Creating a Vision Channel for Observing Deep-Seated Anatomy in Medical Augmented Reality

A Cut-Away Technique for In-Situ Visualization

Felix Wimmer[1], Christoph Bichlmeier[1], Sandro M. Heining[2], Nassir Navab[1]

[1]Chair for Computer Aided Medical Procedures (CAMP), TU München, Germany
[2]Trauma Surgery Department, Klinikum Innenstadt, LMU München, Germany
felix.wimmer@gmail.com

Abstract. The intent of medical Augmented Reality (AR) is to augment the surgeon's real view on the patient with the patient's interior anatomy resulting from a suitable visualization of medical imaging data. This paper presents a fast and user-defined clipping technique for medical AR allowing for cutting away any parts of the virtual anatomy and images of the real part of the AR scene hindering the surgeon's view onto the deep-seated region of interest. Modeled on cut-away techniques from scientific illustrations and computer graphics, the method creates a fixed vision channel to the inside of the patient. It enables a clear view on the focussed virtual anatomy and moreover improves the perception of spatial depth.

1 Introduction

Using Augmented Reality (AR) for in-situ visualization of medical data has been a subject of intensive research during the last two decades [1, 2]. The objective of this research is the use of AR technology for preoperative diagnoses and surgical planning as well as intraoperative navigation. The purpose of medical AR is to augment the surgeon's real view on the patient with the patient's interior anatomy. A stereo video see-through head mounted display and an external optical tracking system allow for precise registration of visualized medical imaging data such as computed tomography (CT), magnetic resonance imaging (MRI) and ultrasound with the patient [3].

Improving data presentation for correct perception of depth, relative distances and layout of "hidden and occluded objects", for instance the position of anatomy inside the human body from the surgeons point of view, is a major issue in AR [4, 5]. In one of the first publications [6] about medical AR, Bajura et al. already identified the problem of misleading depth perception when virtual anatomy occludes the patient. To handle the problem, they render a "synthetic hole [...] around ultrasound images in an attempt to avoid conflicting visual cues".

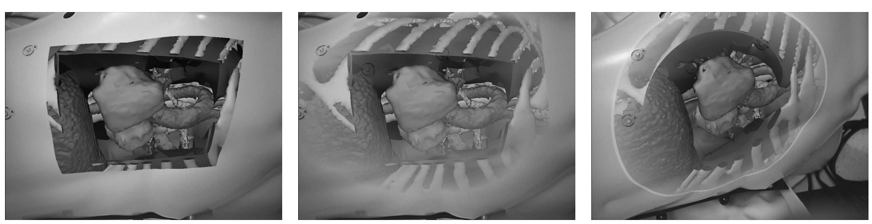
Following this model of creating a virtual hole inside the body of the patient, we developed a fast and user-defined clipping technique, which enables the user to cut away parts of the virtual anatomy and the camera image. The method allows for a clear visibility of the focussed virtual anatomy and furthermore improves the perception of spatial depth. In a preparative step the medical imaging data is segmented into a region of the anatomy the user is interested in (the focus) and an unimportant region. The user defines and positions a volume cutting away all parts of the pre-segmented unimportant region lying inside of it. The pre-defined focus region is not clipped and remains inside the volume. Shape and size of the clipping volume can be defined individually by the user. The remaining part of the unimportant region outside the volume and the borders of the volume provide context information and thus positional and depth cues.

Medical imaging data usually includes a barrage of information. The present cut-away technique is capable of reducing this information to an important fraction of the data set and to reveal the view onto the focussed anatomy. We combine cut-away views known from technical and medical illustrations and various approaches in the field of computer graphics [7, 8, 9] with the beneficial potentials of medical AR technology.

2 Materials and Methods

Medical imaging data taken from a CT or MRI scan is presented using a stereoscopic video see-through HMD. The entire tracking system allowing for tracking the HMD, the patient and several surgical instruments is described in detail at [10]. We use pre-segmented surface models to visualize the anatomy.

