Practicality makes a comeback: Dynamic MRI without the overhead

U. Sümbül[1], and J. M. Pauly[1]
[1]Electrical Engineering, Stanford University, Stanford, California, United States

Introduction: Free-breathing, non-gated time-resolved scans carry great potential for applications such as cardiac imaging, catheter tracking and image guided therapy. However, insufficient temporal resolution and problems with real-time reconstruction have limited their use. The sliding window algorithm solves the second problem, but is known to introduce temporal blurring. Modern approaches such as *k-t* BLAST[1], sparse MRI[2] and PARADIGM[3] provide improved reconstructions. However, they are computationally expensive and inherently non-causal. Thus, real-time reconstruction is not possible even when computational resources are vast. Moreover, they may require separate training scans or longer readouts to embed the training data within the actual scan. In this work, we present a fast, continously auto-calibrating and low-latency acceleration algorithm based on the Kalman reconstruction[4]. The algorithm does not introduce any scanning overhead and works naturally with non-Cartesian trajectories. An incremental motion map update scheme is devised for faster reconstruction. The algorithm is tested via cardiac imaging under changing scan planes.

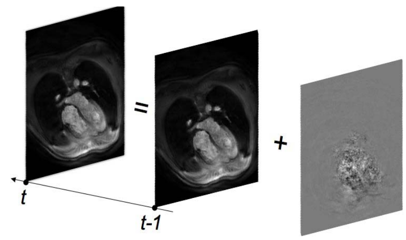

Fig 1 - State evolution model

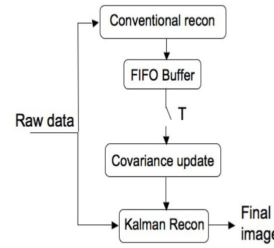

Fig. 2 - Simplified schematic

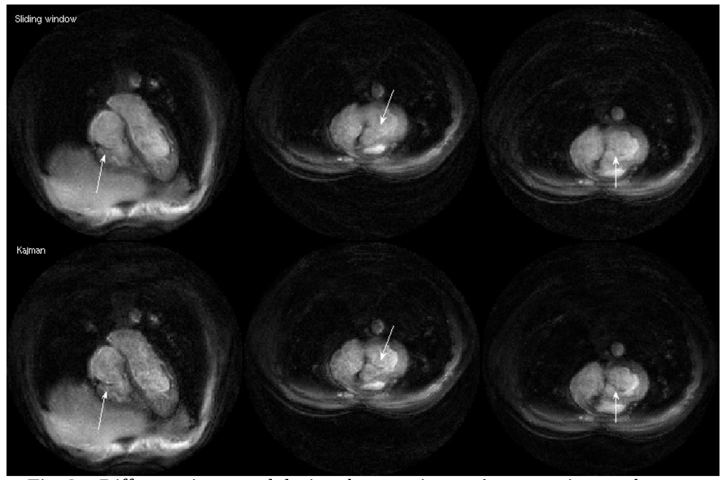

Fig. 3 – Different views used during the experiment. Arrows point out the depiction of the cardiac valve.(top: SW, bottom: Kalman)

Theory: The Kalman reconstruction is based on the observation that image pixels experience a wide range of temporal dynamics and blindly applying the same sliding window for each pixel is not optimal(*Fig. 1*). The algorithm estimates the second-order statistics of individual pixels and reconstructs accordingly. An important feature of the algorithm is causality. Hence, a continuously auto-calibrating design is the only major obstacle towards a practical real-time algorithm. The state-space model in [4] needs the covariance of the difference between consecutive images. The common approach of acquiring low-resolution training data nullifies any hopes of adaptive reconstructions. Since acquisition is asynchronous in dynamic MRI, *hot* pixels should still exhibit rapid changes in the conventional low frame rate reconstruction. We report that a time window of a few seconds is enough for reasonable estimates. Moreover, when a first in-first out(FIFO) buffer of conventional images is maintained, covariance updates of the zero mean noise processes can be performed incrementally with minimal computational cost. Thus, for a speedup factor of *T*, the algorithm performs essentially only 2 undersampled gridding and 2 Fourier operations per image and a single gridding reconstruction every *T* images. *Fig. 2* shows a simplified system view.

