Prior Information Constraint Compressed Sensing (PICCS): A Novel Technique for MR Myocardial Perfusion Imaging

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INTRODUCTION

Recently, a novel reconstruction technique called PICCS (Prior Information Constraint Compressed Sensing) [**1**] has been developed. This technique enables accurate reconstruction of high SNR images with large undersampling factors (>50 in 2D). In this work, PICCS and its utility in MR perfusion imaging is investigated. In PICCS, the sparsity of the difference image between the target image and the high SNR prior image is exploited. When this PICCS sparsity is combined with other known sparsifying transforms such as total variation (TV) norm used in compressed sensing (CS), PICCS enables accurate reconstruction of images using fewer projections than required by CS and standard filtered backprojection (FBP) reconstruction.

MATERIALS AND METHODS

Images were reconstructed iteratively by minimizing the following objective function subject to the data consistency condition: $TV(I - I_P) + \lambda TV(I)$, s.t., $F\{I\}=P$, where I denotes the image to be reconstructed and I_P denotes the prior image reconstructed from the union of the acquired data set using a subset or all of the time frames. P denotes the measured projections at each time frame. $TV(I)=\sqrt{(I_{m+1,n}-I_{m,n})^2+(I_{m,n+1}-I_{m,n})^2}$ is the total variation norm of the image I. A conjugate gradient method was utilized to iteratively minimize the object function. The parameter λ is utilized to trade off the sparsity of the gradient image, $TV(I)$, and the PICCS sparsity, $TV(I-I_P)$, which is the TV norm of the difference between the target image and the prior image. The PICCS reconstruction method was validated using myocardial perfusion data obtained swine with an ECG-gated 3D hybrid radial/Cartesian (stack of stars) MR acquisition technique [**2**]. For each subset of interleaved radial acquisitions in the *kx-ky* plane, a series of *kz* partitions were acquired. Typical scan parameters for an ECG-gated, saturation recovery hybrid gradient echo imaging technique are TR/TE/Flip = 3.4 ms/1.6 ms/20°, FOV = 320 mm x 320 mm, 96 mm slab with 6-10 partitions, and RBW = ±62.5 kHz, 128-256 X 8-16 projections per partition acquired in a single breathhold during the first pass of 0.1 mmol/kg contrast agent injected at 2-3 ml/s. The radial projections were converted into Radon transforms using the projection-slice theorem [3] and the images were reconstructed using standard algebraic reconstruction technique (ART) used in x-ray CT [**3**] without gridding.

RESULTS AND DISCUSSION

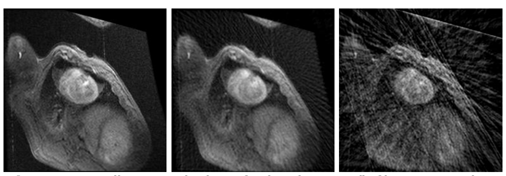

Figure 1: *Fully-sampled perfusion image (left). Comparison of simulated PICCS (middle) and FBP reconstruction (right) using only 16 projections.*

Figure 1 compares perfusion simulation results obtained with the PICCS technique using only 16 projections (an acceleration factor of 25) to a fully sampled original perfusion image and that reconstructed with FBP. A sliding-window consisting of 8 time frames were used to constrain PICCS reconstruction. As clearly seen from the images, the PICCS technique produces a relatively artifact-free image with high SNR (middle), whereas the FBP reconstructs an image (right) with significant streak artifacts. This leads us to believe that PICCS is well-suited for reconstruction of high SNR and temporal images with high temporal resolution needed for quantitative myocardial perfusion imaging.

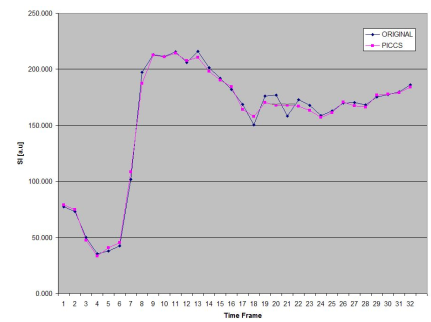

Figure 2: *The corresponding LV signal vs. time for PICCS and fully sampled images is shown.*

To evaluate the temporal accuracy, the signal-intensity-time curves derived from the PICCS images were compared to those derived from the fully-sampled Cartesian images in the left ventricle. As clearly seen from Figure 2, the PICCS technique (cyan) clearly demonstrates the temporal characteristics of the LV cavity and is in good agreement with that of the fully-sampled Cartesian images (blue), which is essential to accurately quantify myocardial perfusion. With appropriately selected MR acquisition parameters, a PICCS time series can convey the temporal dynamics with good fidelity for extremely undersampled data. There is no doubt that with the continued improvements in our PICCS techniques, higher acceleration factors can be achieved.

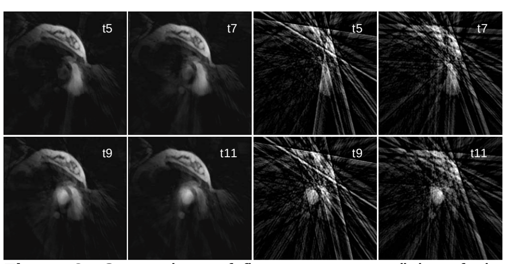

Figure 3: *Comparison of first-pass myocardial perfusion images obtained with a 3D MRI technique. Images reconstructed using only 8 projections with PICCS (left) and FBP (right) are shown.*

Figure 3 shows the myocardial perfusion images reconstructed using only 8 projections with the PICCS (left) and FBP (right) methods using data obtained with the 3D stack-of-stars myocardial perfusion imaging technique. PICCS offers an acceleration factor of 50 compared to a fully-sampled radial technique, which is critical for quantitative myocardial perfusion imaging. As clearly seen from the images, the PICCS technique provides relatively artifact-free images, whereas the FBP technique leads to images with significant streak artifacts.

CONCLUSIONS

The PICCS technique, which enables accurate reconstruction of images from projection datasets with an undersampling factor of 50 or more in 2D acquisitions, may provide a new foundation for myocardial perfusion imaging by providing high spatial and temporal resolution images with high SNR.

REFERENCES

1. Chen, *et al.*, Phys. Med. Biol., in press. **2.** Peters, *et al*., MRM*,* 43, 2000. **3**. Kak and Slaney, IEEE Press, New York, 1988.

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