A Virtual Reality Training System for Pediatric Sonography

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A virtual reality training system is presented, simulating an ultrasound examination of a baby's head. Unlike books or traditional multimedia programs, it allows interactive exploration of a detailed three-dimensional anatomical model, based on MRI and matched ultrasound data. About 30 structures have been labeled and described, and can thus be interrogated directly on the screen. The advantages of dealing with real anatomy are thus combined with the advantages of learning from a book. The program may be used on any standard PC.

1. INTRODUCTION

For many applications in pediatric radiology, sonography is the imaging modality of choice, due to lack of ionizing radiation, low cost, and ease of handling. Unfortunately, experience has shown that interpretation of these images is extremely hard to learn, due to various reasons:

- ultrasound images show much more artifacts than other modalities, such as noise, speckle, acoustic shadows, etc.
- due to hand-held operation of the probe and limited access (such as through the anterior fontanelle), cross-sections are oblique, making orientation very difficult [6]
- child morphology may differ significantly from that of an adult.

Especially with respect to the second point, printed atlases or collections of pre-calculated images, as in typical multimedia systems, are of limited value.

In this paper, we are aiming at creating a three-dimensional model of a baby's head, which allows a student to simulate oblique cross-sections. This system should provide realistic ultrasound images, as well as explain which structures are to be seen on such an image.

2. PREVIOUS WORK

Over the last decade, a large number of multimedia CD-ROMs have been published for medical education. Although computerized, such media still follow the old paradigm of text printed on pages accompanied by pictures.

As has been shown, spatial knowledge may be much more efficiently represented by computerized three-dimensional models, constructed from cross-sectional images [3]. For educational purposes, such models are now available e.g. for inner organs [2] or neonatal anatomy and pathology [5].

Model-based simulation of ultrasound examinations was first presented in [4]. While in that case an adult head was used as a reference, we are using a baby's head for this study.

3. MATERIALS AND METHODS

The three-dimensional model is based on two MRI data sets (Siemens Vision) obtained from a 3 month old baby, which are T1 and T2 weigthed, respectively. Furthermore, a contrast agent (gadolinium) was used for the second one, further enhancing the blood vessels. Both data sets have a size of $256\times256\times192$ voxels and a spatial resolution of 0.78 mm. Even though originally acquired for diagnostic purposes, these data show no abnormal findings. In addition, a matching ultrasound volume (ATL HDI-3000) was acquired and aligned to the MRI data.

From the MRI data, the main structures such as cerebral cortex, ventricular system, medulla oblongata, cerebellum, pons, cerebral sinus etc. were interactively segmented, using methods such as thresholding, connected components analysis, and mathematical morphology [1]. Still, some structures such as thalamus, nucleus caudatus and arteries (including parts of the cirlce of Willis) proved to be impossible to segment, due to low contrast or noise. Since these were considered essential for the model, a *tube editor* was used to interactively place small spheres into the data volume. These spheres were then connected to form closed tubes. In combination, about 30 three-dimensional objects were obtained. Object names as well as relations between different objects (such as ”PartOf” or ”BranchingFrom”), were described in a knowledge base, and linked to the spatial model.

The model was created on a Linux-based workstation, using the VOXEL-MAN volume visualization environment [3]. While this system provides full flexibility, image calculation may take several seconds, and is thus too slow for building a simulation system. Therefore, we used it as an authoring tool for creating virtual scenes, using an extended QuickTime VR format.

The QuickTime VR format provides a two-dimensional matrix of images. In contrast to a conventional movie format, it thus not only allows to move back and forth, but effectively gives two degrees of freedom, which are controlled by mouse movement. We extended this format in order to also hold information about the objects shown. This concept, called *intelligent movies*, was presented elsewhere [7].