Methods: The RTHawk real-time system[5] is used with a fat-suppressed GRE sequence, a 7-interleaf spiral readout and a 4-element cardiac array in a 1.5T scanner. No ECG-gating or breath-holding was used. FOV/res = 34 cm/2 mm. TE/TR = 3.8 ms/20.6 ms. We started the experiment with a four-chamber slice. The slice is first rotated by 90° and then shifted in the middle of the experiment(*Fig. 3*).

Results: *Fig. 4* shows the time course of a vertical line passing through the valve of the first view, obtained by the sliding window reconstruction(top) and the auto-calibrating Kalman reconstruction(bottom). The frame rate is 44.5 fps. The Kalman algorithm exhibits a reduction in temporal blur and tracks the cardiac valve much better. Moreover, the algorithm adapts to different scenarios almost instantaneously.

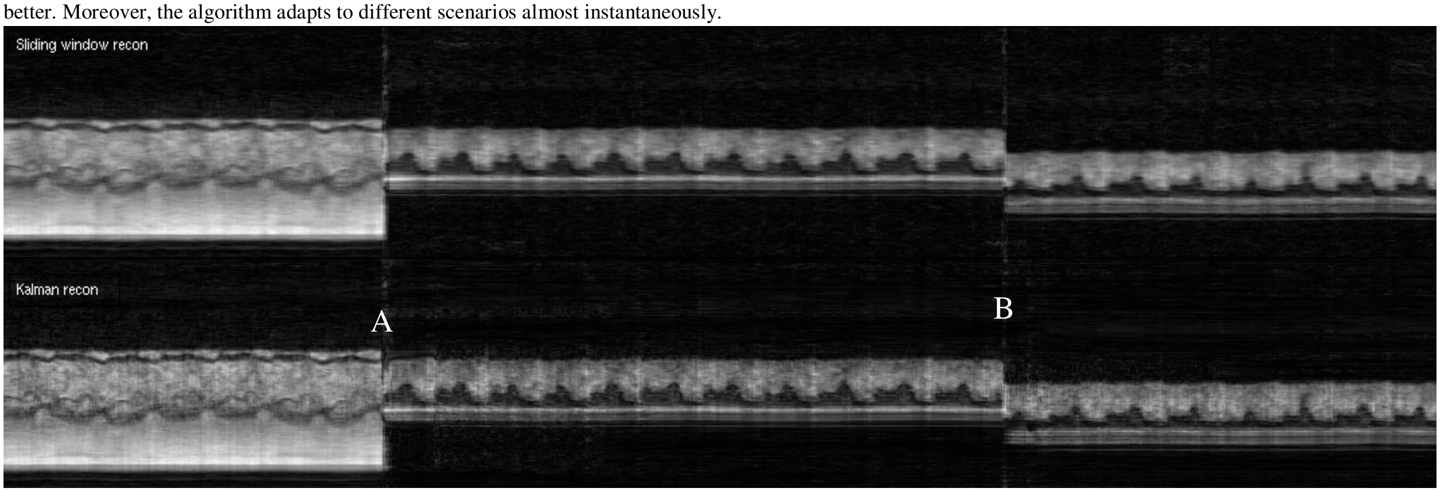

Fig. 4 – Time course of a vertical line passing through the valve in the first view. Kalman reconstruction(bottom) decreases the temporal blur and adapts to changes almost instantaneously. Rotation is applied at **A** *and shift is applied at* **B**.

Conclusions: We proposed a causal algorithm that does not require extra data acquisition. The algorithm is fast so that real-time reconstruction is viable. The approach should be useful when real-time imaging is a necessity as in image guided therapy because the algorithm adapts to changing conditions almost instantaneously. The reconstruction complexity is comparable to the sliding window algorithm while the tracking capability of the reconstruction is better than the sliding window algorithm.

References: **[1]** Tsao J, et al., Magn Reson Med, 50:1031-1042, 2003 **[2]** Lustig M, et al., IEEE Sig Proc Mag, 72-82, March 2008 **[3]** Aggarwal N and Bresler Y, Magn Reson Med, 24, Aug 2008 **[4]** Sümbül U, et al., 16^{th} ISMRM, 792, 2008 **[5]** Santos J, et al., IEEE EMBS 26^{th}, 1048, 2004 2003

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