System for Real-time Reconstruction and Interactive Table Motion in Multi-Station 3D CE-MRA Exams

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BACKGROUND

Fluoroscopic tracking is a recently described technique applicable to multi-station contrast-enhanced MR angiography (CE-MRA) of the peripheral vasculature. [1] Images are generated in real time (every 2.5 seconds) at each station to monitor the arrival of contrast material at that station. Once the operator observes the contrast material passing the distal end of one station, he/she triggers the patient table to move to the next distal station. This process is repeated for each station of the multi-station exam except the final station, for which no further table motion is necessary.

Fluoroscopic tracking for multi-station CE-MRA requires exceptionally stringent performance in the speed and integration of the image reconstruction, MRI pulse sequence (PSD) and operator interface. Performance specifications are dictated principally by the need to generate high spatial resolution 3D images at a frame rate permitting visualization of bolus transit while maintaining a reconstruction time short enough to allow table advance to keep pace with the advancing contrast bolus. The purpose of this work is to develop the performance specifications and describe how these have been met with a custom reconstruction system and operator interface.

METHODS

To simultaneously enable fluoroscopic tracking and diagnostic imaging, the conflicting goals of high spatial resolution and rapid update times must be met. A PSD previously described [2] can be adjusted to provide images of the lower extremities with update times under 2.5s with ~1.5mm isotropic spatial resolution, balancing these competing goals via view-shared (R=8 2D) SENSE acquisition and optimized coil design. A cluster-computing system capable of reconstructing similar SENSE accelerated volumes in approximately one second has been described previously. [3] We extend upon these works to provide: **multiple imaging stations**, each with independent acquisition properties; **interactive viewing of results and control** while the exam is proceeding via a graphical interface or GUI; and **faster reconstructions** to provide a large time window for operator triggering.

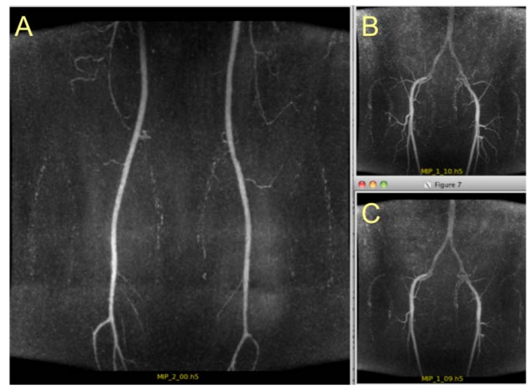

Figure 1: GUI output with most recent (A), N-1 (B) and N-2 (C) updates displayed to operator. Here the operator triggered while viewing N-2 (displayed in position A at that time) during N-1's acquisition.

Multiple Imaging Stations: The SENSE unfolding / view placement and subtraction software has been converted into object-oriented (C++) code, permitting multiple instances of the reconstruction data and supporting state information to be active (prepared and kept in memory for all stations prior to contrast injection) in a single executing program. Each station has full flexibility in the selection of coil count, acceleration parameters, and acquisition matrix sizes, permitting acquisitions to be tailored to the anatomy at each station.

Interactive Viewing and Control: To enable fluoroscopic tracking, the results of the reconstruction must be presented to the operator *during* the scan. To this end, three new pieces of software have been developed. *(1)* A GUI, developed using the Qt4 [4] toolkit, runs on the scan console and connects to the reconstruction programs (henceforth Reconstruction) running on the computing cluster. This GUI displays the three most recently completed timeframes (Figure 1) as subtracted maximum intensity projections (MIP), as well as providing controls for triggering table movement. *(2)* Software enabling network connectivity with the PSD during the scan procedure. *(3)* Management software within the Reconstruction for monitoring the network connections with the GUI and PSD as well as controlling exam progression. During the scan, the operator indicates via the GUI when table movement to the next distal station is needed. This action sends a network message to the Reconstruction, where it is forwarded on to the PSD. The PSD and Reconstruction then coordinate the table movement and prepare for the next station's acquisition.

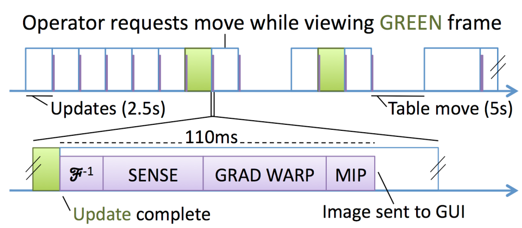

Figure 2: Timing of inter-station table moves (within top line), acquisition (Blue and green blocks, top line), and reconstruction steps (purple, second line).

Faster Reconstructions: The reconstruction process (comprised of reference subtraction, Fourier transformation, 2D SENSE unfolding, gradient warping correction, and MIP generation) has been further optimized for reduced execution time. This maximizes the time available for the operator to determine if the exam should proceed to the next distal station. The optimization was achieved primarily through migration from *ATLAS/LAPACK* to the *Eigen3* [5] linear algebra package, improvements to the cross-node transpose operations, and hand-tuning of the gradient-warping correction code.

RESULTS

These three key new features (support for multiple imaging stations, interactive viewing and control, and faster reconstruction times) have been successfully implemented to enable real-time multi-station 3D CE-MRA. Two- and three-station scans with operator-initiated table movement based upon reconstructed images have been performed, with the reconstructions available to the operator in 110ms (280×280×96, 12-coil, R=8 2D SENSE) after the completion (Figure 2) of data acquisition for each new image.

CONCLUSIONS

Multiple successful interactive studies of volunteers have been performed with this reconstruction system (PSD + GUI + Reconstruction.) The reconstructed frame is presented to the operator while ~95% (>2.3s) of the acquisition time for the next frame remains. The resulting time-series of volumes have been of high quality, while real-time choices – such as which leg to "follow" in asymmetric flow patterns – can guide the acquisition process.

REFERENCES

[1] Johnson, MRM, 2010:64 [2] Haider, JMRI, 2011:34 [3] Borisch, ISMRM 2008, #1492 [4] http://qt.nokia.com [5] http://eigen.tuxfamily.org