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EMORe: Motion-robust XD-CMR reconstruction using Expectation-Maximization (EM) algorithm

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Background:

Uncompensated motion artifacts have been a longstanding challenge in free-breathing volumetric cardiovascular magnetic resonance imaging (CMR). A common approach for motion-resolved volumetric imaging with fixed scan time involves retrospectively binning the acquired data readouts into cardiorespiratory bins using self-gating or Pilot-Tone techniques to estimate cardiac and respiratory motion signals.[1] However, the precision of the binning process relies on the quality of the estimated motion signals, which is often compromised by heart rate variability, irregular breathing patterns, and bulk motion. The resulting imperfect cardiorespiratory binning can lead to motion artifacts. To this end, we propose a novel motion-robust extra dimension-CMR (XD-CMR) reconstruction using Expectation-Maximization[2] (EM)-guided binning with outlier rejection (EMORe).

Methods:

After the potentially imprecise initial binning of the readouts using extracted motion signals, we refine the cardiorespiratory binning during reconstruction using the EM algorithm. Additionally, to integrate outlier rejection with EM, readouts not belonging to any valid cardiorespiratory bin, e.g., due to exaggerated bulk motion, are automatically assigned to an extra outlier bin. The proposed EMORe framework, as shown in Figure 1, iteratively performs the E-step to refine the probabilistic (soft) bin assignments and the M-step to improve the image estimate until convergence.

A realistic MRXCAT phantom[3] study was performed to assess the robustness of EMORe framework against uncompensated motion, compared to standard compressed sensing (CS) reconstruction. We simulated imperfectly binned undersampled (R=3.5) noisy k-space data from four reference cardiac frames—from end-diastole (ED) to end-systole (ES)—at the exhale state. As shown in Figure 2, a fraction of the k-space readouts from four exhale-cardiac bins were deliberately misassigned. Additionally, an equal fraction of readouts from an inhale state (outlier, represented by red) was randomly added to all four exhale-cardiac bins to simulate incorrect respiratory gating or bulk motion. We repeated the process 26 times, with the total fraction of bin misassignments ranging from 0 to 50% in increments of 2%.

Results:

Figure 2 shows a representative example, highlighting the excessive motion artifacts observable in the CS images, whereas the EMORe images are artifact-free. The quantitative results are reported in Figure 3. In summary, CS degrades rapidly with bin misassignments, while EMORe exhibits resilience up to 20% misassignments, which is reflected in its significantly lower normalized mean square error (NMSE) and higher structural similarity index measure (SSIM).

Conclusion:

The proposed EMORe framework makes CMR reconstruction with retrospective binning motion-robust by refining the bin assignment of data during reconstruction and integrating outlier rejection to suppress bulk motion. In the next study, we will apply EMORe to reconstruct in vivo 5D flow patient data.

References

1. Falcão MBL, Di Sopra L, Ma L, et al. Pilot tone navigation for respiratory and cardiac motion-resolved free-running 5D flow MRI. *Magn Reson Med*. 2022;87(2). doi:10.1002/mrm.29023
2. McLachlan GJ, Krishnan T. *The EM Algorithm and Extensions: Second Edition*.; 2007. doi:10.1002/9780470191613

3. Wissmann L, Santelli C, Segars WP, Kozerke S. MRXCAT: Realistic numerical phantoms for cardiovascular magnetic resonance. *Journal of Cardiovascular Magnetic Resonance*. 2014;16(1). doi:10.1186/s12968-014-0063-3