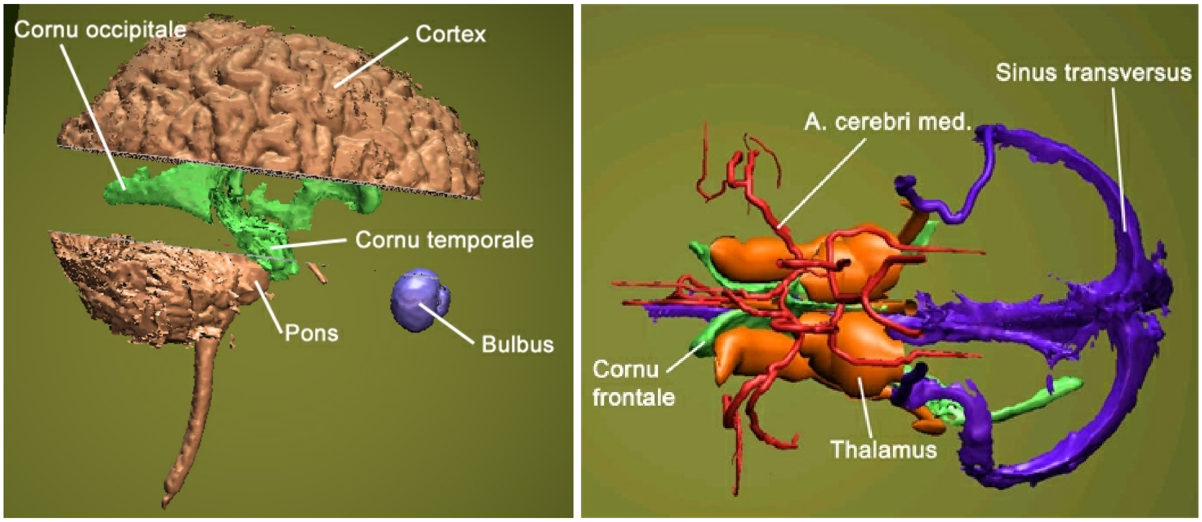

Figure 1. Various views of the MRI head, used as a reference. About 30 structures were segmented or modeled.

4. RESULTS

With the methods described above, we created a set of virtual scenes, which may be grouped into two major categories:

- Three-dimensional views of the objects (Figure 1).

  The two degrees of freedom are used e.g. for rotation of the scene and addition/subtraction of objects, respectively.

- Oblique cross-sections from MRI or/and ultrasound (Figures 2,3).

  While a virtual probe is used in order to select oblique cross-sections, the resulting images are calculated from the MRI data, in order to facilitate understanding for the beginner. In addition, matching cross-sectional views may be calculated from the ultrasound data.

  The two degrees of freedom are used e.g. for moving the probe up/down and left/right, respectively, or moving the probe up/down and rotating it.

Visible objects may be interrogated by mouse click. Likewise, objects may be painted to show their extend, or annotated. Vice versa, any object may be painted or annotated using an object list. The system will even find an image where an object is best visible.

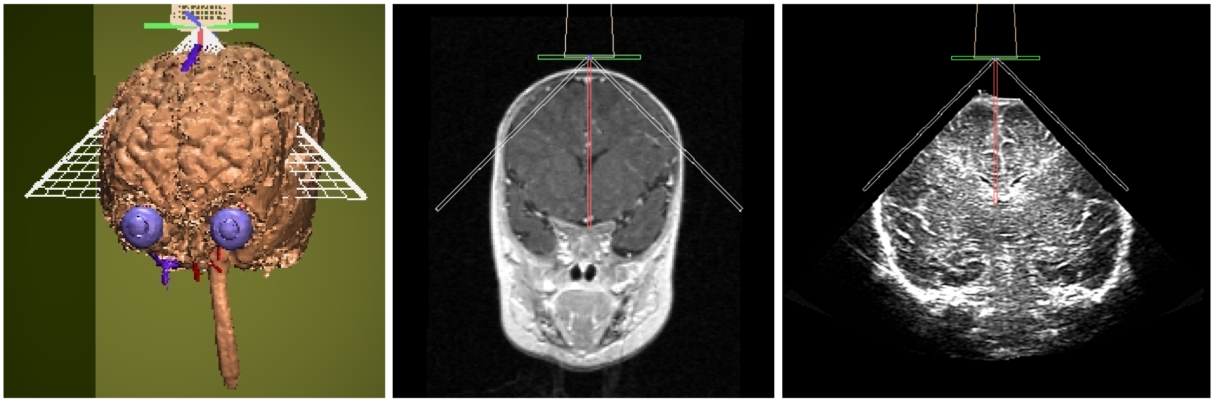

Figure 2. Simulating a typical position of an ultrasound probe on the anterior fontanelle. Using the MRI-based model as a reference, appearance of the brain anatomy may thus be studied.

