Virtual Tomography: A New Approach to Efficient Human-Computer Interaction for Medical Imaging

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ABSTRACT

By utilitzing Virtual Reality (VR) technologies the computer system virtusMED implements the concept of Virtual Tomography for exploring medical volumetric image data. Photographic data from a virtual patient (The Visible Human) as well as CT or MRI data from real patients are visualized within a virtual scene. The view of this scene is determined either by a conventional computer mouse, a head-mounted display or a freely movable flat panel. A virtual examination probe (analogy: medical ultrasound probe) is used to generate oblique tomographic images which are computed from the given volume data. In addition, virtual models can be integrated into the scene such as anatomical models of bones and inner organs. virtusMED has shown to be a valuable tool to learn human anatomy and to understand the priniciples of medical imaging such as sonography. Furthermore its utilization to improve CT and MRI based diagnosis is very promising. Compared to VR systems of the past, the standard PC-based system virtusMED is a cost-efficient and easy maintainable solution providing a highly intuitive time-saving user interface for medical imaging.

Keywords: Human-computer interaction, sonography training, medical education, CT, MRI, Visible Human, virtual reality, 3D visualization, virtual tomography

1. INTRODUCTION

In today's computerized medical imaging, user interfaces mostly are based on the traditional keyboard/mouse approach. Especially when exploring three-dimensional data, this is often a critical limitation. Different efforts have been undertaken to solve the problem of inappropriate human-machine-interfaces. Computer systems utilizing Virtual Reality (VR) technologies have the potential to provide fast access to 3D data. Unfortunately, VR solutions of the past suffer from being complex and expensive. Thereby, costs are incurred for hardware, maintenance and preparatory training. Low-cost solutions like 3D mice, shutter glasses etc. often do not overcome the mouse/keyboard limitations significantly enough.

In the following, the low-cost system "virtusMED" (*Virtu*al *S*cenes for *M*edical *E*ducation and *D*iagnosis) [1,2,3] is described, which provides a highly intuitive, time-saving human-machine interface for the exploration of arbitrary volumetric image data. Based on simple and established VR technologies virtusMED implements the concept of Virtual Tomography. The system was primarily developed to improve medical education, such as learning human anatomy, ultrasound training and continuing education in surgery. Furthermore, it can be used for diagnostic purposes, especially surgical planning.

2. METHODS AND MATERIALS

virtusMED visualizes volumetric image data such as computed tomography (CT) and magnetic resonance imaging (MRI) data within a three-dimensional virtual scene. The view of this scene is determined either by a conventional computer mouse, a head-mounted display or a freely movable flat panel. Main user interface is a virtual examination probe, which is designed similar to a medical ultrasound probe. The motion of the probe is captured by an electromagnetic tracking system. By relocating and rotating it, oblique slice images are generated which are reconstructed in real-time from the given data. In addition, virtual 3D models can be integrated into the scene.

For educational use, data from the Visible Human Project [4] is utilized in addition to CT and MRI data. A virtual patient is reconstructed from the original photographic slice images and CT data. Also, segmentation data from the Voxelman project [5] is integrated to compute virtual anatomical models (bones and inner organs). Fig. 1 and 2 show

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two examples of virtual scenes based on the Visible Human data set. Fig. 3 shows the according user scenario for education.

For clinical use, patient-related radiological image data in DICOM [6] format can be loaded into the system. Virtual models are computed from these data using algorithms based on thresholding.

