Ultrasound Obstet Gynecol 2008; **32**: 906–909
Published online 13 November 2008 in Wiley InterScience (www.interscience.wiley.com). **DOI:** 10.1002/uog.6217

Simple virtual reality display of fetal volume ultrasound

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KEYWORDS: three-dimensional; ultrasound; virtual reality

ABSTRACT

Three-dimensional (3D) ultrasound volume acquisition, analysis and display of fetal structures have enhanced their visualization and greatly improved the general understanding of their anatomy and pathology. The dynamic display of volume data generally depends on proprietary software, usually supplied with the ultrasound system, and on the operator's ability to maneuver the dataset digitally. We have used relatively simple tools and an established storage, display and manipulation format to generate non-linear virtual reality object movies of prenatal images (including moving sequences and 3D-rendered views) that can be navigated easily and interactively on any current computer. This approach permits a viewing or learning experience that is superior to watching a linear movie passively. Copyright © 2008 ISUOG. Published by John Wiley & Sons, Ltd.

INTRODUCTION

Typically, virtual reality (VR) objects are displayed using one of two distinct aspects: panorama or object views. Panorama views display surroundings (Figure 1a), giving the impression of being at the center of the scene with the ability to look in different directions from within. Object views are the counterpart to panoramas: the viewer observes an object seeing different sides and tilted views or viewing heights (Figures 1b and c); this generates the illusion of holding and turning a three-dimensional object or of scrolling through parallel sections (Figure 1d). There are two widely available data containers and display technologies[1,2] that can be used to store, display and manipulate VR objects, and there are a number of tools available that convert image sequences to VR objects (for a collection of useful links see the International VR Photography Association IVRPA website[3]). Online tutorials further explaining the basic technology or the production of educational material are also available[4,5].

In a medical context, VR has been used for various purposes, for example for anatomical specimens and interactive light and electron microscopy[6–8] and for moving images based on magnetic resonance imaging data[9]. A complex VR application involving 3D fetal data was recently reported[10], displaying a 3D rendered fetal meningomyelocele as an interactive stereoscopic VR object. However, the system required a specially equipped, complex lab with video projection and a head-mounted device to register observer movements. We have developed a simple technique for generating and displaying VR objects, derived from 3D volume data of typical prenatal images, that can be viewed on any current computer.

MATERIAL AND METHODS

Ultrasound images

3D volumes of normal fetuses between 8 and 29 weeks' gestation examined sonographically for routine prenatal care were acquired with transvaginal and transabdominal transducers using an automated 3D sweep (RAB4-8L and RIC5-9H transducers, Voluson 730 Expert, GE Medical Systems, Zipf, Austria). For the fetal heart, spatiotemporal image correlation (STIC)[11] was used to acquire a full volume cardiac cycle. 3D views were rendered and rotational or cross-sectional movies from different viewing levels along the heart axis were generated and exported as .avi files (4DView 5.0; GE Medical Systems). Rotational movies up to a total rotation of 360° were generated in steps of 15° and at three different vertically tilted viewing angles. For the cross-sectional movies of the beating fetal heart, ten movies at different levels parallel to the four-chamber view were generated.

Construction of virtual-reality objects

The videos were split digitally into the individual images using non-commercial video editing software[12]. During

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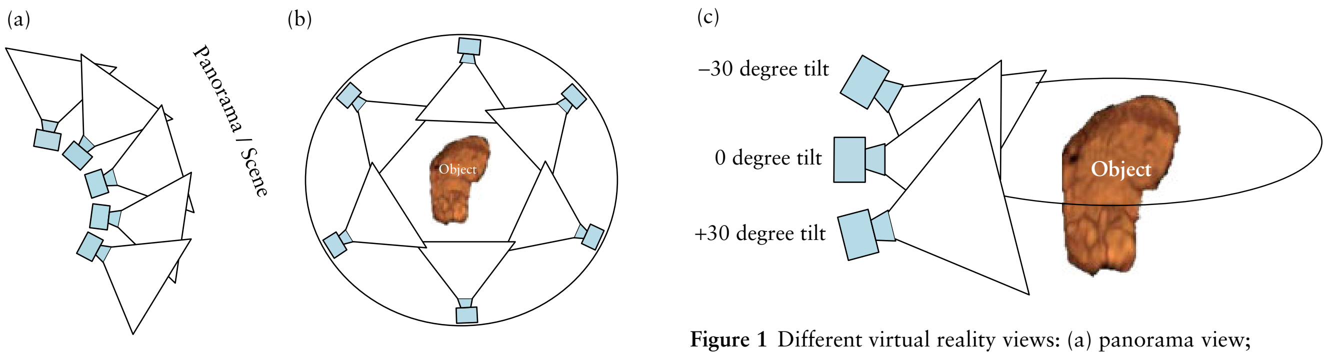
Accepted: 5 June 2008