5. CONCLUSIONS

In this paper, we presented a virtual reality training system, simulating an ultrasound examination of a baby's head. Unlike books or traditional multimedia programs, it allows interactive exploration of a detailed three-dimensional anatomical model, based on MRI and ultrasound data. Each structure is labeled and described, and can thus be interrogated directly on the screen. The advantages of dealing with real anatomy are thus combined with the advantages of learning from a book (associated knowledge). While our system has only two degrees of freedom (in contrast to a real ultrasound probe, which has six), this limitation is mostly overcome by creating a set of different scenes.

Running on standard PCs, this system gives a real-time response to moving a virtual probe, very much like in a real examination. Sonographic manifestation is shown in the context of three-dimensional anatomy. It thus decisively improves the understanding of this type of radiological images.

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REFERENCES

1. K. H. Höhne and W. A. Hanson. Interactive 3D-segmentation of MRI and CT volumes using morphological operations. *J. Comput. Assist. Tomogr.*, 16(2):285–294, 1992.
2. K. H. Höhne, B. Pflesser, A. Pommert, K. Priesmeyer, M. Riemer, T. Schiemann, R. Schubert, U. Tiede, H. Frederking, S. Gehrmann, S. Noster, and U. Schumacher. *VOXEL-MAN 3D Navigator: Inner Organs. Regional, Systemic and Radiological Anatomy*. Springer-Verlag Electronic Media, Heidelberg, 2000. (3 CD-ROMs, ISBN 3-540-14759-4).

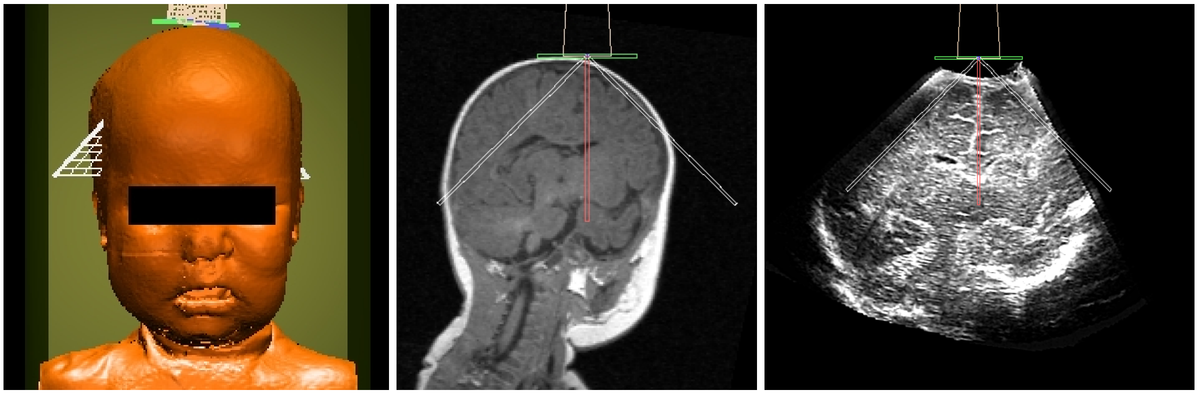

Figure 3. A more oblique cross-section. Using ultrasound alone, these images are particularly hard to understand.

3. K. H. Höhne, B. Pflesser, A. Pommert, M. Riemer, T. Schiemann, R. Schubert, and U. Tiede. A new representation of knowledge concerning human anatomy and function. *Nature Med.*, 1(6):506–511, 1995.
4. S.-I. Kim, K. H. Höhne, R. Schubert, and E. Richter. Neue interaktive 3D-Lernmethoden auf dem Gebiet der pädiatrischen Sonographie auf PC-Basis. *Der Radiologe*, 8:734, 1999. (abstract).
5. E. Richter, H. Krämer, W. Lierse, R. Maas, and K. H. Höhne. Visualization of neonatal anatomy and pathology with a new computerized three-dimensional model as a basis for teaching, diagnosis and therapy. *Acta Anat.*, 150(1):75–79, 1994.
6. E. Richter and W. Lierse. *Imaging Anatomy of the Newborn*. Urban & Schwarzenberg, Baltimore, MD, 1991.
7. R. Schubert, B. Pflesser, A. Pommert, K. Priesmeyer, M. Riemer, T. Schiemann, U. Tiede, P. Steiner, and K. H. Höhne. Interactive volume visualization using “intelligent movies”. In J. D. Westwood, H. M. Hoffman, R. A. Robb, and D. Stredney, editors, *Medicine meets Virtual Reality, Proc. MMVR ’99*, volume 62 of *Health Technology and Informatics*, pages 321–327. IOS Press, Amsterdam, 1999.