# KLT AND WAVELET FILTERING: REDUCING NOISE IN HIGHLY ACCELERATED DYNAMIC IMAGES

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**Introduction:** Real-time (RT) cardiac cine imaging typically sacrifices signal-to-noise ratio (SNR) to achieve sufficient spatial and temporal resolution using parallel imaging [1]. Traditional post-processing techniques such as spatial and/or temporal low-pass filtering can enhance image SNR but typically at the expense of edge sharpness, inevitably causing image blurring.

In our current study, we describe a new approach to denoising dynamic image series by simultaneously taking advantage of the intrinsic spatial and temporal redundancies of RT cardiac cine. This new image filtering technique combines two well-established methods: temporal Karhunen-Loeve transform (KLT) [2] and spatial adaptive wavelet filtering [3]. This is a fully automatic method that neither requires estimation or user selection of any free parameters, nor acquisition of training data. In vivo experiments show that this new approach to denoising of dynamic image series can improve SNR significantly without visible edge blurring.

**Methods:** The proposed approach has three steps: 1. Apply the KLT along the temporal direction, generating a series of "eigenimages". Because of the high temporal correlations, most of the energy is concentrated into a few eigenimages. 2. 2-D spatial wavelet filter with adaptive threshold is applied to each eigenimage. An adaptive threshold is used to define the wavelet filter strength for each of the eigenimages based on the noise variance and standard deviation of the signal, resulting in stronger filtering of the eigenimages that primarily contain noise. 3. Apply the inverse KLT to the filtered eigenimages to generate a new series of cine images with reduced image noise.

The combined KLT+wavelet filter approach was compared with another 3D (time, plus two spatial dimensions) filtering technique, 3D adaptive wavelet filtering. Images were acquired in vertical, and horizontal long-axis, and short-axis views in three healthy volunteers using SSFP real-time cine on a 3.0T MR scanner (MAGNETOM Trio, Siemens Healthcare, Germany). Imaging parameters were: TGRAPPA with parallel acceleration rate = 6, 192 × 96 image matrix reconstructed from 192 x 16 acquired k-space matrix, 6 mm thick slice, flip angle=48$^o$, TE/TR = 1.0/2.56 ms, pixel bandwidth=1447 Hz/pixel, FOV = 380 × 285 mm$^2$. A total of 256 images were acquired per image series over a 10.48 second acquisition during free-breathing.

Image SNR after filtering was assessed using the subtraction method [4] calculated in a region-of-interest (ROI) that covered the whole heart. Image sharpness was measured as the distance between 20% and 80% of the total rise or fall along a cutting line perpendicular to the boundary of the myocardium and the blood pool. The image sharpness measurements were averaged over N frames to cover one cardiac cycle [4].

The advantage of acquiring a longer image series to increase the level of temporal redundancy was also explored by investigating SNR post-filtering in image series ranging in length from 32 frames to 256 frames.

**Results:** Figure 1 demonstrates that the combined KLT+wavelet filter approach has better SNR gain compared to 3D wavelet filter (From T-test measurements, H=1 and p=0.0216). Both filtering approaches demonstrated higher SNR gain when more images were included. The image edge sharpness for the combined KLT+wavelet filter approach was observed to be superior to that of 3D wavelet by 15.13% as shown in Figure 2. Edge sharpness was not affected by the length of the image series.

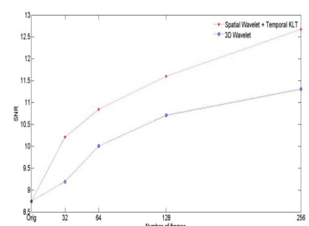


Figure 1: SNR comparison of Combined KLT+Wavelet filter and 3D wavelet filter

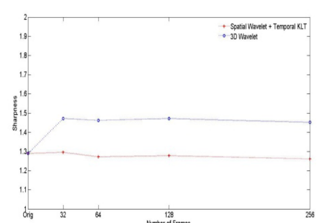


Figure 2: Sharpness expressed as distance in pixels across an edge; higher values = reduced sharpness. KLT+Wavelet filter demonstrates higher sharpness than 3D wavelet.

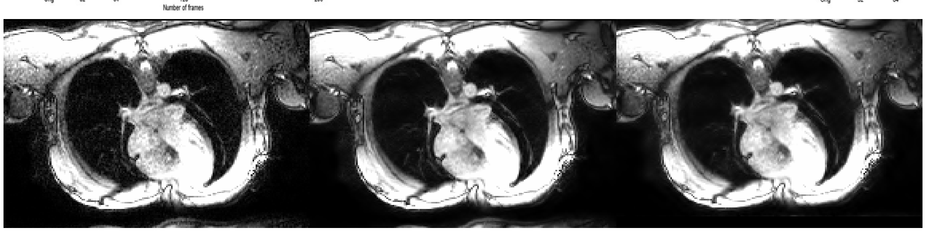

Figure 3: (a) Original Image (b) Output of Combined KLT+Wavelet Filter (c) Output of 3D Wavelet Filter

**Discussion and Conclusion:** Both the KLT+wavelet and 3D wavelet filtering approaches demonstrated the ability to significantly increase the SNR in highly accelerated (rate 6) dynamic real-time cine images without degradation of edge sharpness. The denoising performance of both methods also increased with increasing series length; however, across all series lengths, the KLT+wavelet filter demonstrated superior noise reduction The series length can be easily extended without penalty in free-breathing real-time cine acquisitions, providing another parameter that can be traded for SNR through the use of these filtering approaches. The method can be easily applied to other dynamic imaging methods that may be lacking sufficient SNR, such as real-time velocity imaging and first-pass perfusion imaging.

**References:** [1] Jekic M, et al, J CAriovasc Magn Reson 10 (2008) [2] Ding Y, et al, Magn Reson Med 63:782 (2010) [3] Chang G, et al, IEEE Trans. Image Processing (2000) [4] National Manufacturers Electrical Association Standards (MS 1-2008)