Data-Fusion Display System with Volume Rendering of Intraoperatively Scanned CT Images

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Abstract. In this study we have designed and created a data-fusion display that has enabled volumetric MIP image navigation using intra-operative C-arm CT data in the operating room. The 3D volumetric data reflecting a patient's inner structure is directly displayed on the monitor through video images of the surgical field using a 3D optical tracking system, a ceiling-mounted articulating monitor, and a small size video camera mounted at the back of the monitor. The system performance was validated in an experiment carried out in the operating room.

1 Introduction

Recently, due to developments in clinical engineering, many types of equipment have become available in the operating room: vital signs monitors, anesthesia apparatus, artificial respirators and electric cauteries to count a few. They are essential to collect intraoperative electrocardiograms, breath rates, body temperature and blood pressure, and by exerting their functions they proved to be integral to performing successful operations. Further, in laparoscopic surgery, additional equipment like high intensity light sources, carbon dioxide insufflators, monitors and video recorders have been used; though all have been crucial to carry out the laparoscopic procedures, they also required additional space in the operation theatre [1]. Regarding imaging devices, a plain X-ray imaging device and an ultrasonic imaging system are sometimes introduced and used during operations. Moreover, in recent years, surgery navigation systems that utilize magnetic sensors or precise optical position sensors such as OPTOTRAK (Northern Digital Inc., Canada) have been studied in a number of surgical settings. In such technologies, however, position sensors and additional monitors to provide guided information for surgeons have been necessary. Feasibility and effectiveness of such systems has been pointed out in the literature and they have successfully assisted surgeons and reduced their fatigue caused by long operation hours.

On the other hand, accuracy and speed of the intraoperative navigation systems are important factors to consider. However, before these factors are taken

into account, usability of the whole system in the operating room environment, especially its ergonomic parameters and simplicity, require prioritization, since in the cluttered OR and with growing complexity of operative procedures, simply increasing the number of devices would not facilitate operations. Ergonomics of the environment, especially providing navigation data, prevention of technical difficulties and comfort of the OR staff should be firstly considered.

In the present study, we designed a data fusion display system and when prototyping devices for clinical use, their ergonomics as well as an easy-to-understand intraoperative display of navigation images were taken into consideration. A novel interface for advanced operation planning that was based on the guided images with volume rendering of intraoperatively scanned CT images rather than preoperative ones was also proposed. In recent years, intraoperative navigation, in which the target position is provided to assist an intuitive understanding of the surgical field has been studied and applied in many clinical areas [2][3], mainly orthopedics and neurosurgery. Position measurements of a surgical field have been usually performed with magnetic and marker-type optical position sensors, and preoperatively scanned CT or MRI images have been commonly used to represent inner structures. We believe that the time gap between acquisition of inner structure data and the actual operative procedures should be as short as possible for the correct depiction of the operated site. In this study, a mobile C-arm type CT (Siemens-Asahi Medical Technologies, Ltd.) was applied to acquire the inner structure data in the operating room; this provided the source of information for surgery navigation. In the literature [4], registration-free navigation with scanned images obtained by C-arm CT has been reported. This paper attempts to design and implement a data-fusion LCD display system for surgical navigation, which involves combining Maximum Intensity Projection MIP-based volumetric rendering of CT data, which was acquired intraoperatively from mobile 3D-CT device, with real-time views. A preliminary experiment was performed to validate the system.

2 Method

The functions desirable for an image presentation device that would be used as an intraoperative surgery navigation system were thought to be as follows:

1. It would be preferable if the image presentation device itself never limited the space required by other surgical equipment.
2. The image presentation device and position sensors should not interfere with the operative space. The position of the display monitor should be easily changeable and the monitor should be easily removable from the operative field when not used.
3. The monitor should be located in the vicinity of the surgical field. And it also allows the assistant on the other side reference to the same navigation images.
4. In order for a surgeon to better understand the spatial relations and directions between the surgical field and navigation images, the line of sight

for observing the surgical field and that for the navigation image should be correspondingly adjusted.