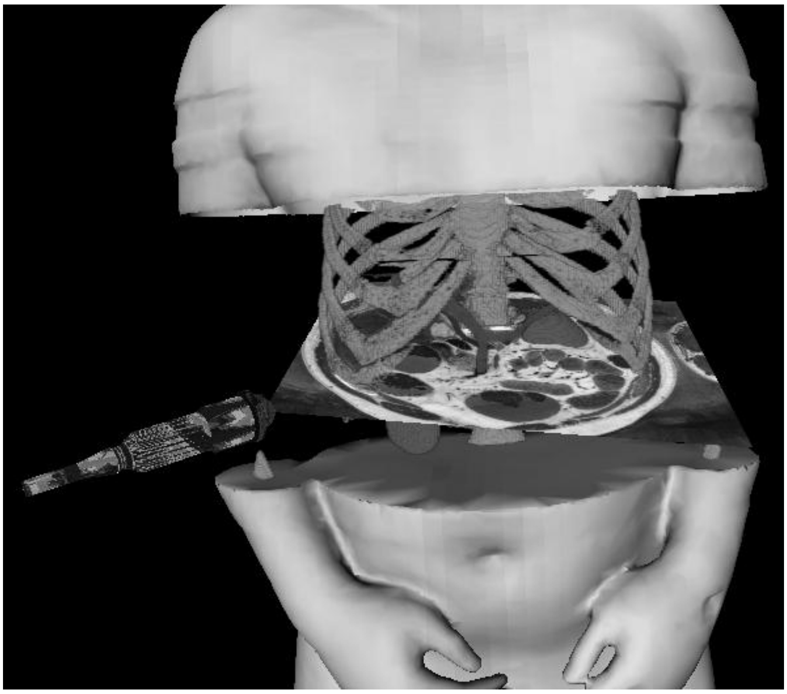

Fig. 1 Data from the Visible Human Project is utilized to create a virtual patient for educational purposes. An oblique reconstructed photographic slice image is defined by the virtual probe. Virtual anatomical models (skin, bone structures, kidneys, vessels) are shown in addition.

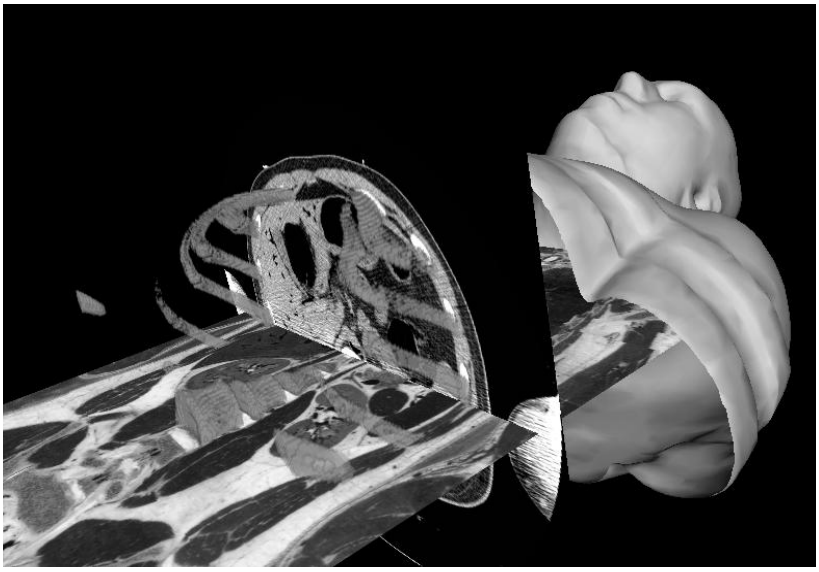

Fig. 2 Understanding the principles of medical imaging: The virtual scene shows one photographic slice image (coronal) together with a CT slice (transverse). In addition, 3d models of bone structures and skin are visualized.

When exploring the 3D data several options are available. Multiple slices can be visualized simultaneously and region of interests can be volume-rendered and optionally be displayed translucently or clipped by the current slice [Fig. 2, 5 and 6]. Furthermore, the current slice can be displayed as planar image, thus basically simulating the visualization of a conventional 2D ultrasound device (Fig. 4).

Fig. 5 shows an example of exploring MRI data. In this case a model of the patient's head is computed from the original data to serve as orientation for the user when navigating in 3D. The model is volume rendered and clipped by the current slice.

How to assess CT data is shown in Fig. 6. The hip of a patient with an acetabular fracture is visualized together with different slice images. CT data can be visualized in an alternative way, which is illustrated in Fig. 7. Virtual radiographs are computed from the same data set which is visualized in Fig. 6. To produce these images the user can define

Fig. 3 Learning human anatomy: Using a photographic sketch of the human body, the student can examine a virtual patient. On the screen arbitrary slice images are presented within a virtual 3d scene. Main user interface to produce these slices is the virtual examination probe which can be used like a medical ultrasound probe.

Fig. 4 Visualizing a slice image as planar image to simulate the way of visualization known from ultrasound.

a point of view either by using the conventional mouse, the probe or the freely movable flatpanel. Fig. 8 demonstrates the use of the flatpanel. By moving it around freely in space any x-ray image can be produced, thus simulating a real radiography or fluoroscopy examination.