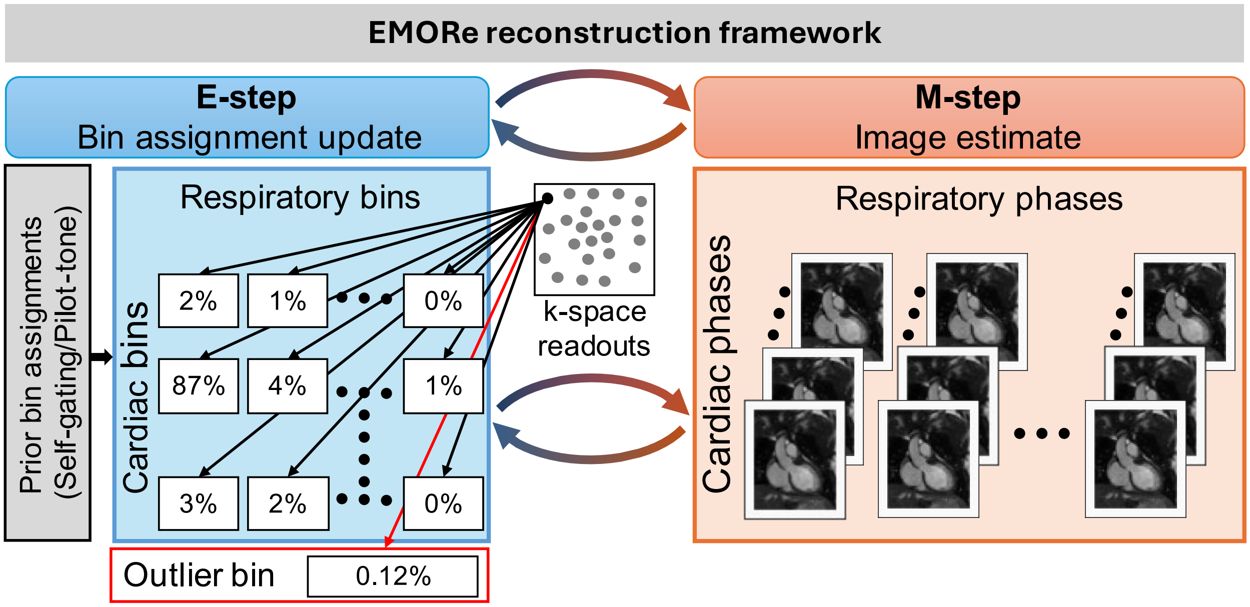

Figure 1: The proposed EMORe framework. (Left) In the E-step, we refine bin-assignment of readouts to valid and outlier bins, given the measured k-space readouts, prior bin assignment from self-gating or Pilot-tone, and current image estimate. (Right) In the M-step, we improve the image estimate using the measured data and the refined assignments. Both steps are repeated until convergence, resulting in motion-compensated images.