5. It would be preferable if cabling for the surgery navigation devices was not installed on the operating room floor.

To fulfill the abovementioned requirements, we considered that monitors and the position measurement device should hang from the ceiling of the operating room. Fig.1 shows a 3D CAD image of the positional layout of an optical position sensor, its measurement area, 5 monitor arms, and 4 shadowless lamps. The data-fusion display and optical position sensor were originally built into the operating room. This design enabled the minimalization of the operating room clutter, even when devices for surgery navigation had been installed. The monitors were mounted on 5 degrees-of-freedom multi-joint arms so that they could be observed from various positions and angles. Further, the layouts of the

Fig. 1. 3D CAD layout of data-fusion display and measuring range of ceiling-mounted OPTOTRAK in the operating room

Fig. 2. The High-Tech Navigation Operating Room

Fig. 3. The setup of a data-fusion display. The operator is grabbing and moving the monitor to the position from where he wants to observe the inner structure. A small video camera is inset in the backside of the monitor.

devices were carefully designed not to disturb the measurement area of the position sensor. The room was constructed as the High-Tech Navigation Operating Room in an operation building of the Dai-San Hospital, Jikei University, Tokyo, as shown in Fig.2. A report on the system was presented in MMVR13 [5].

The data-fusion display system was composed primarily of a 15-inch LCD monitor affixed to a ceiling-hung articulating arm and a small video camera installed at the back of the monitor. The system was equipped with a detachable sterilization lever; therefore it could be manipulated by a surgeon and positioned where it was most convenient for her to utilize the navigation data, i.e. in the immediate proximity of the surgical field. The left image in Fig.3 shows the data-fusion display and the right image shows the small video camera installed at the back side of the monitor. In order to capture the scene of the surgical field, a small color video camera, Dragonfly (Point Grey Research Inc., Canada) was used. Time-sequentially captured images were sent to a PC (Dual CPU: Xeon 2.8GHz, 2GB RAM, nVidia QuadroFX1000) through an IEEE1394 interface. This camera could collect stream VGA quality images at 30 frames per second without compression and was incorporated in the ceiling-hung LCD monitor thus providing "through"-the-monitor images for the operating surgeon. The position and direction of the monitor was constantly measured and tracked by the ceiling-hung optical 3D position sensor OPTOTRAK. Further, the system enabled surgeons to observe a patient's inner structure from the viewpoint of the monitor using VR augmentation with video see-through way during surgery.

In the present study, a mobile C-arm type CT was applied to acquire the inner structure data used as an information source for surgery navigation inside the operating room. To enable CT measurements during surgery, a non-metal operating table with dynamoelectric mobility characteristics (MAQUET GmbH & Co. KG) was incorporated. 3D volume data in 12 cm^3 was measured once with a scanning period of two minutes. The display of an acquired internal structure data was available immediately by volume rendering onto the video image of

Fig. 4. Configuration of the navigation system and key coordinate systems

the surgical field. As shown in Fig.4, key coordinate systems are that of OPTOTRAK as a global basis, the navigation display, and the volume data obtained by the C-arm CT. An optical marker flag is attached to the C-shaped frame of the CT, and its position during the measurement of volume data is obtained. The positional relationship between the marker flag and the data position of the C-arm CT should be calibrated once in the operating room. A cube-shaped gypsum block was used for the calibration of the C-arm CT data position. The cube-shaped gypsum was created using a rapid prototyping system (Zprinter, Zcorporation) with powder lamination technology, its shape was designed with a 3D CAD system and the physical model directly created from the digital data. The gypsum block was measured by the C-arm CT as shown in Fig.5(a), and the calibration was conducted using the corner position in the measured data coordinate and the corner position in the physical space obtained by OPTOTRAK. Finally, the transformation matrix between the marker flag of the C-arm CT and the coordinate system of the C-arm data itself could be solved. Fig.5(b) shows the result of the cube registration and fusion representation of the segmented cube surface model on the video images of the data-fusion display. After this calibration, the measured data position of the C-arm CT becomes a known parameter until the marker flag attached to the C-arm is repositioned.