The application of the present cut-away technique is illustrated in Figures 1. Different shapes can be used for the clipping volume. Figures 1 (a) and (b) show a box and Figure 1 (c) a sphere used as clipping volume. The clipping technique is intended to be applied in conjunction with a technique described at [10] used to modify the transparency of the camera image. Figure 1 (a) shows a clipping box without integrating the transparency modulation technique (ghosting), whereas Figures 1 (b) and (c) illustrate the combination of clipping volumes and the transparency modulation technique.



(a) (b) (c)

Fig. 1. Cut-away with Volume Clipping: (a) using a box as the clipping volume, (b) the clipping box in conjunction with ghosting of the skin [10] and (c) the usage of a clipping sphere in conjunction with ghosting of the skin [10]

The present technique generates a depth map by grabbing the depth buffer after off-screen rendering of the skin and the chosen clipping volume. This depth map is used to clip objects in the scene by performing a depth test in a shader program.

2.1 Setting up Size and Position of the Clipping Volume

When using a box for clipping, the user is able to interactively define the coordinates of each vertex of the box by key-pressing, mouse movement or movement of his head (see Figure 2 (a)). If a sphere or a cylinder has been chosen, the user can define the position and the radius of the volume. When the user found the right location and size of the volume, it can be fixed permanently to this position.

2.2 Generation of the Clipping Depth Map

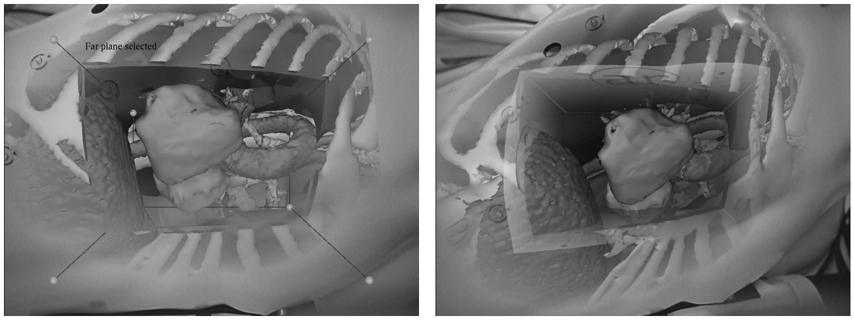
In order to generate the depth map, first all buffers are cleared and the skin is rendered to the depth buffer. Afterwards the depth test is flipped, which means that fragments pass the depth test, that have a higher depth value than those, which are already in the depth buffer. Consequentially the clipping volume is rendered to the depth buffer. The depth values of the clipping volume are stored in the depth buffer at the corresponding pixel positions, if they are greater than those of the previously rendered skin. Additionally the stencil bit[1] is set at the corresponding pixel positions. The resulting stencil mask is used to clip the camera image and to display the volume. The depth values of the skin remain in the buffer at all pixel positions where they are bigger than the depth values of the clipping volume. The resulting depth buffer is stored to a designated buffer called depth map.

2.3 Clipping of Virtual Anatomy and the Camera Image

A render mode chosen by the user determines, if a segmented virtual object should be clipped or not and thus if it should be a focussed object or not. When rendering an object that should be clipped, a fragment shader program is performing a second depth test in addition to the standard depth test, using the previously created depth map as an input parameter. This shader performs a lookup into the depth map at the screen coordinates of the fragment and compares the received depth value with the depth value of the fragment. If the depth value is smaller (closer to the eye), the fragment is discarded. For this reason every fragment, which has a smaller depth value than the corresponding fragment of the clipping volume is discarded and thus the part of the dataset lying inside the clipping volume is clipped.

[1] The stencil buffer is an additional buffer beside the color buffer and depth buffer, and available on usual modern computer graphics hardware.

Fig. 2. (a) Setting up the clipping volume and (b) texturing the clipping volume



(a) (b)

The camera image gets only clipped, if the clipping volume is not used in conjunction with ghosting of the skin. If applied without ghosting of the skin, the generated stencil mask can be utilized to display the camera image only at those screen positions where the stencil bit is not set. In this way, every part of the skin lying inside the clipping volume is clipped and a window on the skin is generated offering the depth cue occlusion for improved perception of virtual anatomy (see Figure 1 (a)).

