# A Real-time System For Interactive Large FOV MR Imaging

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## Introduction

Real-time MR systems are required for interactive and dynamic applications. In interactive continuously moving table (iCMT) MR imaging, an extended field-of-view (FOV) (>100 cm) is built up by acquiring **k**-space data as the local imaging FOV (< 45 cm) is translated interactively along the patient (in *x*-direction) in response to fluoroscopic images provided via real-time reconstruction [1]. Rather than link the data acquisition at $k_y$- and $k_z$-phase-encodes with predefined constant table velocities, the ordering of the ($k_y$, $k_z$)-phase-encodes is treated as an independent process to enable variable, adaptive table motions. Here, we present a robust, real-time MR imaging platform with good frame refresh rate and minimal reconstruction latency for real-time large FOV iCMT imaging using standard general-purpose hardware. The proposed system was evaluated on ten volunteers for rapid large FOV imaging and reconstruction.

## Materials and Methods

A direct data access interface was developed using a stand-alone local Ethernet connection running the standard TCP/IP network protocol [2,3]. A research workstation (equipped with 2.2 GHz Athlon processor) running Linux was directly connected to the local network of a clinical 3 T MR scanner (Signa, GE Healthcare, Waukesha, WI) and defined as a client node. In real-time mode, a server program (on the scanner) streamed the MR raw data to the research workstation after each readout acquisition. A real-time imaging platform was developed using C++, visualization toolkit (VTK) and graphical user interface (Qt) libraries and was integrated with an optical table position encoding system [3]. This platform implemented data acquisition, real-time image reconstruction, and visualization using multiple threads. The iCMT MR imaging algorithm consisted of two main routines: (a) a hardware-enabled *data acquisition routine* responsible for real-time acquisition of the table position and MR readouts, real-time data processing, and accurate filling of the large hybrid ($x$, $k_y$, $k_z$)-space, [4] and (b) an *image reconstruction routine* that ran continuously using the remaining CPU processing power to reconstruct real-time preview images from the continuously updated hybrid-space data. The task of 3D reconstruction was broken into two separate processes, reconstruction in the *x*- and in the (*y*, *z*)-directions, to allow decoupling of the table motion from the phase-encodings order. To ensure real-time, synchronized hybrid-space filling and processing, the raw data packet repeatedly arriving at the workstation invoked a software routine that simultaneously acquired each $k_x$-readout and its related table position. Duplicate acquired data – produced due to the acquisition patterns and flexible table motion – were combined linearly to minimize gradient-induced geometric distortion [5]. To provide a real-time preview image for monitoring, a 2D FOV-sized Fourier projection image was reconstructed every TR at the location of the local FOV. A real-time digital-subtraction mode (from a pre-acquired mask data) was implemented to suppress background tissue signals allowing improved visual tracking of an injected MR contrast bolus for a contrast-enhanced (CE) MR angiography test [6]. Once the data acquisition was completed, the final 3D large FOV images were reconstructed by simply taking the Fourier transforms of the hybrid-space data in the ($k_y$, $k_z$)-direction. A multi-threaded hardware-optimized FFT algorithm (FFTW; MIT, Cambridge, MA) [7] was used in the readout and the phase-encoding directions independently. Fast SPGR and balanced SSFP pulse sequences were modified to work in real-time. A 3D variable-rate **k**-space sampling acquisition [8] was incorporated into the pulse sequences. Ten healthy volunteers were scanned using a body coil for transmit and receive to evaluate the real-time system performance. Typical scan parameters included: undersampled ($k_y$, $k_z$)-phase-encode acquisitions with 10% to 40% of hybrid-space coverage, TR: 2.8 ms to 9.1 ms, TE: 1.8 ms to 2.8 ms, flip angle: 25° to 50°, number of slices: 16 to 32, local moving FOV: 30 cm to 45 cm ($256\times128$-256 acquisition matrix), the large FOV: 110 cm to 145 cm (768-1024 $\times$ 128-256 reconstruction matrix), and total scan time: 48 s to 87 s.

## Results

The real-time iCMT imaging system underwent successful integration and testing in all subjects. No safety problems or adverse reactions were encountered. Figure 1 shows a screenshot of the system user interface during a real-time bSSFP MR acquisition of a volunteer illustrating a preview projection image (a), the real-time table motion profile (b), a large FOV middle slice (c), and a subtracted MIP image (d). The maximum delay in receiving each readout was only one TR. The real-time system was capable of performing a complete 2D Fourier reconstruction of a FOV-size (256 × 256 matrix) preview image within one TR (≥ 3.0 ms). However, the apparent image refresh period was limited by the slower central hybrid-space acquisition. Projection image refresh rates between two to six images per second were achieved. The reconstruction time required for each final 3D large FOV volume was only 2 s.

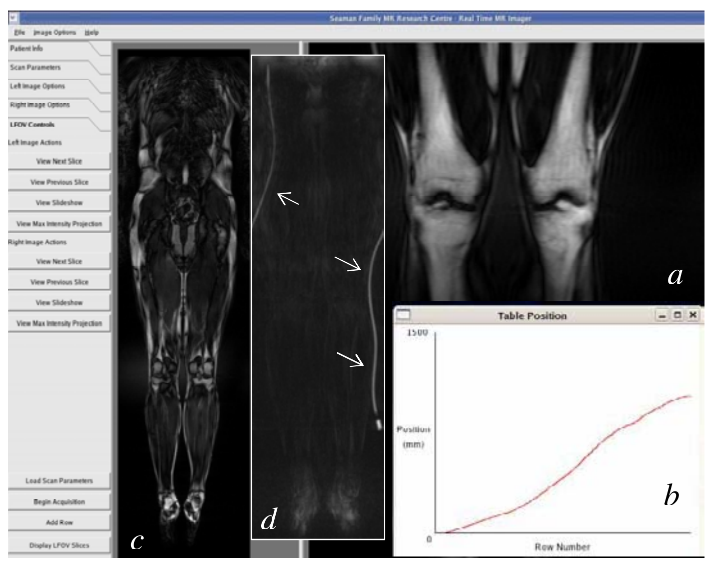


*Figure 1: Screen capture of the Real-time iCMT MR Imaging system showing a projection image (a), the real-time table motion profile (b), a large FOV middle slice (c), and a subtracted image (d). Tubes (→) filled with diluted MR contrast (1%) were placed close to the legs.*

## Conclusions

We have developed a unique real-time system for iCMT MR imaging on a conventional MR scanner. In this implementation the data acquisition, data processing, and image visualization are all ongoing processes during the scan procedure, thereby noticeably minimizing the reconstruction time. It also allows for interactive table motion and produces real-time preview images with mask subtraction (not shown here), both of which are important for acquiring optimal large FOV images and CE angiograms. We anticipate that the implemented system will be useful for a variety of MR applications, including whole-body screening, angiographic runoff studies, and real-time imaging.

## References

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