Fig. 5. (a) C-arm CT images of a gypsum block; (b) Results of the cube registration and fusion representation of the cube surface model on the video images

3 Results and Discussion

For camera calibration of the data-fusion display, a checkered board was used. Its position was changed in pre-set time intervals and the respective images captured. The internal camera parameters and positional relationship between the camera coordinate and the marker flag attached to the display could be instantly obtained by image processing and computer vision algorithm. This was a very useful in calibrating parameters that could be executed quickly and easily in the operating room. For details on calculations and algorithms applied, we referred to the reports of Tsai [6] and Zhang [7].

Fig.6 shows the differential error between the detected checkered board corners in the captured images and the re-projected corners of the computed projection matrix on the image plane. The calibration was performed at about 700-800 mm distance from the display, assuming that the object was placed as during an operation. The graph shows results of error calculations when the image resolution was set as 360 240 pixels. The RMS error was 0.126 pixel. 35 points of the grid per one frame and the calibration was done with 22 captured frames. We believe that such accuracy in calibration with perspective matrix is sufficient for video see-through navigation. When intraoperatively scanned CT data was loaded into the data-fusion system, the volume data at 256 256 256 resolution was transferred through a gigabit network into the computer located in the operating room. Parallel processing of the display position tracking and rendering of the volume data with a 3D texture technique was implemented, and this method allowed a 12 fps update rate of the surgical field video images and the superimposed volume data. The operator was able to intuitively confirm the intraoperative inner structure obtained by the C-arm CT just by observing through the display, as shown in Fig.7(a). Fig.7(b) represents the augmented navigation image for an elbow joint depicted on the data-fusion display.

Head-mounted displays have been very common as image presentation devices for augmented reality. However, their prolonged usage causes fatigue and they also obstruct the operator's view. For operating room applications and by using a mobile ceiling-hung arm, our system enabled a surgeon to intuitively ob-

Fig. 6. Reprojection error of camera calibration

Fig. 7. Images of the volumetric navigation system for an elbow joint

Fig. 8. Time-sequentially generated images in the data-fusion display. The volume data of the mobile 3D-CT was superimposed onto the live video image according to the varying direction of the display.

serve a patient's inner structure from his viewpoint. Further, the devices could be easily removed from the proximity of the surgical field when the navigation was not necessary. Fig.8 shows time-sequentially generated images on a data-fusion display while changing the viewing direction. The volume data of the mobile 3D-CT was smoothly superimposed onto the live video images accordingly with the varying directions of the display. We assumed that the subject was static and that updating the data was limited due to reduction of radiation exposure. Thus, the data acquisition was conducted fragmentarily and with the minimal

possible amount of exposure. Furthermore, the time of one scanning time with the mobile 3D-CT was two minutes. In effect, the volume rendering image did not correspond to the deformation tracking. Even with such limitations, however, this kind of visual representation would be effective for intuitive confirmation of the static subject just after the performing the intraoperative measurements.

4 Conclusion

In the present study we designed and created a data-fusion display for clinical applications in the operating room. The system enabled volumetric MIP image navigation using intraoperative C-arm CT data. The 3D volumetric images reflecting a patient's inner structure were directly displayed on the monitor, which also simultaneously displayed the superimposed video images of the surgical field. In the system, a 3D optical tracking device, a ceiling-mounted articulating monitor and a small size video camera mounted at the back of the monitor were utilized. The system performance was validated in an experiment carried out in the operating room. In addition, it was very important and challenging for the system that the surgical navigation data was intraoperatively obtained and was not based on preoperative images. We think, however, that preoperative imaging will still be necessary because data resolution and measurement ranges were limited in the intraoperative imaging system. A combination of techniques that utilize several medical imaging modalities would be crucial for on-coming surgery navigation.

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