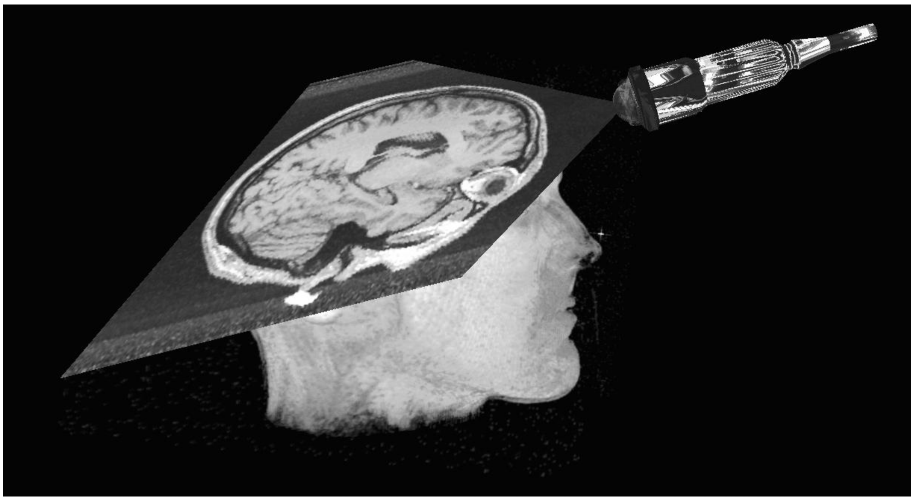

Fig. 5 Exploring MRI data of a head with the virtual examination probe. The current slice truncates the virtual model of the head, which is computed from the original data by thresholding.

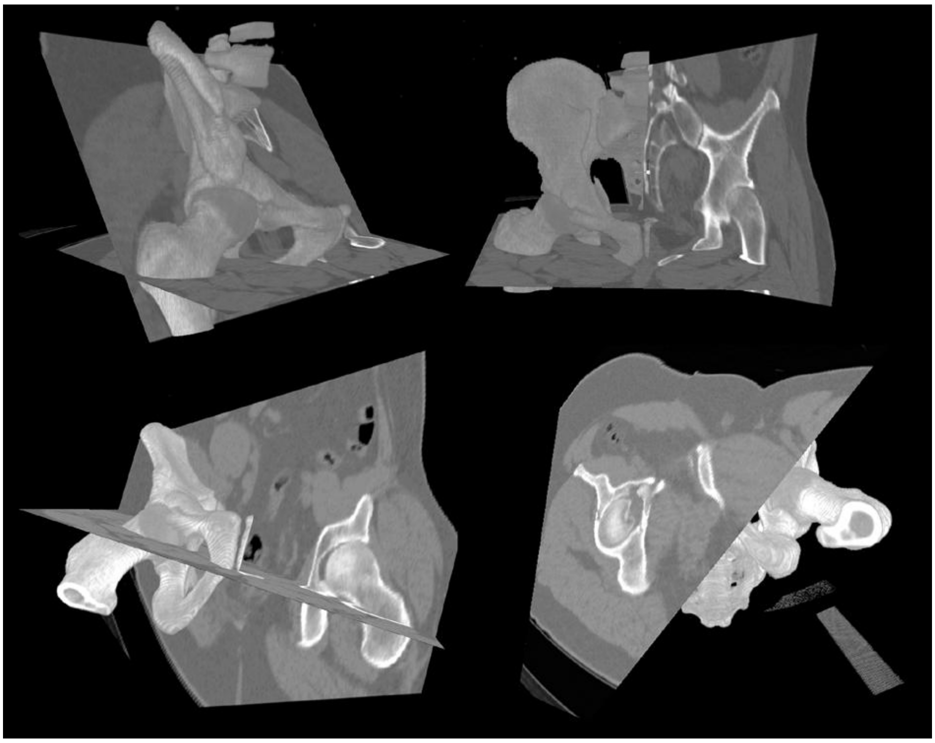

Fig. 6 Acetabular Fracture: Presenting a computed tomography dataset within the virtual 3D scene. The original image data is volume rendered after a threshold has been applied. Arbitrary slice images can be visualized in addition, optionally clipping the displayed volume.