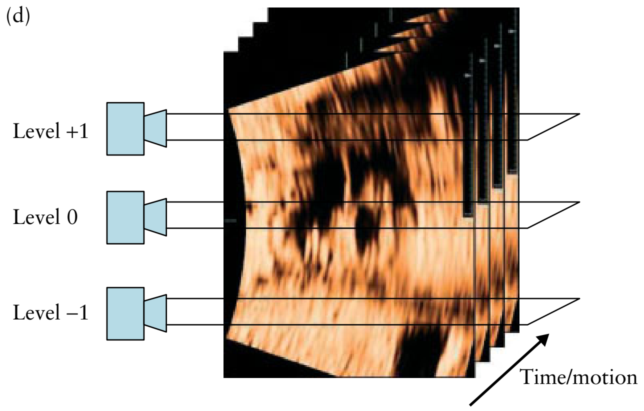


Figure 1 Different virtual reality views: (a) panorama view; (b) 'surround' object (three-dimensional surface rendering of an embryo) imaging; (c) object imaging with (tilted) views from different vertical perspectives; (d) motion imaging at different levels along a moving object (fetal heart) (see also Movie S3).

Table 1 Image reassembly for a static virtual reality object, viewable from n different horizontal aspects (columns 1 to n) and three tilting angles (rows 1 to 3) (see also Figure 2a)

	Column 1	*Column 2*	*Column 3*	. . .	*Column n*
Row 1	Image 1/1	Image 1/2	Image 1/3	. . .	Image 1/n
Row 2	Image 2/1	Image 2/2	Image 2/3	. . .	Image 2/n
Row 3	Image 3/1	Image 3/2	Image 3/3	. . .	Image 3/n

this process, filters could be used to crop or enlarge all images in a batch process. Using a simple, commercially available program[13] (for other software see ivrpa.org[3]) the individual images were reassembled and VR objects were generated and saved in two data formats (QuickTime VR (QTVR) as .mov files and Flash .swf files). These formats allow user interaction to manipulate the viewing aspect by horizontal rotation, zooming and tilting or parallel scrolling.

For reassembly, all individual still images were loaded into a two-dimensional grid (Tables 1 and 2 and Figures 1 and 2). Images from subsequent horizontal aspects were loaded into adjacent cells of one row, starting from the most lateral aspect in the first cell of a row. In the case of moving images, all individual frames of each horizontal aspect were loaded in adjacent cells before the next movie's frames were loaded in the following cells. If vertically tilted (Figure 1c) or parallel (Figure 1d) views or cross-sections of the object had been generated, the individual images from adjacent angles were arranged in subsequent rows in this grid, starting with the most cranially tilted view or the lowest imaging level in the top row. This set-up provided the basis for both the horizontal rotation and the change of vertical viewing angle or parallel shifting of the VR object.

Finally, output was generated setting resolution/file size, starting orientation, zoom options, and replay speed in the case of the fetal heart.

RESULTS

Following this protocol, the total production time of a VR object movie from a conventional horizontally rotational movie was about 15 min, including both splitting the movie file into single images and constructing the VR object movies on a digital light table (Figure 2).

The VR object movie enables users to rotate, tilt, pan and enlarge the object on computer using the computer mouse. The VR objects can be magnified to full-screen resolution. The sample VR movies show a 360° surround display of 3D-surface rendering of a normal 8-week embryo (Figure 3 and Movie S2, available online; for assembly technique see Figures 1b, 1c and 2) with three different viewing angles, a scrollable stack of parallel horizontal sections of a normal fetal brain at 21 weeks' gestation (Movie S2) and a normal beating fetal heart with ten different viewing levels (Figure 1d and Movie S3).

Table 2 Image reassembly for a moving virtual reality object, viewable from n different horizontal aspects, three tilting/parallel levels, displaying movies with m frames for each possible aspect in repeating loops (see also Figure 2b)

Row 1	movie 1.1/frame 1	movie 1.1/frame 2	. . .	movie 1.1/frame m	movie 1.2/frame 1	. . .	movie 1.n/frame m
Row 2	movie 2.1/frame 1	movie 2.1/frame 2	. . .	movie 2.1/frame m	movie 2.2/frame 1	. . .	movie 2.n/frame m
Row 3	movie 3.1/frame 1	movie 3.1/frame 2	. . .	movie 3.1/frame m	movie 3.2/frame 1	. . .	movie 3.n/frame m

