# Adaptive Un-Gated Cardiac MR Fluoroscopy: Validation by a Dynamic Phantom Study

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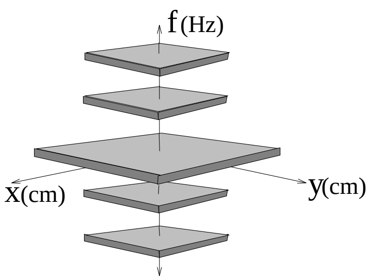
## Introduction

The goal in cardiac MR imaging is to reconstruct a time-varying image (TVI) from samples of its Fourier transform. Since MR data acquisition is limited in speed, it is usually not feasible to sample each point in k-space at the required Nyquist sampling rate. In [1], the authors presented a model-based approach that adapts the MR data acquisition and reconstruction to the spatial and temporal characteristics of the object being imaged. This permits one to reconstruct a high-spatial and temporal resolution movie of the object from data acquired at a sub-Nyquist rate. In this paper MR experiments using a mechanical cardiac phantom demonstrate the effectiveness and advantages of the adaptive approach.

## Theory



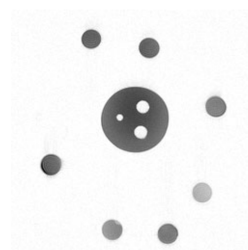

***Banded Spectral Model:*** The banded spectral model, introduced in [1], characterizes the cardiac TVI by its spatio-temporal-spectral (STS) support as shown in the adjoining figure. This model captures the approximate periodicity of cardiac motion and also the fact that the highly dynamic portion of the FOV is localized in the central heart region. The specific STS support for a subject depends on his heart-rate, heart-rate-variability and hear position, and can be estimated using a calibration MR scan as described in [2].

***Adaptive Acquisition:*** Based on the banded spectral model, we seek to determine when and where to sample in k-space so that the underlying TVI can be reconstructed from the acquired data and the requirement on sampling speed is minimized. We also need to satisfy the time-sequential (TS) sampling constraint i.e. only one k-space line (for spin-warp imaging) can be acquired at a given time-instant. This problem was studied in [3], and leads to a TS-acquisition scheme that prescribes the order in which the phase-encodes need to be applied and the repetition time $T_R$

***Reconstruction:*** The TVI $I(\mathbf{r},t)$ can be efficiently reconstructed from the TS-sampled data by filtering the data with a multidimensional (spatial and temporal) linear shift-invariant filter that has unit magnitude response over the STS support of the object.

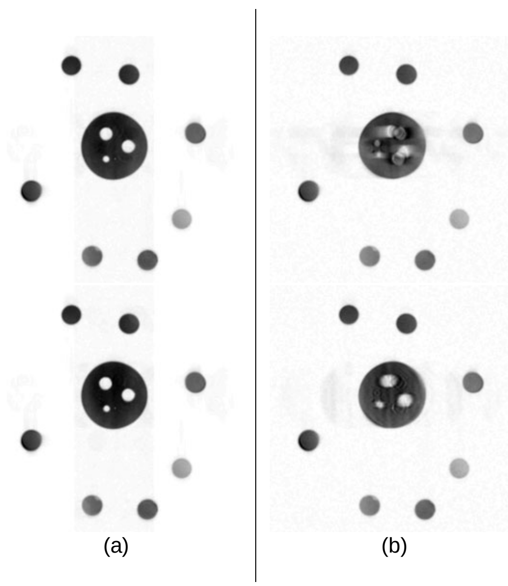
## Method

The TS imaging method was tested using a FLASH pulse sequence on a VARIAN/SISCO 4.7T MR scanner. Figure 1 shows a 256x256 static snapshot of the mechanical phantom that was constructed to mimic the cardiac TVI characteristics as outlined above. The central disk (bottle containing $CuSO_4$ gel) with vessel-like inclusions was rotated in-plane to-and-fro using a stepper motor which could be software controlled. The outer region of the FOV contained a few static disks (test-tubes with $CuSO_4$ gel) that modeled the periphery of the thoracic slice which is relatively static. The motor was driven at 0.2Hz, and the STS support of the dynamic object estimated using a calibration scan. The first 10 harmonic bands of the STS support captured 93% of the dynamic energy of the TVI and the dynamic region occupied 1/3$^{rd}$ of the FOV along each dimension. The TS-acquisition scheme for this STS support was computed and the $T_R$ for reconstructing a cine with 256*256 image frame size, was found to be 17.8ms. This is almost 18 times larger than the Tr=1ms that would be required using a non-adaptive progressive sampling scheme in which adjacent k-space lines are acquired sequentially. MR data was acquired according to the prescribed TS sampling pattern. For comparison data was also acquired at more than twice the temporal sampling rate ( $T_R = 8ms$ ) using the non-adaptive progressive sampling pattern.



## Results and Discussion:

The adjoining figure shows two frames (at time instants 5s apart) from the cines reconstructed using (a) the adaptive TS-sampling approach and (b) the progressive sampling scheme. One can see that the adaptive scheme produces virtually artifact-free reconstructions as opposed to the non-adaptive scheme. Furthermore, since the dynamic object is rotating at 0.2Hz, the object was in the same phase of its motion at the time-instants shown. This is clearly reflected in the TS-sampled reconstruction, but not in the progressively sampled case. This demonstrates that the adaptive scheme can produce artifact free reconstructions that faithfully capture that underlying dynamics of the imaged object even when acquiring at less than half the rate of non-adaptive methods.



(a) (b)

## References

[1] Zhao, Q, Proc. ISMRM, pp 1776, 2001
[2] Aggarwal, N, and Bresler, Y, Proc. ISBI, 2002
[3] Willis, N and Bresler, Y, IEEE Trans Info Theory, 43:190, 1997

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