Time Domain Principal Component Analysis for Rapid, Real-Time MRI Reconstruction from Undersampled Data

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INTRODUCTION

- Linac-MR hybrids allow for the real time imaging and tracking of target structures during a treatment. In order to properly do real time imaging a minimum of 4 frames per second is desired.
- Currently the Linac-MR at the Cross Cancer Institute (CCI) is capable of 4 frames per second for a single image. However, a faster frame rate would proved more flexibility for MR sequence choice, or the capability for volumetric acquisitions.
- A previous study at the CCI looked into using an acceleration method based on Principal Component Analysis (PCA) for real time MRI.[1] This method was successful at accelerating imaging for real-time reconstruction - however image quality was found to degrade over time.[1]
- In this work we reframe the use of PCA to create an accelerated imaging and reconstruction strategy that is robust through time. This new strategy characterizes time evolution of k-space with PCA, a characterization that is constantly updated as new frames are acquired.

AIM

To develop a robust acceleration method for MRI using Principal Component Analysis for use in real time imaging on a Linac-MR hybrid device.

METHOD

- The original PCA method used an initial (fully sampled) database of 30 dynamic frames to characterize Principal Components (PCs) of the images, which could then be used to fit to subsequent undersampled frames. As noted above, however, the database was seen to become outdated over time.
- In the new strategy presented here, PCs are used to characterize the time evolution of k-space. This characterization is constantly updated a window of M frames (60 frames in this implementation) to be relevant to the current frame. Figure 1 provides a visual representation of the proposed method.
- A set of complimentary undersampling patterns, typically four, are applied evenly throughout the 60 frames (see Figure 2). Within these undersampling patterns, a set of core phase encodes near the centre of k-space is sampled in every frame. These core phase encodes are used to calculate the PCs which represent the time evolution of k-space. The peripheral k-space is incoherently undersampled so that each phase encode is sampled once every four frames. A pre-determined number of PCs are fitted to this undersampled data within the time domain.
- By using this fitting method, un-acquired k-space data in the current frame can be estimated and used for reconstruction. A simple matrix inversion technique (using the pseudo-inverse) was used for fitting. Reconstruction time was ~50 ms/frame.

FIGURES

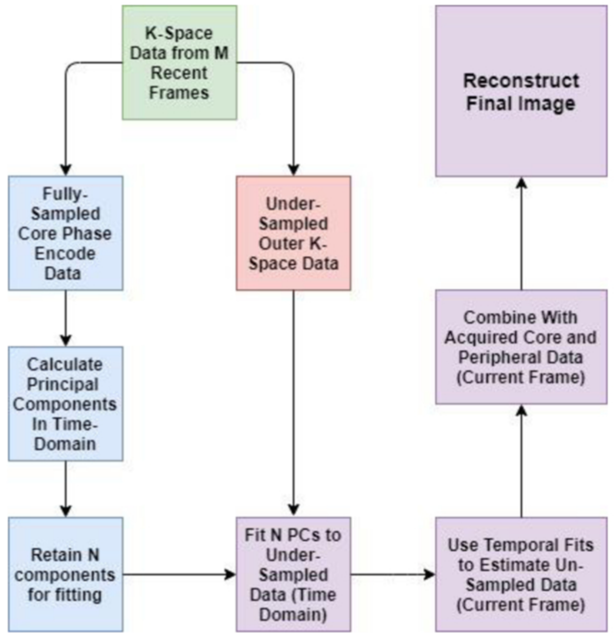
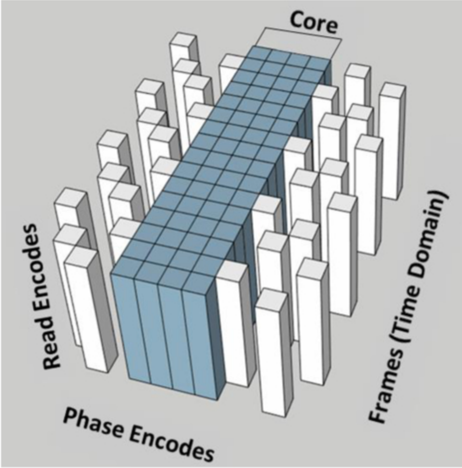


