

Laparoscopic Virtual Mirror for Understanding Vessel Structure Evaluation Study by Twelve Surgeons

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ABSTRACT

In this paper we present the evaluation of a virtual mirror used as a navigational tool within a medical augmented reality (AR) system for laparoscopy. 12 surgeons of our clinical partner participated in an experiment to evaluate whether laparoscope augmentation extended by a virtual mirror is useful for improved perception of complex structures. Such complex structures are encountered for instance in laparoscopic resection of tumor affected liver tissue. The blood vessels supplying the tumor have to be cut and closed before tumorous tissue can be removed. A laparoscopic camera and an optical tracking system allow for the visualization of visualized medical volumetric data registered with the real anatomy. Previously injected contrast agent provides an accentuation of blood vessels within the visualization. For evaluating the suitability of a virtual mirror to support the mentioned procedure, we designed a phantom consisting of wooden branches simulating the structure of blood vessel trees. Quantitative results of the experiment show the advantage of a mirror in certain cases, when blood vessels cannot be directly seen from the camera point of view due to self-occlusion of the structure. Results of a questionnaire filled out by the surgeons after the experiments confirm the acceptance of AR technology for particular medical procedures.

Keywords: Augmented reality, navigated surgery, medical visualization, user interaction.

Index Terms: H.5.1 [Information Interfaces and Presentation]: Multimedia Information Systems—Artificial, augmented, and virtual realities; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Interaction styles; I.3.6 [Computer Graphics]: Methodology and Techniques—Interaction techniques; J.3 [Life and Medical Sciences]

1 INTRODUCTION

This paper presents a clinical evaluation investigating the perceptible advantage of a virtual mirror integrated into a laparoscopic augmented reality (AR) scenario. The evaluation focuses on the (partial) resection of organs or organ segments, e.g. of the liver, where blood vessels need to be closed before tumorous segments are removed. Therefore parts of tissue like tumor affected liver segments, but also complete organs have to be removed and affiliated blood vessels are closed.

Keyhole surgery using an endoscopic device to get a view on the operation site displayed on an external monitor is established in the ORs. Extending this technology with an AR system allows for the augmentation of the laparoscopic camera images with 3D visualization of medical imaging data. A contrast agent can be injected

into the blood circuit in the region of interest immediately before imaging data acquisition to highlight blood vessels. A suitable rendering technique enables 3D visualization of a local vessel structure from the volume data.

Feuerstein et al. [3] report the accuracy of a similar system setup for rigid targets and determined the error for target position (0.4mm RMS) and orientation (0.12) of tracking system in use, the navigation error (1.05mm RMS) and the augmentation error (1.58mm RMS). Regarding soft tissue, in most cases its pose and shape will change between data acquisition and surgical intervention. Even though data is acquired intraoperatively using e.g. a C-arm device, surgeons cannot rely on the accurate augmentation due to breathing, motion of organs like heartbeat, pushing and pulling tissue with surgical instruments and manipulation of the tension of tissue as cutting modifies its structure. Nonetheless, some basic characteristics of the structure like relative position and order of blood vessels, vessel size and branches remain in spite of all extraneous, deforming influences. Information about these characteristics can be used to plan the next step in the surgical workflow, for instance to decide where to cut next. In most cases such structure can be understood satisfactorily from the monocular point of view of the laparoscopic camera. Due to the user controlled navigation of the laparoscopic camera, the visual cues *occlusion* and *motion parallax* provide information about the depth order of structure elements. However, in the majority of cases the camera is controlled by an assistant while the surgeon is interacting with the instruments, which makes an intuitive exploration of the structure by moving the camera point of view almost impossible. Furthermore, the moving space of the camera is restricted to a limited number of ports providing access to the inside of the patient. In some cases the area of interest can not be seen directly from this restricted camera point of view. Hence, perceptive information about depth order of structure components is too insufficient to guide surgical instruments intuitively to the operation site. Figure 1 shows such a situation inside our phantom when a certain region of the structure, a red ball on the branch, is not directly visible even though the camera can be slightly repositioned. The mirror image provides the desired view on the area of interest.

