Real-time 3D Non-Cartesian Phased-array Contrast-enhanced MRA

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INTRODUCTION

Real-time vascular MRI has been applied for both interventional guidance and fluoroscopic triggering of contrast-enhanced MR angiography (CE-MRA). 3D real-time imaging [1] has been limited by acquisition and processing speed and thus 2D imaging has been the dominant mode. We present a 3D real-time acquisition, reconstruction, and interactive visualization system capable of limited resolution, phased array scanning using only the unused processing resources of the manufacturer's operator console host computer with no additional hardware. As a first application, we have developed a 3D fluoroscopic imaging capability for CE-MRA. With the conventional 2D fluoro-triggering currently provided on many platforms, the operator must prescribe an imaging volume and then interactively locate a 2D slice suitable for monitoring contrast arrival. Our system requires no specification of a monitoring slab and is capable of providing real-time images throughout the duration of the acquisition. It guarantees coverage of the areas of interest and may give advance notice of contrast arrival to ease breath-hold coaching. Use of the 3DPR acquisition known as Vastly undersampled Isotropic Projection imaging (VIPR) allows monitoring to be performed over the actual imaging volume. Our initial system imaged a 40x40x40 cm volume every 2 s using 8 coils with 0.25 s latency.

MATERIALS AND METHODS

We implemented our system on a General Electric 1.5T TwinSpeed system with EXCITE hardware. The standard operator console workstation has dual 2.66 GHz Intel Xeon processors with 2 GB of RAM. The GE Raw Data Server transmits data from the data acquisition hardware to the workstation through a TCP/IP connection. We have developed a client that receives raw data and reconstructs limited resolution volume images. These images are written to disk and can be interactively manipulated with hardware-rendered real-time multiplanar volume reformat MIPs.[2] The client runs as a background process, without interfering with normal operator interaction.

Though VIPR's time-resolved imaging capabilities generally make fluoro-triggering unnecessary, some patients are only capable of short breath-hold durations and some clinical pathologies lead to exceptionally delayed contrast arrival times, for example in aortic dissection, arterial occlusion with delayed filling from collaterals, or due to the valsalva maneuver during a breath-hold. Fluoroscopic monitoring allows matching the breath-hold interval to the period when contrast is concentrated in the imaging volume. Phased array VIPR provides sensitivity over the entire torso so contrast arrival can be monitored in the chest before initiating a breath-hold for abdominal imaging. The symmetric k-space acquisition allows the scan to be easily subdivided into 1-2 s interleaves, each with unique sets of projections. For real-time monitoring, the interleaves are processed individually; while the set of interleaves acquired during the 30 s breath-hold is later reconstructed into high-resolution time-resolved vascular volumes.

The real-time system uses a gridding-based algorithm similar to that in the conventional VIPR reconstruction. Radial lines are regridded as they are acquired onto a 64x64x64 Cartesian grid out to a radial k-space dimension of k_r=24. Four half echoes covering four unique radial lines are sampled during each 4.4 ms TR. A calibration and correction algorithm is employed to reduce sensitivity to k-space location errors due to gradient delays and eddy currents.[3] Processing is performed individually for each receiver and receiver magnitude volume images are combined to produce a final volume image at the completion of each 2 s acquisition interleave.

The system was tested on phantoms and human volunteers. The real-time reconstruction produces volume images with 9.2 mm isotropic spatial resolution. Scanning was initiated when contrast was injected and breath-hold coaching began when enhancement was seen in the right heart, with a 30 s breath-hold beginning when contrast was in the aorta. Subsequent interleaves during the breath-hold were processed individually with the real-time system and together with a conventional VIPR reconstruction, which generated a time series of volume with 1.7 mm isotropic spatial resolution and 2 s temporal resolution over a 44 cm diameter spherical FOV.

RESULTS AND DISCUSSION

The sequence runs at a rate of 227 views/s - with an 8-receiver phased array coil, the data acquisition rate is 5 MB/s. For each 2 s time frame, the regridding process requires 300 ms to interpolate data into a Cartesian space. The regridding is scheduled continuously and finishes nearly immediately after acquisition, contributing minimally to the latency between acquisition and display. The latency is thus due only to frame processing, which consists of a 3D FFT requiring 160 ms; receiver combination requiring 36 ms; chopping and normalization requiring a total of 24 ms; and disk output requiring an additional 30 ms. Each 2 s time frame is then displayed 250 ms after acquisition is complete. Processing time is related almost linearly with the number of receiver coils.

Spatial resolution is currently limited by the spatial frequencies that can be adequately sampled in a single time frame. The number of projections (and thus the supported resolution) can be improved by combining multiple frames with temporal filtering to exploit the variable sampling density of 3DPR.[4] The acquisition interleaves frames can then be shortened, improving temporal resolution to our goal of 1 frame/second.

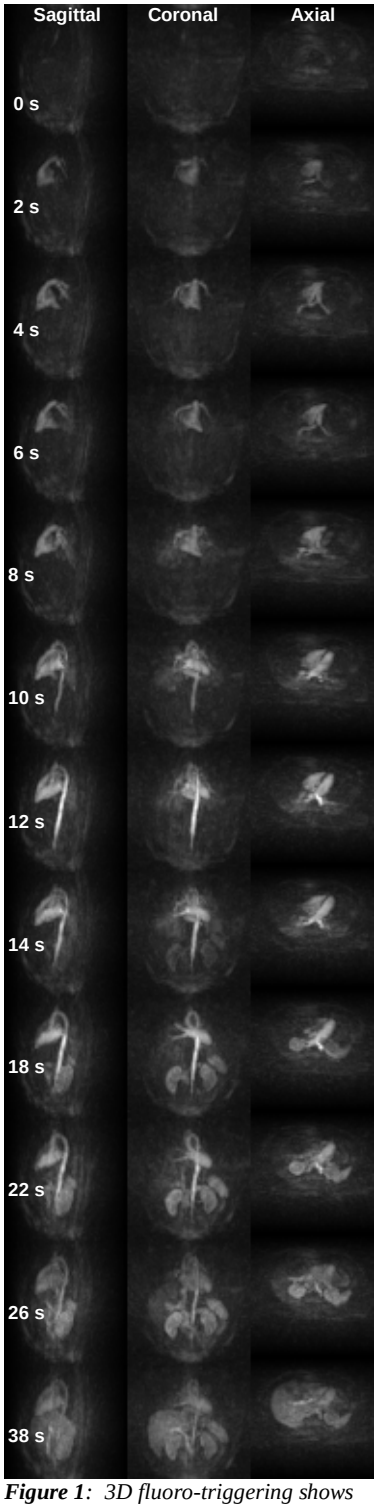

***Figure 1**: 3D fluoro-triggering shows sagittal, coronal, and axial full-volume MIPs at 2 s intervals during an thoracic/abdominal MRA exam. A subset of these images reveals enhancement progressing from the right side of the heart, through the lungs, to the left side, and into the aorta before reaching the abdominal organs.*

CONCLUSIONS

We have developed a real-time 3D MRI system that runs on standard hardware. Our first application simplifies and improves performance of fluoroscopic monitoring for 3DMRA. The system can easily be extended to a distributed computing implementation for higher performance.

REFERENCES AND ACKNOWLEDGEMENTS

1. O Wieben, *et al.*, MRM 52:4, 921-926 ('04)
2. EK Brodsky, *et al.*, Proc. 12th ISMRM, 1937 ('04)
3. EK Brodsky, *et al.*, Proc. 11th ISMRM, 322 ('03)
4. AV Barger, *et al.*, MRM 48:2, 297-305 ('02)

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