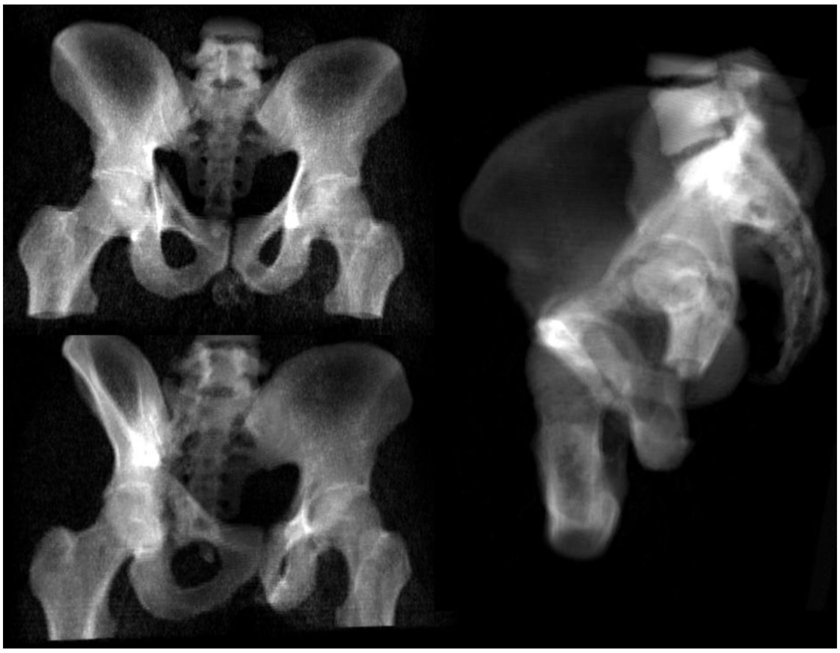

Fig. 7 Virtual x-ray images computed from CT data. In contrast to a real examination any desired view can be achieved in virtuality. The data shown here is the same as used in Fig. 6.

Fig. 8 Using a freely movable flat panel to produce virtual radiographs, e.g. for CT-based diagnosis and case presentation in trauma surgery.

Using a head-mounted display the user can define the view of the virtual 3D scene just by moving his head or walking around. Fig. 9 illustrates the according user scenario. In addition to the HMD the probe is used simultaneously to gain access to any desired detail in short time.

For diagnostic purposes a special version of virtusMED was developed allowing to use the virtual probe for every kind of user interaction. Fig. 10 shows the setup of this system. Two screens are used to display the 3D scene and the current slice image as 2D planar image at the same time. Two buttons are attached to the probe, which are used to move the whole data set within the virtual scene, to define multiple slice images and to perform several context-related tasks such as loading and saving data or changing parameters.

Fig. 9 Using a head-mounted display with virtusMED. The user can define the view of the 3D scene by moving his head around. In addition he uses the probe to generate arbitrary slice images.

The system is realized using a standard PC (Pentium IV, 1.500 MHz, 1 GByte of main memory, GeForce3-based graphics card) and a common electromagnetic motion tracking system. Graphics programming is based on OpenGL. Technologies have been applied that were derived from the development of a virtual reality system for echocardiography (ultrasound diagnosis of the heart) [7].

3. RESULTS

The system was applied for learning human anatomy in addition to conventional teaching material such as books or multimedia CD-ROMs [Fig. 3]. It shows out, that it especially helps to improve the understanding of spatial relationships. The system was also successfully tested for sonography training. Furthermore virtusMED was used for continuing education in surgery within courses of the surgical association AO international [8]. 40 trauma surgeons have been interviewed and judged the use of the system for such purposes with an average score of 1.65 on a scale from 1 (very useful) to 6 (not useful at all).

Regarding the use for diagnostic purposes, an evaluation of the benefit of using virtusMED is currently undertaken. First results show that in trauma surgery the visualization of oblique slices which truncates a virtual bone model [Fig. 6, lower right-hand] and the virtual x-ray feature [Fig. 7] were judged as helpful for diagnosis of traumatic bone fractures and corresponding surgical planning.

Also, a survey of radiologists was done. It showed out that virtusMED has the potential to improve tumor diagnostics (e.g. larynx carcinoma), whenever spatial assessment is of major importance, and to ease and speed up case demonstrations.