1.1 Related Work

Endoscope augmentation was proposed for different medical applications like brain surgery [9], liver surgery [7, 3, 8], transbronchial biopsy [2] and cardiac surgery [5] to support different procedures in the surgical workflow such as port placement and navigation of instruments inside the patient. Fuchs et al. introduced a system for laparoscope surgery displaying data with a head mounted display [4] instead on an external monitor. However, all approaches only allow for one point of view to observe the AR scene. An entire exploration of objects such as complex blood vessel structures cannot be performed satisfactorily for further navigational steps during the intervention. The present paper reports a first evaluation of the already introduced concept of a laparoscopic mirror to explore hidden structures and support understanding of complex topology [6]. Another application for a virtual mirror, the preparation of canals

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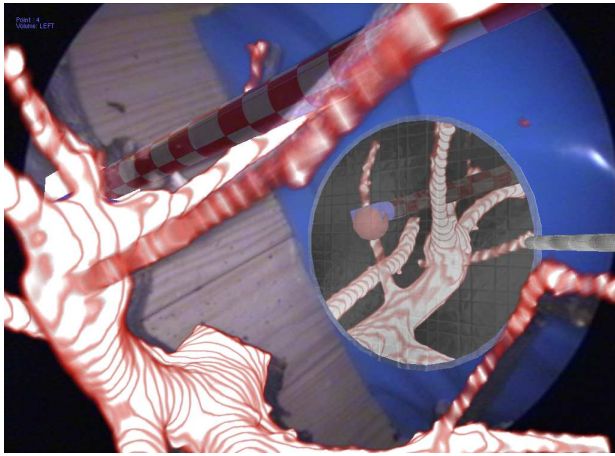


Figure 1: Instrument reaches a spot, which can only be seen thanks to the mirror. A blue plastic foil blocks the view to the second branch

for pedicle screw implantation in spine surgery, was presented in [1]. In that case a surgical drilling device is virtually extended by a mirror to control drill direction and depth.

2 METHOD

For visualization of volumetric imaging data (CT) registered with the phantom, an optical tracking system and a laparoscopic camera is used. All components of the experimental setup will be described in the following section.

2.1 Laparoscope Augmentation

Our AR system used for laparoscope augmentation is described in [6]. For the present experiment, we augment the recorded video images of laparoscopic camera (figure 2) with the visualized volumetric CT data of a phantom. Volume data is visualized using a CG¹, 3D texture based, view aligned volume renderer and a 1D transfer function for the allocation of voxel color and transparency.

In addition to the visualization of volumetric imaging data, virtual entity of the AR scene includes an augmented surgical instrument and the virtual mirror. For spatial localization of the tracking targets, that means the laparoscopic camera, a surgical instrument and the phantom, we use an optical tracking system consisting of four infrared tracking cameras². The tracking cameras are attached to a frame at the ceiling in our lab and cover a tracking volume of approximately $2.5m^3$. The tracking targets, each consisting of a set of at least four retroreflective spherical markers, are located respective a predefined world coordinate system. Functionality of synchronization and visualization is provided by the medical augmented reality framework CAMPAR [10] on our augmentation workstation³. All code was implemented using C++ and OpenGL⁴. The used laparoscope has 30° optics (telecam SL ntsc, KARL STORZ GmbH & Co. KG) and is equipped with a standard light source.

2.2 Phantom

The phantom (figure 3) consists of a wooden box with 6 retro reflective CT markers attached to the upper border of the box. We installed two branches inside the box, separated them visually for

¹C for Graphics, high-level shading language created by NVIDIA.

²ARTtrack2, A.R.T. Weilheim GMBH

³Intel Xeon(TM), CPU 3,20 GHz, 1,80 GB RAM, NVIDIA Quadro FX 3400/4400

⁴Open Graphics Library - www.OpenGL.org



Figure 2: Laparoscopic camera (upper image) & surgical instrument (lower image). Both instruments are equipped with a marker tree to make it trackable by our outside-in tracking system.

the laparoscopic camera by a plastic foil and scanned the whole phantom with a CT imaging device. The visualization of the two branches registered with the phantom is separated virtually by clipping planes. During the experiment the box is closed with a wooden plate that consists of twelve holes for each branch used as ports to the inside of the box. After the CT scan we defined 5 spots for each volume, which are visualized as a sphere colored slightly different than the visualization of the branches.

