The KLT Filter as a method of "Smart Averaging" to improve SNR in real-time cine MRI

Y. Ding[1], Y-C. Chung[2], and O. P. Simonetti[1]

[1]The Ohio State University, Columbus, OH, United States, [2]Siemens Medical Solutions USA, Inc., Columbus, OH, United States

Introduction: It has been shown that Karhunen-Loeve transform (KLT) filter can be applied to real-time dynamic cardiac MR images to improve the signal-to-noise ratio (SNR) without compromising the boundary sharpness [1]. KLT filtering takes advantage of temporal redundancy and can be viewed as a kind of "smart averaging" without the need for image registration. Since cardiac motion is quasi-periodic, the temporal redundancy of real-time cardiac MR images increases with the number of cardiac cycles included. Therefore, acquisition of a longer series of images covering more cycles can be used to improve the performance of the KLT filter, resulting in greater SNR gain. In this abstract, we show how the SNR of KLT filtered images increases with the number of frames in real-time cine imaging of the heart.

Theory: Because of the unitary nature of the KLT transformation, the mean noise variance in the original images σ_o^2 and that of the filtered images σ_f^2 are related [1]:

$$\sigma_f^2 / \sigma_o^2 = p / N \qquad (1)$$

where p = eigenimages cutoff and N = the total number of images. All eigenimages containing significant spatially coherent structures should be kept to avoid boundary blurring and fine structure smearing. Because real-time cardiac images are quasi-periodic, we hypothesis that when N increases, p increases at a lower rate. Therefore, SNR enhancement is expected to increase with the number of frames acquired.

Methods: The study was approved by our institution's Human Subjects Committee and all subjects gave written informed consent to participate. Nine free-breathing 256-frame real-time cardiac MR cine series were acquired without ECG synchronization in short-axis, horizontal long-axis, and vertical long-axis views in three healthy human subjects. A real-time steady-state free precession (SSFP) cine sequence [2] combined with the TSENSE [3] parallel imaging method with acceleration factor 4 was used. The imaging parameters were: voxel size = 2.08 × 2.08 × 8 mm^3 , 192 × 144 matrix, flip angle = 66 degrees, temporal resolution = 60.0 ms, TE = 1.04 ms, bandwidth = 1185 Hz/pixel, and scan time = 16 s. for each series. All images were acquired on a 1.5T clinical MRI system (MAGNETOM Avanto, Siemens Healthcare Inc., Erlangen, Germany) with a 12-element cardiac phased-array coil. KLT filter was applied to each image series. The number of frames included in KLT filtering was varied from 32 to 256 to simulate acquisition times from 2 s. to 16 s.. Shrager et. al. proposed that the full-width-at-full-maximum (FWHM) of the autocorrelation function is a good measure of structured pattern in spectroscopic signals [4]. We used this criterion to determine KLT filter cutoff p by removing any eigenimages with autocorrelation FWHM $\leq$ 2.0 pixels as containing only noise. This criterion has been shown to correspond well to visual inspection [1].

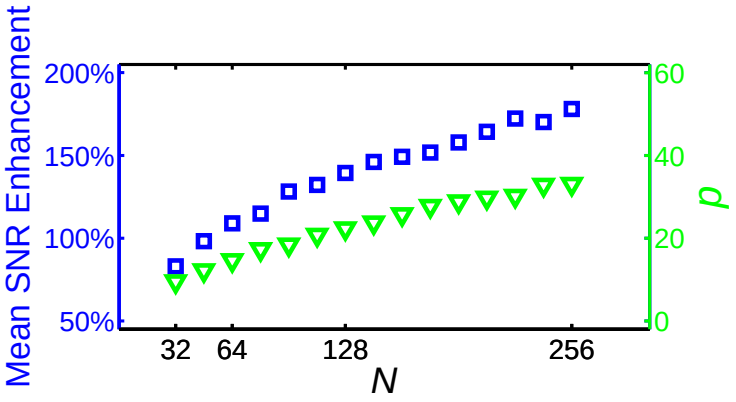

Fig. 1. The SNR enhancement (defined as the percentage increase) in the KLT filtered images increases with total number of frames N. Eigenimage cutoff p increases with N, but at a lower rate.

Results and Discussion: Fig.1 shows that the SNR gain and the eigenimage cutoff of the KLT filter increases with the total number of frames acquired. When N = 256 (16 s. of imaging) the mean SNR gain is over 170%. Our results indicate that KLT filter provides a means of trading scan time for image SNR in real-time, free-breathing, cine MR. Note that the eigenimage cutoffs of the KLT filter increase too, but at a much lower rate. This implies the quasi-periodic nature of the cardiac motion over multiple heartbeats. Compared to traditional averaging of cines acquired with free breathing [5], the temporal KLT filter is a "smart averaging" process with no requirement for image registration.

Conclusion: We have demonstrated that the combination of prolonged acquisition time and the KLT filter is a practical way to recover SNR. Further experimental study is warranted to optimize the image acquisition time in the clinical protocol.

References: [1] Ding Y, et.al. Proc. ISMRM p2863, (2008). [2] Carr JC, et.al. Radiology, 219: 828-834 (2001). [3] Kellman P, et.al. MRM 45: 846-852, (2001). [4] Shrager R, et. al. Anal Chem 54:1147 -1152 (1982). [5] Kellman P, et.al. MRM 59: 771-778, (2008).