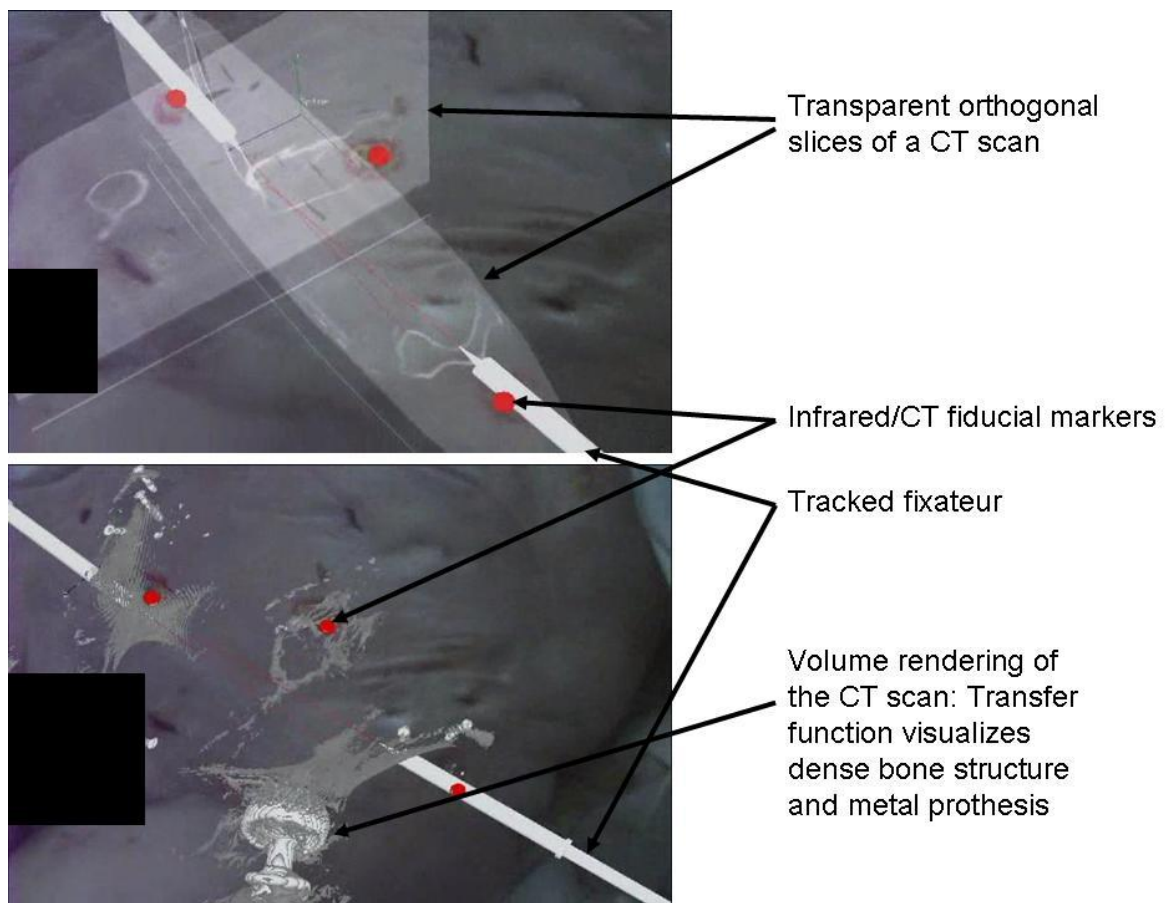


Fig 2. Cadaver studies with an HMD based system using the CAMPAR software framework

3.3. Interoperability

The data synchronization routines for data from different computers offer a smooth collaboration without changing or opening devices in the operating room. The open design of the software framework uses standard programming interfaces like OpenGL, OpenInventor, Cg, DICOM, and NTP. This offers compatibility to common and stable libraries.

3.4. Evaluation

The concept of the software framework proved to be a strong base for projects aiming at the operating room.

Applications and demos based on the framework have been presented to the scientific community [4]. Its maturity could be shown in two cadaver studies [5].

4. Conclusion

We present the requirements for the software for in situ visualization for surgeries and a software framework that meets all the requirements. We emphasize on the fact that visualization software in the operating room must ensure the reliability of the system, which mostly relates to the problem of synchronization of data. As important is the fact that an in situ visualization system must be easy to use in order to be accepted. The software framework CAMPAR offers primitives to support this. CAMPAR also offers primitives for accessing data of other hardware in the operating room.

This software framework has been realized in close collaboration with a team of surgeons and different applications have been realized and tested on cadavers using this software framework (Figs. 1, 2).

References

- [1] M. Bajura, H. Fuchs, and R. Ohbuchi. Merging virtual objects with the real world: seeing ultrasound imagery within the patient. In Proceedings of the 19th annual conference on Computer graphics and interactive techniques, pages 203-210. ACM Press, 1992.
- [2] F. Sauer, A. Khamene, and S. Vogt. An augmented reality navigation system with a single-camera tracker: System design and needle biopsy phantom trial. In Proc. Int'l Conf. Medical Image Computing and Computer Assisted Intervention (MICCAI), 2002.
- [3] W. Birkfellner, M. Figl, K. Huber, et al. A head-mounted operating binocular for augmented reality visualization in medicine—design and initial evaluation. IEEE Transactions on Medical Imaging, 21(8):991-997, 2002.
- [4] M. Feuerstein, S.M. Wildhirt, R. Bauernschmitt and N. Navab. Automatic Patient Registration for Port Placement in Minimally Invasive Endoscopic Surgery, Proceedings of Medical Image Computing and Computer-Assisted Intervention (MICCAI 2005), Palm Springs, USA, October 2005
- [5] J. Traub, P. Stefan, S. M. Heining, et al.. Stereoscopic augmented reality navigation for trauma surgery: cadaver experiment and usability study, Computer Assisted Radiology and Surgery (CARS 2006), Osaka, Japan, June 2006
- [6] A. P. King, P. J. Edwards, C. R. Maurer, Jr., et al.. A system for microscope-assisted guided interventions. IEEE Transactions on Medical Imaging, 19(2):94-102, 2000