Real-Time Motion Extraction from 2D Image-Based Navigators in Under 20 Milliseconds: An Integrated 2D Navigator Image Processing During MR Data Acquisition

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INTRODUCTION: Direct tracking of cardiac motion using an image-based navigator[1-4] has the potential to provide superior respiratory navigator gating for coronary MR imaging compared to the conventional liver-diaphragm navigator. However, only limited processing of these 2D navigator images is possible due to the constraints of real-time processing, where typically within 50 ms (or less) is available.[1,3] In this work, we propose a real-time processing method that allows 2D navigator setup, processing, and adjustment in scan instruction in real-time based on the processed motion information. The proposed 2D real-time navigator image processing enables prospective gating and motion correction techniques such as PAWS[5] and slice-following from 2D navigators.

METHODS: The proposed real-time interactive (RTI) software is integrated to the image acquisition hardware on a commercial scanner (GE Signa HDx 14.5, GE Healthcare, Waukesha, WI). It extracts 2D navigator data from the scanner memory immediately after k-space signal acquisition, and rapidly reconstructs the navigator image and extracts motion. The software is initiated at the start of a 2D navigator-enabled scan, and is designed to allow operator interaction with the scanner hardware in real-time.

This software has two components that each runs on two different scanner hardware processor boards: a *back-end* component that processes the raw navigator signal acquired from the receiver coils directly on its scanner memory storage location, and a *front-end* component that provides a graphical user interface (GUI) for real-time display and operator interaction. Figure 1 shows the block diagram of the 2D navigator processing by this software, which is divided into a setup phase for 2D ROI selection, and the cardiac imaging phase.

For a k-space segmented coronary imaging sequence, all computations must be completed within the time needed to perform the fat saturation pulse (19 ms) and any catalyzation pulses (~28 ms for a 6 Kaiser-Bessel flip angle ramp[6]). To minimize computation load on the *back-end* so that all 2D navigator processing completes without encountering a run-time error, the processing was limited to a single operator-selected coil element, image reconstruction utilized a partial 2D FFT method, and a reduced 2D Least-Squares (LSQ) template matching search window estimated using an SI displacement from a 1D LSQ reference.

For feasibility, the computation load of processing 2D navigator k-space matrix with dimensions of 196x32 (SIxLR) processed into an image with a matrix of 256x64 using zero-filling was examined. This software was incorporated into a 3D SSFP coronary MRA sequence, where the 2D navigator processing times from 12 healthy volunteers were analyzed in a retrospective manner.[3]

RESULTS: Figure 2 shows the front-end GUI of the developed software performing a prospectively PAWS-gated 3D SSFP Coronary MR angiography scan, in this case using a fat selective 2D navigator acquisition.[2,3]

Table 1 shows the average time required for each task performed during the *time-critical block* on the *back-end* from a typical case, requiring 13 ms. A fully 2D FFT'd navigator image would require 21.4 ms to reconstruct, and a full 2D LSQ template matching over a larger search window (approx. 2x size) would require ~6 ms, for a total of approximately 28-30 ms for motion extraction. Over all 12 subjects, the processing time of the ROI-dependent processes (SI-direction 1DFFTs and 2D LSQ matching) was found to be highly correlated ($R^2 = 0.97$) to the number of 2D ROI pixels; ranging between 6-13 ms in processing time, and 600-1800 pixels in ROI size. The total computation time for PAWS gating from the end of 2D navigator image acquisition varied between 10 and 19 ms, which is within the duration of a fat saturation pulse prior to imaging.

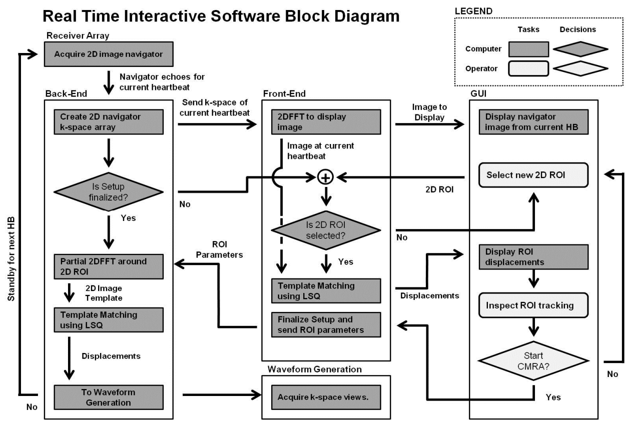

Figure 1. Block diagram of 2D navigator image processing for prospective imaging. In this setup, cardiac imaging commences after the operator selects the appropriate 2D ROI for tracking in a cardiac imaging sequence.

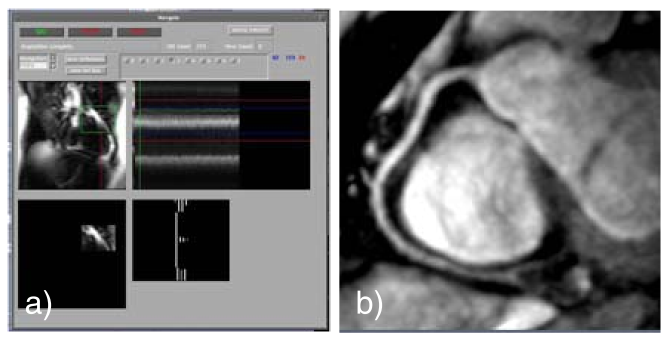

Figure 2. a) Front-end GUI display of the proposed RTI software integrated with the scan tracking with a 2D fat image navigator (top left), timecourse display (top right), template (bottom left), and PAWS[5] bins (bottom right). **b)** An example of a reformatted right coronary artery from a 2D navigator gated 3D SSFP CMRA sequence[3] that was prospectively gated with the PAWS algorithm for scan time reduction (targeted RCA imaging time = 187 sec for 128 accepted heart beats; 2D navigator efficiency from tracking epicardial fat = 63%; [Data from Ref. #3]).

Table 1. Avg. processing time over 100 HBs on the *back-end*.

Back-End Tasks	Processing Time
ROI-size Independent Tasks	
LR-direction 1D FFTs (64 points; 196 lines total)	3.3 ms
ROI-size Dependent Tasks (2D ROI = [74x13]; 962 pixels)	
SI-direction 1D FFTs (256 points; 18 lines total)	5.1 ms
1D LSQ matching for estimate of SI position	0.1 ms
2D LSQ matching for detailed template matching	3.1 ms
Miscellaneous Tasks	
PAWS algorithm	< 0.1 ms
Sending Signal to Waveform Generator	< 0.3 ms
Total *Back-End* Processing Time	~ 13 ms

DISCUSSIONS: The proposed RTI software was successfully implemented on the standard clinical scanner by enabling the pulse sequence to communicate with two software components that run concurrently with 2D navigator-based imaging without the use of any additional dedicated hardware. Acquisition and processing of 2D navigator data in real-time using the proposed method is expected to increase the reliability of free-breathing coronary MRA.

REFERENCES: 1) Henningson et al. MRM In Press. 2) Keegan et al. JMRI 2007;26(3). 3) Kawaji et al. RSNA 2012. 4) Dewan et al. MRM 2008;60(3). 5) Jhooti et al. MRM 2000;43(3). 6) Le Roux et al. JMR 2003;163(1).