2.3 Experiment

The experiment compares two visualization modes *ViNoMir* (augmented branches) and *ViMir* (augmented branches including the mirror). For *ViMir*, the mirror is installed 165mm in front of the endoscopic camera and oriented 45° towards the point of view (figure 4). The mirror can be placed at four different positions (left, right, top, bottom), whereupon the center of the mirror is moved orthogonally 70mm away from the view axis of the laparoscopic camera according to the respective position. The virtual mirror reflects the visualized branches as well as the virtually extended surgical instrument. The background of the reflected scene is black. A textured cylinder connecting the mirror with the camera provides visual cues about the spatial position of the mirror respective the camera position. The reason for the evaluation of two visually sep-



Figure 4: Illustrative view on the mirror attached to the camera.

arated different tree structures is to avoid learning the structure of



Figure 3: Two wooden branches are installed on the bottom of the box. The closed box provides twelve ports to each branch.

one branch while working with the first visualization mode and using this knowledge for the second visualization mode. The AR scene is presented on a monitor positioned in the working space of the subjects as shown in figure 5. Every subject had to reach five spots for each of the two branches. For every target spot, we predefine one of 12 ports, which has to be used for the laparoscopic camera. The selected ports only provide a restricted view on the target spot due to self occlusion of the branches. The surgical instrument can be inserted through an arbitrary port. The combination and order of branches and the visualization mode changed for every subject. When subjects reach the target spot they ask the investigator to lock the result to measure time and accuracy. Overall 12 surgeons participated and 60 spots were analyzed. Before a subject starts the experiment, we provide the following information:

The instruments you are using are a laparoscopic camera and a surgical instrument. The camera images can be augmented with virtual objects by our AR system. Wooden branches simulating a complex structure were installed inside the box. We made a CT scan of the phantom and visualize the imaging data in 3D registered with the phantom. You have to reach visualized spots, small red spheres, on the structure. We compare two different visualizations each on a different structure: Augmented structure only and augmented structure plus virtual mirror. The mirror is positioned 165mm in front of the laparoscopic camera and oriented 45° towards the camera. The mirror can be repositioned at four different locations by request (left, right, top, bottom). The camera can only use one port to get a view to the inside of the box. Start position of the camera for every new point is the entry of a port. For the surgical instrument, you can use arbitrary ports. Please do not pull or push too hard to avoid breaking the branches! We measure time and accuracy. Before we start, you will test the system with an augmented dummy object.

Immediately after the experiment, we asked the subjects to fill out a questionnaire.

3 RESULTS

The quantitative results are valid for particular situations when the view on the region of interest is restricted by a small degree of freedom of the laparoscope camera due to a limited number of ports. Accuracy is measured virtually. Therefore a predefined, constant error has to be taken into account composed by the tracking error and the manually designed virtual clamp, which does not exactly conform to the real clamp of the surgical instrument.

After outliers deviating 3 times the STD from AVG where excluded, overall measuring data of 106 spots, 54 *ViNoMir* and 52 *ViMir*, was analyzed. Results show that subjects guide the instrument with higher accuracy to the predefined target spot using the *ViMir* mode. However, using the *ViNoMir* mode takes less time (see table 1). We also analyzed xyz distances from the spot to the tip of the instrument relative to the instrument coordinate system with z as the instrument axis. Comparing the two visualization

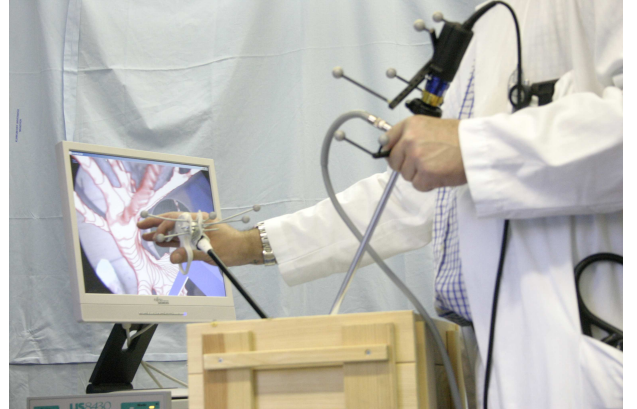


Figure 5: Subject is guiding the surgical instrument using the video images of the laparoscopic camera presented on a monitor.

Table 1: Tendency of measured data given as AVG(STD) shows higher accuracy using the virtual mirror based method.

mode	dist	time
<i>ViNoMir</i>	14.29mm(5.28)	69.70sec(64.45)
<i>ViMir</i>	13.45mm(4.79)	87.49sec(82.20)

modes, measured distances in x and y direction differ not significantly ($x = 0.84mm$, $y = 0.38mm$), however in z direction difference of distances is $x = 1.64mm$. We assume that the view along the instrument axes without using a mirror does not provide sufficient visual information for position control.

