Interactive Visualization of Time-Resolved 3D MRA on Commodity PC Hardware

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INTRODUCTION

MRA techniques such as Vastly undersampled Isotropic Projection imaging (VIPR) can acquire time-resolved 3D images over a large field-of-view [1]. For 3D exams, limited multiplanar reformatting is essential for efficient diagnosis, especially with the large FOV provided by VIPR. The temporal information could potentially aid clinical diagnosis, provided that it is easy to examine. Current commercial workstations are expensive, do not offer high frame rates for interactive manipulation and do not deal well with time-resolved 3D datasets. At many institutions, the workstations are centrally located in radiology reading rooms and there is limited research access. Modern personal computer graphics cards are well suited to interactive visualization of 3D MR data. With hardware support for geometry transforms, texture mapping, MIPs, and other pixel blending modes, well-developed volume-rendering techniques can allow for interactive manipulation of large volumes [2]. We demonstrate interactive visualization of time-resolved 3D MR angiography, with MIPs through 256x256x256 volumes using arbitrary cut-planes and viewing angle, at frame rates in excess of 10 fps on workstations costing under $500. Use of the OpenGL graphics API allows for support of a wide variety of hardware with easy portability between architectures or operating systems.

MATERIALS AND METHODS

Modern graphics cards have a hardware pipeline optimized for transforming and rendering texture-mapped polygons at a very high rate. To take advantage of this, the volume is rendered as a collection of slices. To get the full benefit of hardware in-slice interpolation, the slices should be as orthogonal to the viewing angle as possible. The volume can be represented to the video card either as a collection of 2D slices or as a single 3D texture. The 2D implementation loads the volume three times, as slice sets on three orthogonal planes. The rendering process interpolates using the slice set nearest orthogonal to the viewpoint, which introduces some sampling artifacts at certain oblique viewing angles. The 3D implementation loads the volume only once and rendering can use slices exactly orthogonal to the viewpoint, allowing for trilinear interpolation. The 2D slice implementation requires three times the memory, but is faster on current hardware. The 3D texture implementation requires less memory and produces a higher quality image, but has slower performance.

In each frame, the entire volume is rendered from an arbitrary viewing angle. The MIP operation occurs in hardware, with user-controlled cut planes to control the visible extent. Window-leveling also takes place in hardware through the use of palletized textures. For working with time-resolved exams, multiple time frames can be loaded simultaneously. If the required memory exceeds available video memory, the penalty for swapping in datasets is roughly $^1/_3$ second. It is possible to switch between time frames while maintaining the same viewing parameters. It is also possible to display multiple time frames simultaneously in different colors using a multi-pass rendering technique. On hardware that supports stereo rendering with 3D glasses, lateral shift depth cues can ease interpretation of complex structures.

RESULTS AND DISCUSSION

Our interactive visualization tool has proved very useful in reducing our dependence on commercial radiology workstations. It achieves comparable image quality with frame rates in excess of 10 fps for full-volume MIPs. This frame rate is adequate to allow for interactive manipulation by unskilled users. On commonly available commercial workstations, interactive manipulation of a 40 cm thick MIP is at 2-3 fps with low quality images, with full-resolution renderings appearing after a 1 s delay. The ability to conveniently view multiple time frames appears to be useful in easing diagnosis in cases with complex flow patterns. In patients with dissections, late-enhancing vessels can be shown in green, allowing easy assessment of whether vessels branch from the true or false lumen. Showing early-enhancing vessels in red and late-enhancing vessels in blue allows depiction of the entire circulatory system.

CONCLUSIONS

We have demonstrated interactive visualization of time-resolved 3D MR data on inexpensive workstations. Minimal amounts of software development are necessary to take advantage of the rendering capabilities of the graphics hardware. A simple implementation can be under 500 lines of code, with most of that devoted to image file reading and user interaction. The technique can easily be expanded to larger datasets or more advanced rendering techniques.

REFERENCES

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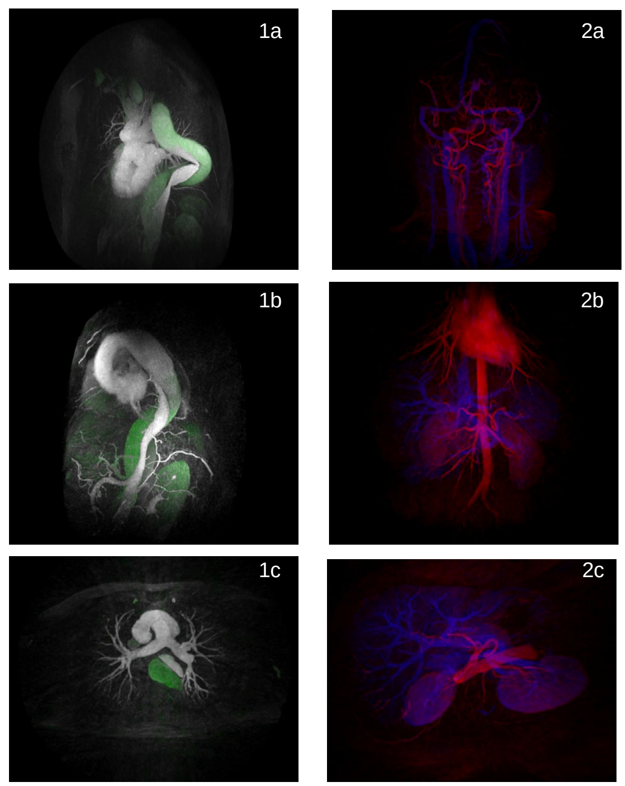

Figure 1: Assessing whether vessels branch from the true or false lumen in an aortic dissection case is aided by depicting an early time frame in white and late time frame in green. Data for (b) was acquired using 12-channel (8 active) torso phased array receiver coil (IGC Medical Advances, Milwaukee, WI).

Figure 2: Showing an early time frame in red and a late time frame in blue gives an image of the entire circulatory system, with arteries in red and veins in blue.