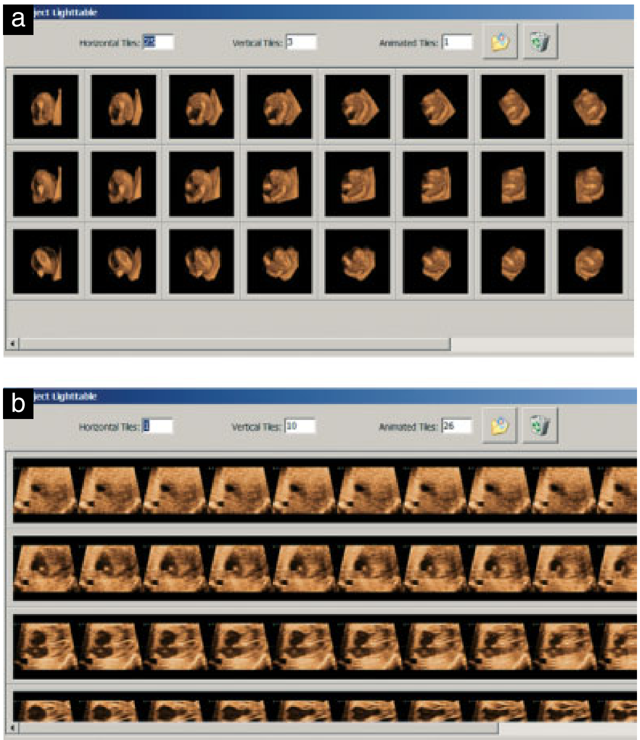


Figure 2 Arrangement of the individual images in a two-dimensional grid on a digital light-table for construction of virtual reality objects and movies. (a) The images from one horizontal surround view are placed in a row, and corresponding tilted views are aligned in columns. (b) For movies, all frames for every view are loaded into adjacent cells in one row; parallel sections at different levels (or views from tilting angles) are placed in rows.

Figure 3 Example of an interactive virtual reality object view of an 8-week fetus (see downloadable file, Movie S1). The object can be rotated through 360° and viewed at three different tilting angles using the mouse and can be magnified.

DISCUSSION

The technique described here for fetal volume and 3D rendered ultrasound imaging permits generation of photorealistic virtual displays easily, using readily available tools. While display of these VR movies requires only a current computer, the viewing experience is enhanced beyond simply watching images or linear movies: the movements on the computer screen are controlled by the user clicking and dragging the object with the mouse. By tilting, rotating or panning the VR object, the user can experience a true VR representation.

VR objects have been used in medical imaging and education. VR movies have been shown to be an effective anatomical learning tool. They are useful for inexpensive review of radiological imagery and have also been applied successfully to different medical applications, including such complex settings as the display of neurosurgical procedures[7,8,14–17]. Nieder *et al.*[6] pointed out the utility of VR for preserving and sharing examples of anatomical variation and developmental anomalies. They noted that abnormal specimens have a high instructional value, which is particularly true in prenatal ultrasound. Yet, opportunities for individual examiners to study by ultrasound structurally abnormal fetuses are limited to the occasional patient or to when some form of imagery is demonstrated by an expert who may use various levels of technology to create an impression as close as possible to a real examination. With abnormal specimens preserved in a virtual format and made available, however, an interested viewer can easily access and visually experience them. We believe this approach of ‘preservation and sharing’ can be extended to all fetal structures and views obtainable by prenatal ultrasound in particular and by volume ultrasound in general.

Generating rotational 3D objects, images or movies of planes at different cross-sectional levels (the ‘tomographic imaging’ approach) are now standard functions available in various commercial ultrasound systems and their offline processing software. This technology was also used to generate the views and movies that are the basis for the VR objects presented here. However, the complexity of such technology, the level of operator expertise necessary to acquire, process and display these data and the lack of suitable ‘specimens’ – both normal and in particular abnormal – may have limited its usefulness for many interested ‘virtual’ examiners. The simple approach described here, however, allows separation of the sometimes cumbersome acquisition and processing of volume data from the simple and intuitive viewing and spatial manipulation that is possible using non-linear VR movies.

In principle, any object captured digitally by ultrasound or any other imaging modality (e.g. computed tomography or magnetic resonance imaging) that is capable of generating views or movies from different horizontal and tilting angles or cross-sectional levels can be displayed this way. The dynamic nature and the quality of the source material is fully retained. Moreover, combined with the ability to manipulate the reconstructed 3D object using any pointing device, typically a computer mouse, such a VR object can be studied intuitively and displayed easily on any standard computer. This provides an enhanced interactive experience as opposed to the operator simply viewing a rotating object or following a linear film sequence.