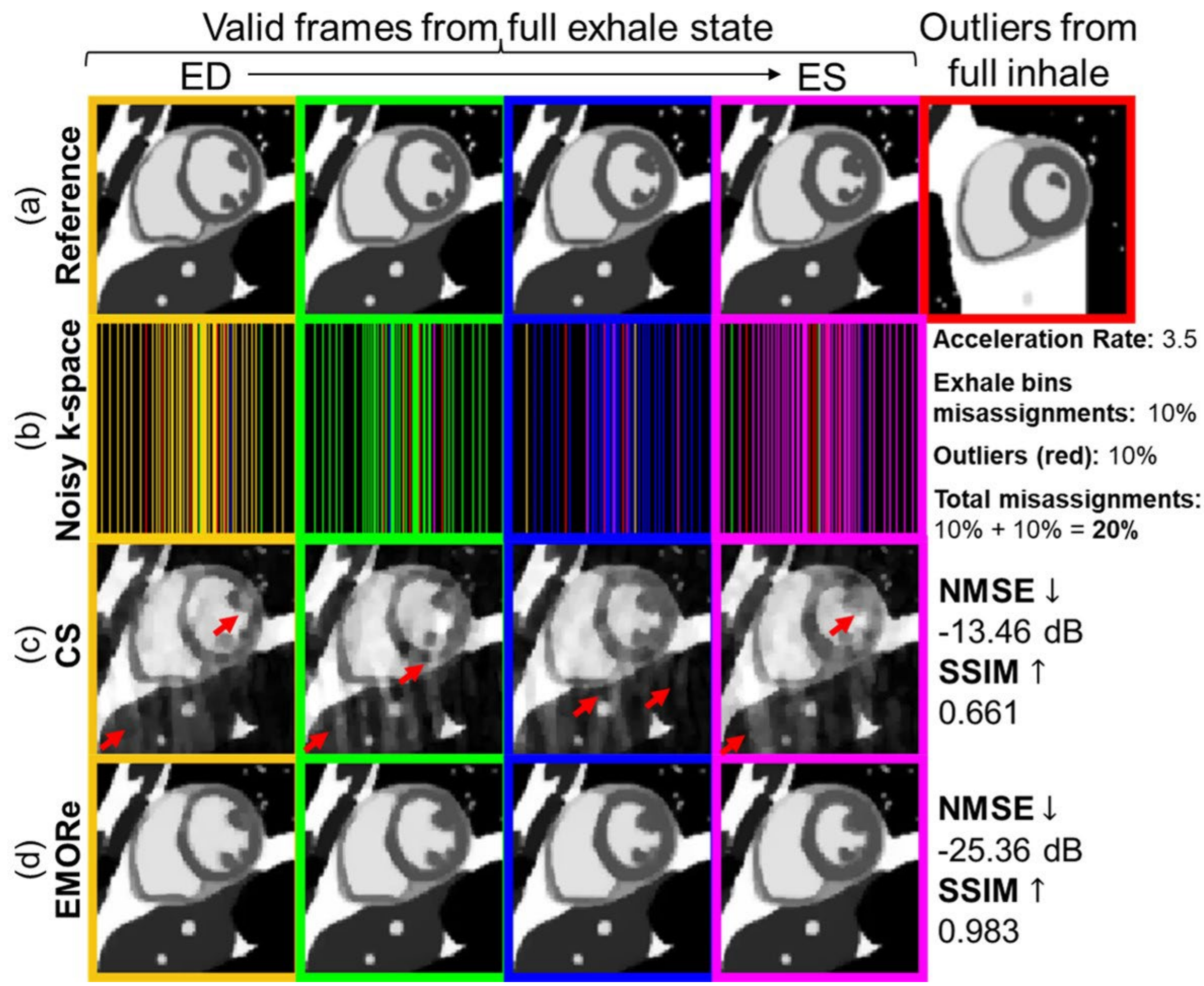

Figure 2: A representative realization of the MRXCAT phantom study. (a) The true reference valid frames representing four cardiac phases—ED to ES—at full exhale. Additional outlier frame (red) represents ES at full inhale. (b) The imperfectly binned k-space data from respective frames, undersampled by factor of 3.5 with additive Gaussian noise, 10% bin misassignments among exhale bins and 10% additive outlier readouts (red) from the outlier frame. (c) The compressed sensing (CS) reconstruction of the valid frames using the binned k-space data with corresponding NMSE (dB) and SSIM with respect to the reference. The red arrows highlight the uncompensated motion artifacts. (d) The EMORe reconstructed images with corresponding NMSE (dB) and SSIM.

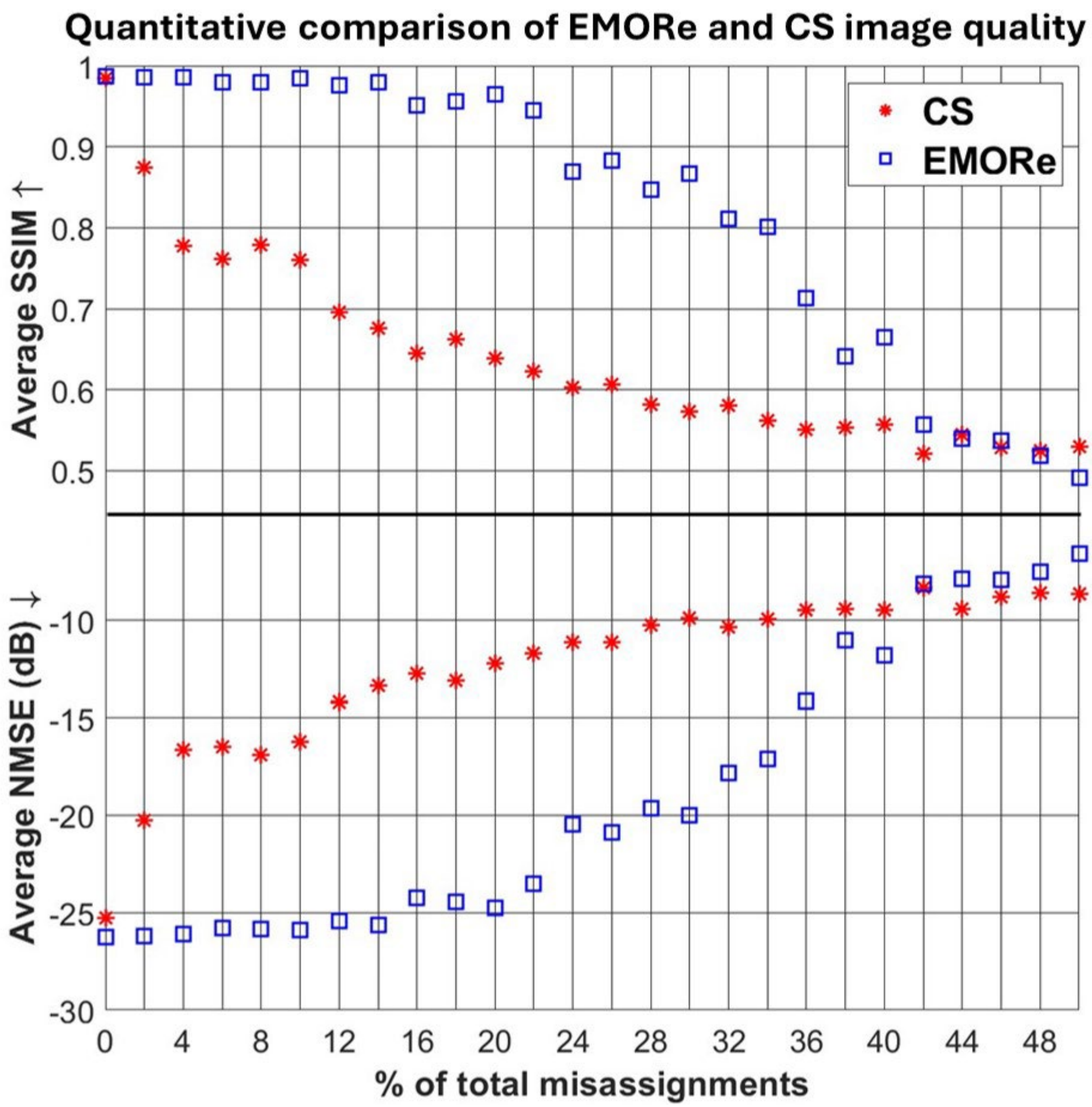

Figure 3: Image quality assessment of EMORe compared to the CS reconstructions against incorrect assignments. For a fixed percentage of total misassignments, the plots display the average (top) SSIM and (bottom) NMSE (dB) of 10 random realizations of misassignment locations. As the percentage of misassignments increases, the CS reconstruction performance degrades significantly, while EMORe demonstrates robustness up to approximately 20% misassignments.