Figure 1: *Reconstruction flow chart for a single frame.*

Figure 2: *Schematic of the acquisition pattern for this new technique. Core data is acquired every frame, but outer k-space data is under-sampled in a repeating pattern.*



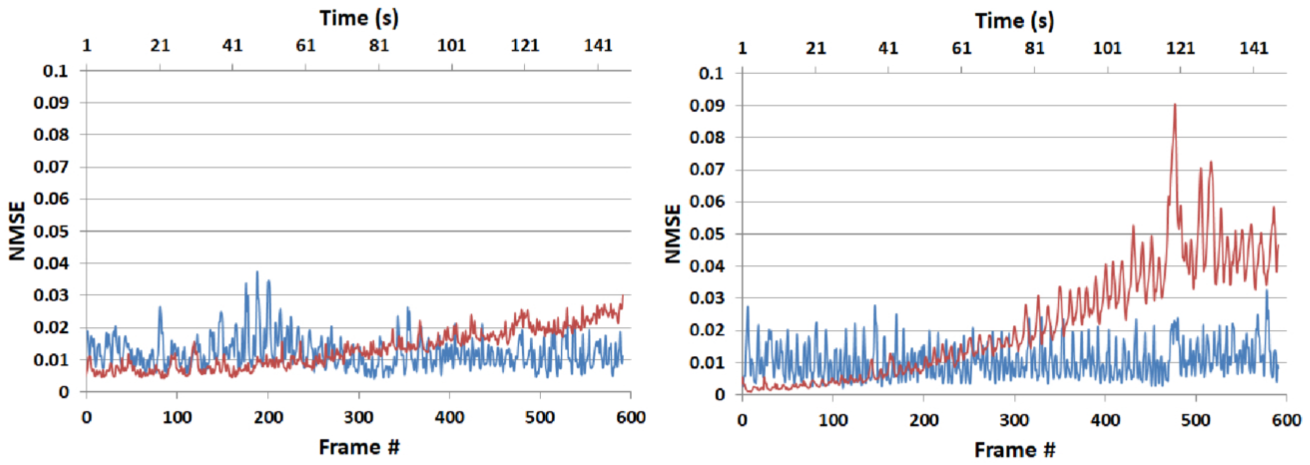


Figure 3: *Comparison of NMSE over time between the Original PCA Method and the New PCA Method using 2 Principal Components for two different patients. Red plots represent the Original Method while blue represents the New Method.*