Because of the elegance of this digital format and its widespread availability, combined with the generally small file size, this approach is ideally suited for teaching over the web. A typical VR object with the same level of detail, but with added maneuverability, decreases the file size compared with a conventional 'static' rotational movie by a factor of about 15. Alternatively, using the highest resolution, subtle details can be preserved, and would be suitable for distribution on other media such as CD or DVD.

A simple but powerful addition in QTVR is the concept of so-called 'hotspots'. Hotspots are user-selectable regions 'on the surface of' or 'in' a virtual object that link to other views or objects. By linking virtual object with hotspots, rather like using hypertext links on the internet, interactive visual diagnostic algorithms or an interactive atlas, possibly with audio narration, could be implemented. Another possible extension of the VR concept would be the inclusion of stereoscopy.

The VR protocol given here for fetal volume ultrasound can be applied to other anatomical regions in obstetric and gynecological imaging or to other fields. By making its ouput more widely available, this technology may generate a better understanding of the value of volume imaging.

ACKNOWLEDGMENT

The technique presented in this article has been granted patent pending status by the U.S. Patent and Trademark Office.

REFERENCES

1. Apple Inc. Quicktime VR. http://www.apple.com/quicktime [Accessed 1 June 2007].
2. Adobe Inc. Adobe Flash. http://www.adobe.com/flash, accessed 1 June 2007].
3. International Virtual Reality Photography Association. http://ivrpa.org [Accessed 1 June 2006].
4. 4Directions Project. Quicktime Virtual Reality for Educators and Just Plain Folks. http://www.edb.utexas.edu/teachnet/qtvr/ [Accessed 1 June 2007].
5. The Learning Alliance. http://www.letmedoit.com/qtvr/index.html [Accessed 3 June 2006].
6. Nieder GL, Scott JN, Anderson MD. Using QuickTime virtual reality objects in computer-assisted instruction of gross anatomy: Yorick – the VR Skull. *Clin Anat* 2000; **13**: 287–293.
7. Nieder G. QuickTime VR anatomical resource – Links. http://www.anatomy.wright.edu/QTVR/links.html [Accessed 1 June 2007].
8. Trelease RB, Nieder GL, Dorup J, Hansen MS. Going virtual with QuickTime VR: new methods and standardized tools for interactive dynamic visualization of anatomical structures. *Anat Rec* 2000; **261**: 64–77.
9. University of Michigan Medical School 2000; Medical Gross Anatomy QuickTime VR Movies. http://anatomy.med.umich.edu/qtvr/qtvr_movs.html [Accessed 3 June 2006].
10. Groenenberg IAL, Koning AHJ, Galjaard RJ, Steegers EAP, Brezinka C, van der Spek PJ. A virtual reality rendition of a fetal meningomyelocele at 32 weeks of gestation. *Ultrasound Obstet Gynecol* 2005; **26**: 799–801.
11. DeVore GR, Falkensammer P, Sklansky MS, Platt LD. Spatiotemporal image correlation (STIC): new technology for evaluation of the fetal heart. *Ultrasound Obstet Gynecol* 2003; **22**: 380–387.
12. Lee A. Video editing software VirtualDub-1.6.17. http://www.virtualdub.org [Accessed 14 January 2007].
13. Rauscher T. Panorama and object movie converter: Pano2QTVR 1.6.2. http://www.pano2qtvr.com [Accessed 3 June 2006].
14. Vrints CJ, Bosmans J, Claeys MJ, Snoeck JP. User-friendly and low-cost computer system for immediate review, analysis, and reconstruction of intracoronary ultrasound images. *Cathet Cardiovasc Diagn* 1998; **43**: 357–362.
15. Temkin B, Acosta E, Malvankar A, Vaidyanath S. An interactive three-dimensional virtual body structures system for anatomical training over the internet. *Clin Anat* 2006; **19**: 267–274.
16. Pommert A, Höhne KH, Burmester E, Gehrmann S, Leuwer R, Petersik A, Pflesser B, Tiede U. Computer-based anatomy: A prerequisite for computer-assisted radiology and surgery. *Acad Radiol* 2006; **13**: 104–112.
17. Balogh A, Preul MC, Schornak M, Hickman M, Spetzler RF. Intraoperative stereoscopic QuickTime Virtual Reality. *J Neurosurg* 2004; **100**: 591–596.

SUPPORTING INFORMATION ON THE INTERNET

The following supporting information may be found in the online version of this article:

Movie S1 QuickTime Virtual Reality object movie of a normal fetus at 8 weeks.

Movie S2 QuickTime Virtual Reality image stack of a normal fetal brain at 20 weeks (as .mov and as .swf flash files, the latter integrated in a sample webpage).

Movie S3 QuickTime Virtual Reality object movie stack of a normal beating fetal heart at 29 weeks.