Accelerated cardiac cine imaging, with retrospective gating

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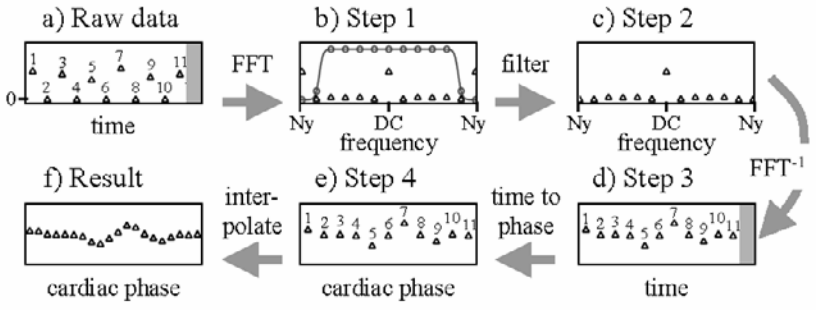
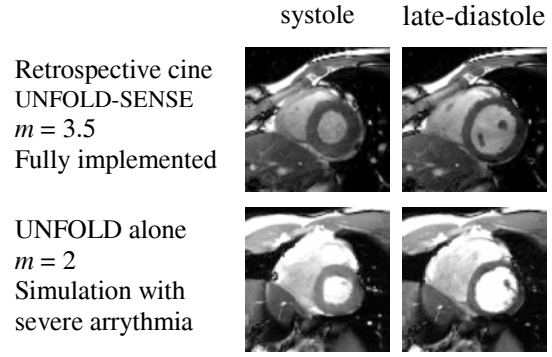
Introduction: There are two main approaches to cardiac gating, in cine imaging: prospective gating, and retrospective gating. While the two may be identical at the acquisition stage, they differ in the way time samples are mapped onto a cardiac phase axis, at the reconstruction stage. Retrospective gating is generally preferred, because it better captures the end-diastolic part of the cardiac cycle, which is when the left atrium contracts and provides a boost in blood volume to the left-ventricle. Because prospective gating mostly misses this crucial part of the cycle, it tends to underestimate the ejection fraction [1]. A third strategy, which could be called 'fully retrospective gating', acquires each k-space location over more than one heartbeat. But it prolongs scan time, and is not typically used.

Parallel imaging is very helpful in cardiac cine, to reduce breath-hold duration and/or to increase the number of slices scanned in each breath-hold. Previous work has shown that fusing parallel imaging with a temporal acceleration strategy can have much impact in reducing the artifact content [2,3]. But to date, this type of work has been done exclusively with prospective gating, as the temporal interpolation needed in retrospective gating was generally believed non-compatible with these acceleration schemes. Clinical impact was limited by the fact that retrospective gating is generally preferred. The present work presents a retrospectively gated cine method, with both spatial and temporal acceleration, which finally makes methods such as UNFOLD, TSENSE or UNFOLD-SENSE compatible with the best gating strategy available.

Theory: The figure on the right describes the several steps of the proposed algorithm. (a) As the acquisition process flip-flops between two sampling functions, each k-space location is sampled on no more than half the time frames. Missing locations are filled with zeros. (b,c) After a temporal FFT, a filter is applied to remove Nyquist-bound artifacts. Due to arrhythmia, more or less temporal frequency points may be present, depending on k-space location. (d,e) After a temporal FFT^{-1}, the time points are distributed over a cardiac phase axis. They may be distributed uniformly (as depicted here), or in any other fashion. As typical in retrospective gating, based on the fact that arrhythmia results mostly from variations in the length of diastole (and not systole), only the spacing of points in the diastolic part of the cycle gets modified in our implementation. (f) The temporal interpolation inherent to retrospective gating is then performed. Once all k-space locations have been processed, k-space matrices are assembled, and parallel imaging is performed. Here, the parallel imaging method introduced in [3] and improved by King [4] and Yan *et. al.* [5] was used.



Results: The method was fully implemented on a 3T GE scanner. A cine dataset was acquired with acceleration of 3.5 (55 lines instead of 192, including calibration lines, using a cardiac array with only 8 coil-elements), and reconstructed as described above. (Data collected from the scanner's memory in real-time, 192x192 matrix, 32x32 cm FOV, 8 mm slices, TR = 3.5 ms, *t* res = 10xTR). In a movie loop, the results play smoothly, confirming that all cardiac phases were well captured. Images at systole and end-diastole are shown in the figure on the right. A simulation was also performed, with fairly severe arrhythmia and no data rejection (mean RR interval = 1s, std = 0.2 s), which for UNFOLD alone (no parallel imaging) yielded an acceleration of 2.0. This was meant as a challenging test, in terms of arrhythmia. Artifacts were faint: at reasonable window settings, as used here, results looked equivalent to the 'truth', and difference images appeared black.



Discussion: As an alternate approach to this problem, one might try generating a large system of equations, with the UNFOLD, parallel imaging and retrospective-gating assumptions built-in, along with sampling and ECG information, and solve these equations with an iterative solver (e.g., conjugate gradients or LSQR). Such approach would be more in line with the types of work in Refs [6,7]. Although undeniably useful, numerical solvers do have weaknesses, as errors in the pre-conditioning or regularization steps may lead to inaccuracies (artifacts and/or amplified noise). Whenever possible, breaking a seemingly large problem into many small ones is considered desirable (for example, gridding non-Cartesian data [8] is faster, simpler, and arguably more robust in certain ways than a 'brute-force' solution). This work shows how a retrospectively gated reconstruction, which includes spatial and temporal acceleration schemes, can also be broken into small steps.

Conclusion: This work describes a fast, simple to implement, seemingly-robust way to fuse retrospective gating with temporal acceleration in cine imaging, immune to noise amplification and compatible with parallel imaging.

References: **[1]** Sievers *et al*. JCMR 2005;7:441. **[2]** Kellman *et al*. MRM 2001;45:846. **[3]** Madore. MRM 2004;52:310. **[4]** King. ISMRM 2005:2418. **[5]** Yan *et al*. ISMRM 2006:3655. **[6]** Hansen *et al*. MRM 2006;55:85. **[7]** Shin *et al*. ISMRM 2006:691. **[8]** Jackson *et al*. IEEE TMI 1991;10:473

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