2.4 Displaying and Texturing the Clipping Volume

In order to provide further depth cues, the borders and planes of the clipping volume can also be displayed. Therefore, fragments of the clipping volume lying in front of the skin are removed using the generated stencil mask. The borders of the clipping volume can be displayed in a semi-transparent or opaque way. Shading and texturing the clipping volume provides further context information for perceiving the focussed anatomy. Figure 2 (b) illustrates these effects. Here a semi-transparent texture showing a linear gradient from white (close to the observer) to dark (distant to observer) was chosen to improve depth estimation.

3 Results

We used a thorax phantom to evaluate qualitatively the present visualization technique. Originally, the phantom only consisted of a spinal column installed inside the phantom. However, we extended the virtual anatomy by surface models segmented from the Visible Korean Human (VKH)[2] data set. Virtual models are registered manually with the thorax phantom, which is in our case sufficient for evaluating the visualization method.

[2] The Visible Korean Human project provides different full body data sets: CT, MRI and anatomical images http://vkh3.kisti.re.kr/new

4 Discussion

The present method uses polygonal surface models to allow for real time visualization. Surface models have to be segmented and triangulated before the visualization can be performed. Future work will include the integration of this approach into a ray cast based volume renderer to be able to render volumetric CT or MRI data directly without time wasting, preparative steps. However, such a rendering technique requires powerful hardware to obtain real-time rendering.

Acknowledgement. We want to express our gratitude to the radiologists and surgeons of Klinikum Innenstadt München, Frank Sauer, Christopher Stapleton, Mohammad Rustaee and the NARVIS group for their support. This work was granted by the BFS within the NARVIS project (www.narvis.org).

References

1. Cleary K, Chung HY, Mun SK. OR 2020: The operating room of the future. Laparoendosc Adv Surg Tech. 2005;15(5):495–500.
2. Peters TM. Image-guidance for surgical procedures. Phys Med Biol. 2006;51(14):R505–R540.
3. Sauer F, Khamene A, Bascle B, et al. Augmented reality visualization in iMRI operating room: System description and pre-clinical testing. Proc SPIE. 2002;4681:446–54.
4. Furmanski C, Azuma R, Daily M. Augmented-reality visualizations guided by cognition: Perceptual heuristics for combining visible and obscured information. In: Proc. IEEE and ACM Int'l Symp. on Mixed and Augmented Reality (ISMAR). Washington, DC, USA: IEEE Computer Society; 2002. p. 215.
5. Sielhorst T, Bichlmeier C, Heining S, et al. Depth perception a major issue in medical AR: Evaluation study by twenty surgeons. Lect Notes Computer Sci. 2006; p. 364–72.
6. Bajura M, Fuchs H, Ohbuchi R. Merging virtual objects with the real world: Seeing ultrasound imagery within the patient. Proc SIGGRAPH. 1992; p. 203–10.
7. Feiner S, Seligmann DD. Cutaways and ghosting: Satisfying visibility constraints in dynamic 3D illustrations. Vis Comp. 1992;8(5&6):292–02.
8. Diepstraten J, Weiskopf D, Ertl T. Interactive cutaway illustrations. Comp Graph Forum. 2003;22(3):523–32.
9. Weiskopf D, Engel K, Ertl T. Volume clipping via per-fragment operations in texture-based volume visualization. In: Proc IEEE Vis. Washington, DC, USA: IEEE Computer Society; 2002. p. 93–100.
10. Bichlmeier C, Wimmer FJ, Heining SM, et al. Contextual anatomic mimesis: Hybrid in-situ visualization method for improving multi-sensory depth perception in medical augmented reality. In: Proc. IEEE and ACM Int'l Symp. on Mixed and Augmented Reality (ISMAR); 2007. p. 129–38.