Radial Acquisitions with Real-Time Tracking and Adaptive Imaging Parameters

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Introduction: MR catheter tracking and adaptive image parameter systems have been developed to facilitate image-guided cardiovascular interventions. The catheter tracking provides real-time images that follow the device as it is moved though the vascular tree. The adaptive parameter software allows the FOV, spatial resolution, temporal resolution, and other image parameters to react, in real-time, to changes in catheter speed so suspicious plaque and other localized pathology can be inspected with greater detail.

Previously, these systems made use of rectilinear acquisitions (True-FISP, FISP, and FLASH). The use of these imaging techniques resulted in a number of limitations with respect to temporal resolution and minimum FOV (due to aliasing in the phase encoded direction). To address these issues, current versions of our tracking and adaptive parameter systems have been modified to employ radial true-FISP imaging, coupled with high speed radial reconstruction techniques. These developments have made possible significantly increased frame rates and smaller FOVs. Furthermore, the adaptive parameter software has been configured to adjust the number of radial projections collected for each image based on the speed of the catheter, thereby providing an effective way to control the temporal resolution during the intervention that was not possible with rectilinear acquisition strategies.

Materials and Methods: This work has been conducted on a standard Siemens 1.5T Sonata imager. All of the adaptive tracking software was implemented in C++ using IDEA and ICE, the pulse sequence and image reconstruction software development environment provided by the vendor. No external workstations as an interface for reconstruction or interaction with system variables were required. As in previous interactive imaging systems, real-time tracking is performed and catheter position, orientation, and insertion speed are continually monitored. The tracking software uses novel pulse sequences and localization algorithms that collect 3 to 8 non-selective projections, perform 1-D Fourier transforms, and extract the location and orientation of tip tracking coils. The software can accommodate the following tracking coil configurations: single-coil tracking markers, multiple-coil single-channel tracking markers, and multiple-channel phased array coils (which can also be used for catheter-based micro-imaging). The system alternates between tracking and imaging. Prior to each image acquisition, the scan plane position/orientation are adjusted. Gradient waveforms and RF pulses are recalculated automatically (**fig 1**) **[1]**.

The tracking data from multiple time points is used to calculate catheter insertion speed. The adaptive parameters are set according to functions of device insertion speed. The current system has two modes. In "Continuous Mode", the adaptive parameters (e.g., resolution or FOV) are set according to a continuous sigmoidal function of insertion speed (**fig 2**). In "Binary Mode", the adaptive parameters are set according to a binary (i.e., threshold) function, where the parameters are set to one value when the catheter is stationary and second value when the catheter is moving. These functions specify the relative values of each adaptive parameter within its own allowed range. The value of these functions (Binary or Continuous) is calculated once per tracking cycle, based on the current catheter insertion speed. This value is then used to adjust each adaptive parameter value relative to its own dynamic range. The necessary changes to the sequence timings, gradient wave forms, and RF pulses are calculated and implemented in real-time automatically by the pulse sequence software as per its standard operation. In both modes, the adaptive parameters are prevented from being set to values that would violate hardware constraints **[2]**. In addition to adaptive parameters that have been previously implemented, in versions of the system that employed rectilinear imaging (spatial resolution, FOV, Bandwidth, TE, TR, image orientation), image parameters specific to radial imaging have now been incorporated (i.e. number of radial projections per image). The adaptive imaging system has been tested using vessel phantoms and *in vivo* porcine imaging experiments to evaluate its performance and utility in simulated models and animal models of future clinical trials. All animal procedures were approved by our institutions IACUC.

Results: In all trials, the system was able to correctly respond to the catheter's insertion speed and adjust the values of the adaptive parameters accordingly. The system also successfully updated the scan plane position and orientation to follow the catheter. The system collected all necessary tracking data within 40 ms; an additional 10 to 20 ms was then required to perform the localization, calculate the velocity, update the image parameter values and re-implement gradient waveforms, frequency offsets, etc., required to redefine the new acquisition. A sample image from an *in vivo* porcine experiment is included below (**fig 3**).

Conclusions: In many ways, radial imaging compliments real-time tracking and adaptive parameter systems better than rectilinear imaging. The most significant features that make radial trajectories attractive are: high frame rates, control over temporal resolution, and aliasing properties. The adaptive parameter software can adjust the number of projections collected for each image and effectively control the temporal resolution in a way that was not possible with rectilinear imaging. Furthermore, the system can adapt the FOV to values smaller than was previously possible since radial imaging does not suffer from aliasing artifacts in the phase encoding direction as the FOV becomes smaller than the sample. Finally, the over-sampling of low spatial frequencies allows radial imaging to achieve improved spatial resolution and adequate SNR in less time than is required by rectilinear techniques. This increased efficiency leads to increased frame rates and better quality real-time imaging for guiding vascular interventions.

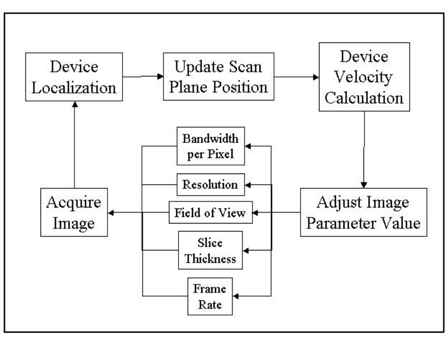

Figure 1: Schematic diagram of adaptive parameter system.

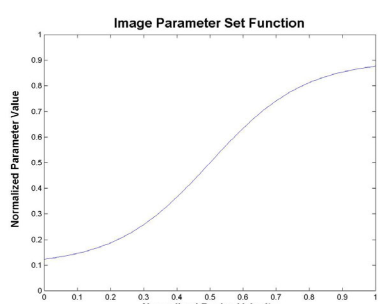

Figure 2: Continuous Mode

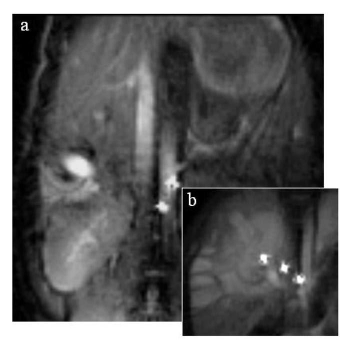

Figure 3: (a) Sample image from *in vivo* experiment; (b) catheter guided into renal artery.

References:

[1] C Flask *et al.* JMRI **14**, 617-627(2001)

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