When the first prototype of virtusMED was demonstrated at the 87th annual meeting of the Radiological Society of North America (RSNA) [9] in November 2001, it received highly positive feedback and was judged the best of 105 R&D exhibits with the magna cum laude award. 98 attendees were interviewed. They were asked to judge the usefulness of the system on a scale from 1 (not useful at all) to 5 (very useful). 40 radiologists judged 4,55 in average, 32 other physicians judged 4,28 in average and 22 technicians judged 4,09 in average. In December 2002 the new diagnostic version of virtusMED (Fig. 10) gained the cum laude award from the RSNA (highest category together with four other software systems among 131 presentations).

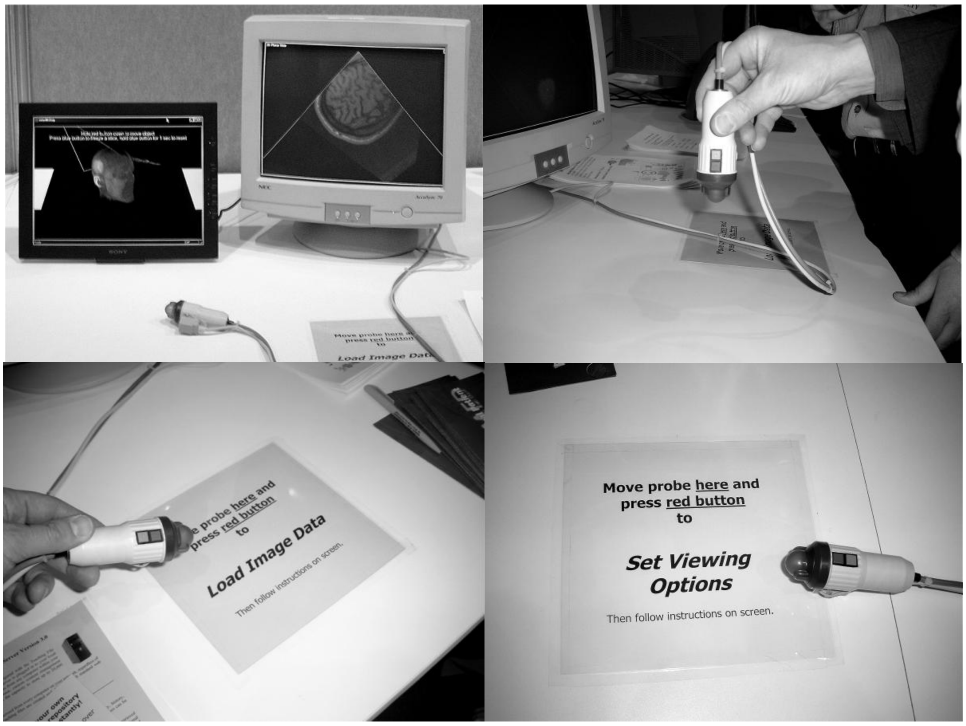

Fig. 10 Using virtusMED for diagnostic radiology. One screen presents the virtual 3D scene, while another simultaneously presents the current slice as planar image. Using two buttons on the probe, any interaction can be done: Loading image data, changing viewing parameters, moving the virtual objects and producing multiple slices (demonstration at RSNA 2002).

4. DISCUSSION

The idea of combining virtual reality techniques and medical imaging is probably as old as virtual reality itself. Still, a breakthrough is missing due to complexity and costs of VR systems. virtusMED represents a low-cost system which is based on common and approved components. It is easy to install, to handle and to maintain. The virtual examination probe has shown to be a simple, but very valuable human-machine interface to gather information about any volumetric data - a tool which is not known yet in medical imaging.

The positive results state that virtusMED has the potential to provide a totally new way of handling medical image data. On the one hand, virtusMED offers affordable virtual reality based learning and training in health care. It has been shown to be a very valuable tool for learning anatomy and sonography. On the other hand, time-saving and/or more precise image based diagnoses could be made possible through a tool beyond the common radiology workstations which are crucially based on the use of keyboard and mouse. Although clinical evaluations still have to be completed, there is a strong hint that virtusMED can significantly improve diagnostic radiology and surgical planning.

It shows out that the great initial success of the system is not the result of a new, highly sophisticated (but complex and isolated) technology for computer-based medical imaging but the result of reasonably combining existing technologies.

While the main purpose of virtusMED is improving health care tasks, the use of the system beyond medical applications is also promising, since the described user interfaces are valuable for the exploration of every kind of volumetric image data (e.g. for material testing).

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