Occlusion effects tell subjects when they reach the target spot with the instrument. However we notice an interesting effect during the experiment when surgeons have problems to reach a spot due to physical barriers because of the branches. When the tip of the instrument is already close to the target, they rather stop and ask to lock the result than keep on trying to move the clamp to the correct position. By contrast using the mirror to get an additional view on the target, motivation increases to keep on trying until both perspectives, the direct view and the mirror image, prove to have successfully located the spot.

Ten male and 2 female subjects (AVG age: 32, AVG work experience: 5.8 y) filled out the questionnaire. The scale of the multiple choice questionnaire was 1 = I strongly agree * 2 = I agree * 3 = I am undecided * 4 = I disagree * 5 = I strongly disagree. Results are given as AVG(STD).

- "The augmentation of blood vessels with or without the mirror provides no advantage during the intervention." - 3.82(0.72).

- "The system is useful to understand the structure of blood vessel trees even though an exact overlay of virtual and real blood vessels can not be guaranteed" - 1.81(0.57).
- "The position of the mirror in front of the camera restricts the view on my work space and therefore is not helpful" - 4.0(0.43).
- "Position of the mirror reduces my view on the work space, however the additional visual information provided by the mirror image to locate the surgical instrument and to understand the structure of blood vessel trees is beneficial" - 1.91(0.51).
- "Augmentation of the 3D structure including the mirror provides an advantage compared to the classical visualization of CT data on a monitor." - 1.91(0.79).
- "The augmentation of blood vessels without the mirror is more helpful" - 3.73(0.86).
- "An additional mirror positioned anywhere within the scene is restricting my view and provides no advantages" - 4.27(0.62).
- "Do you think that the experiment setup is capable to simulate the real medical intervention sufficiently?" - 2.73(1.05).

In general subjects believe in the perceptive advantage of laparoscope augmentation. They also support a virtual mirror to get additional views on the operation site even though their field of view is partially hindered by the additional object. Suggestions of the surgeons to use such an AR system range from all types of laparoscopic surgery like cholecystectomy and adrenalectomy to advanced control of oncologic surgery in resection of colon and rectum and lymphadenectomy. Furthermore arthroscopic surgery, minimally invasive spine surgery and neurosurgery were mentioned. Surgeons can imagine to use the virtual mirror for visualization of 3D datasets in all procedures where currently 2D monitor control is performed: laparoscopy, arthroscopy, thoracoscopy and even procedures using flexible endoscopes.

4 DISCUSSION

Creation of a reproducible phantom fulfilling all the conditions to simulate a realistic anatomical environment for such an experiment is quite difficult. In a real scenario a direct view on the blood vessels is not possible. In addition, tissue is deformed during the procedure and an accurate, stable registration can hardly be guaranteed. Regarding liver resection, physicians have several visual hints to locate a certain liver segment for instance due to the pose of the patient, recognized organs around the operation site and shape of the liver. The present phantom is not capable of simulating such visual hints. However, we assume that the phantom providing limited access to a closed, non-deformable body is suitable to evaluate visualization modes respective their efficiency for understanding the topology of structures like blood vessel trees. Regarding the novelty of the mirror concept, we assume that performance of *ViMir* can be improved after a certain training phase. After the experiment, we asked surgeons to propose ideas to improve the experimental setup. Surgeons suggested inserting a deformable tree-like structure into Leberkaese⁵ and bake it in a pan shaped like a liver or hiding the structure under granulate material to restrict the direct view.

5 CONCLUSION

This paper presents the evaluation of a virtual mirror for laparoscope augmentation. We invited 12 surgeons of our clinical partner to participate in an experiment and fill out a questionnaire. For evaluating the suitability of the visualization of medical imaging

⁵special German, Austrian food consisting of fine grinded beef, bacon and onions. Everything is baked as a loaf in a bread pan.

data registered with the real environment including the virtual mirror to understand complex anatomical structures like blood vessel trees, we designed a phantom consisting of wooden branches simulating such structures. Quantitative results show that the mirror could improve the accuracy in particular along the instrument access. The procedure takes longer using the mirror, however the physicians do not mind this since they are provided with more visual information to control the position of instruments. Especially in certain situations when blood vessels can not be directly seen from the camera point of view due to self-occlusion of the structure the mirror provides perceptive advantages. Results of a survey performed immediately after the experiment suggest the suitability of AR technology and a virtual mirror for a number of medical procedures.

ACKNOWLEDGEMENTS

We would like to thank the radiologists and surgeons of Klinikum Innenstadt, München, Germany for their precious contribution in obtaining medical data and participating in the experiment. Thanks also to Joerg Traub, Marco Feuerstein, Tobias Sielhorst and Julia Duenzl for their support.

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