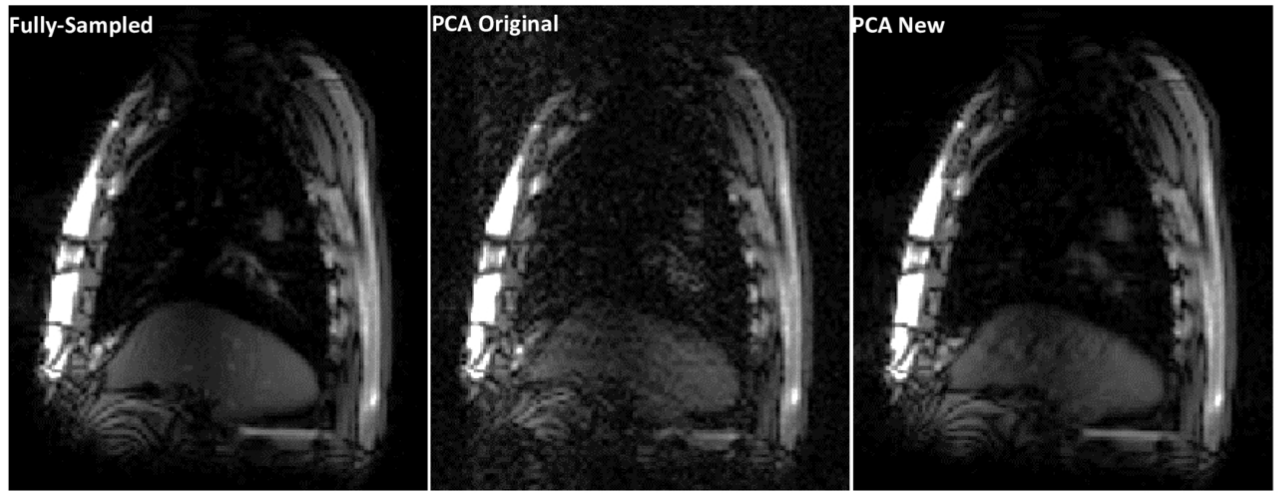
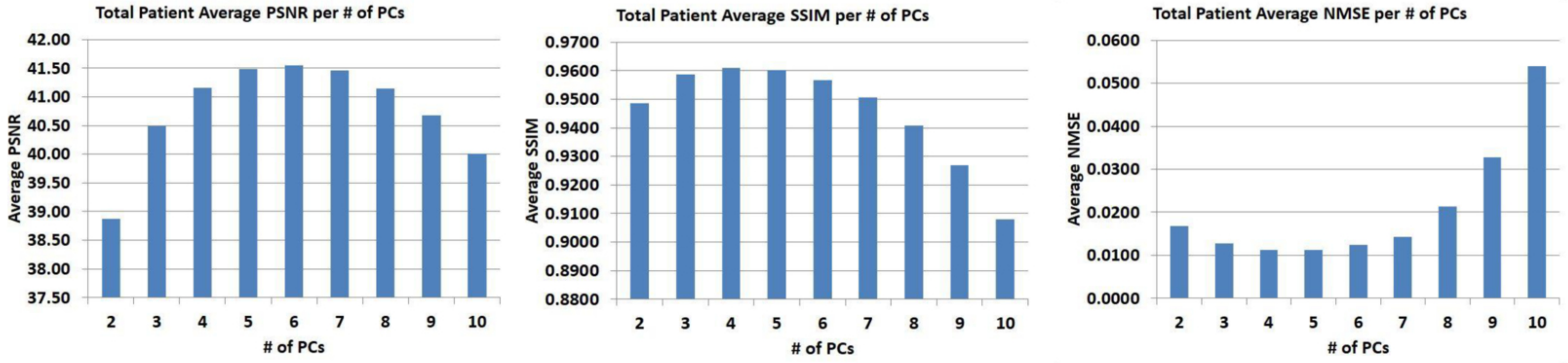


Figure 4: *Reconstructed Image of the last frames for the patient corresponding to the right chart in Figure 3. As is reflected in the NMSE from Figure 3, the new method is more robust to artifact for prolonged real time acquisitions.*

Figure 5: *Total Patient Average Normalised Mean Square Error (NMSE), Peak SNR (PSNR) and Structural Similarity Index (SSIM) per number of Principal Components (PCs) kept.*



ANALYSIS

- The reconstruction method was applied retrospectively to fifteen lung patients using MATLAB Software.
- After reconstruction, each retrospective accelerated frame was compared to its fully-sampled counterpart to assess the fidelity of the images produced.
- Several metrics were used to assess the quality of the accelerated reconstructions, including normalized-mean-squared error (NMSE), Peak Signal-To-Noise (PSNR) and Structural Similarity (SSIM).

RESULTS

- As shown in Figure 3 our method appears to be more robust over time when compared to the previous PCA reconstruction method, although the original method outperformed initially.
- Figure 4 is a demonstration of the last reconstructed frame from the patient represented by the right chart in Figure 2. It can be seen that there is significantly more artifact in the previous method as compared to our new method
- The comparison of each method was done with an acceleration factor of approximately 3. The acceleration factor can be controlled by changing the size of the core and the density of sampling in peripheral K-space.
- A comparison was done to find the optimal number of PCs to utilize during reconstruction. As shown in Figure 5, ~5 PCs provides the overall best results for this particular undersampling pattern. More PCs seem to provide more fidelity but contribute more uncertainty which appears as noise.
- Occasionally spikes of high NMSE would appear in certain frames during reconstruction. Further investigation will be required to identify the cause.

CONCLUSIONS

- This reconstruction method appears to be more robust over time when compared to the previous method.
- Using NMSE, PSNR and SSIM, the optimal number of PCs used for fitting could be tuned for a given acceleration pattern.
- Further investigation is needed to determine how this method behaves at higher acceleration factors.

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