Choice of Bandpass Filter on Accuracy of Myocardial Deformation Recovery With SinMod

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Introduction

Tagged MRI has been an excellent technique for measuring myocardial deformations and cardiac mechanical functions since its development in the late 1980s [1, 2]. In data processing, a number of approaches have been proposed in recent years [3]. Among all, frequency-based methods have become more widely popular for analysis of myocardial displacements [4, 5]. In particular, the SimMod [5] has the distinct advantages over HARP analysis which has become popular for frequency domain analysis of tagged images. Bandpass filtering the off-center peak of tagged image spectrum remains a critical step for accurate recovery of the cardiac motion with SinMod. In this abstract, we compared the performance of three different types of bandpass filters in analyzing myocardial deformation using the SinMod method.

Methods

Applying a bandpass filter in tagged MRI processing means zeroing all frequency components outside a cutoff frequency of an off-center peak. The reason for doing the filtering in the frequency domain is generally because it is computationally faster to perform two 2D Fourier transforms and a filter multiplication than to perform a convolution in the image (spatial) domain. In this abstract, three different types of bandpass filters, i.e., disk (ideal low-pass filter), Butterworth, and squared cosine filter were applied and compared. Their formulas are shown in Table 1. In SinMod, the intensity distribution around each pixel is modeled as a cosine wave front. A band-pass filter is applied to isolate off-center spectral peaks upon which a lowpass and a highpass filters are used followed by inverse Fourier transformation. Both phase and frequency for each pixel are determined directly from the frequency analysis and the displacement is calculated from the ratio of phase difference and local frequency. In order to validate the accuracy of SinMod method with different bandpass filter, simulated data were generated from the 13-parameter kinematic model of Arts et al. [6]. In this abstract, we considered the images in the systolic phase, the first five frames.

Table 1. Formulas for three types of bandpass filter

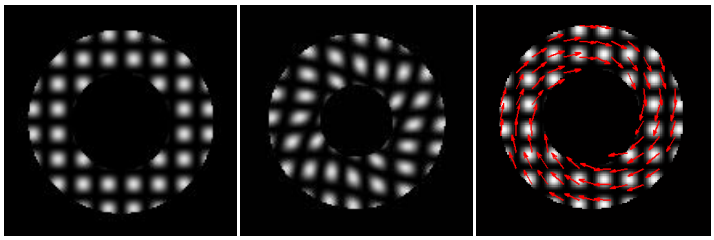
Disk filter	Butterworth filter	Squared cosine filter
$f = \begin{cases} 1 & if\ w - w_c \le w_{cutoff} \\ 0 & otherwise \end{cases}$	$f = \frac{1}{1.0 + ((w - w_c)/w_{cutoff})^{2n}}$	$f = \begin{cases} cos^2(\pi r/2) & if\ r < 1 \\ 0 & otherwise \end{cases}$ where $r = \lvert \ln((w_p + iw_q)/w_c) \rvert$
w_c is the off-center frequency for tagged images, w_{cutoff} is the cutoff frequency, n is the order for Butterworth filter, w_p and w_q are frequencies in two orthogonal cosine wave vector directions.		

Results

In order to assess the accuracy of computed motion fields of SinMod with different bandpass filter, we employed average angle error, average length error, and the relative root mean squared (RRMS). Table 2 shows these comparison results. Figure 1 shows the simulated tagged MR images at end-diastole and end-systole, together with the corresponding motion field from squared cosine bandpass filter.

Table 2. Average angle error (AngErr) in radian, average length error (LenErr) in pixel and relative root mean squared error (RRMS) in percent between ground truth motion field and motion field from SinMod using disk, Butterworth, and squared cosine bandpass filter.

Frame	Disk			Butterworth			Squared cosine		
	AngErr	LenErr	RRMS	AngErr	LenErr	RRMS	AngErr	LenErr	RRMS
01	0.2092	0.5936	0.2183	0.2073	0.3839	0.1743	0.1993	0.2430	0.1499
02	0.2872	0.9524	0.2361	0.3078	0.8151	0.2306	0.2936	0.4477	0.1997
03	0.3201	1.1939	0.2635	0.3309	1.0786	0.2623	0.3232	0.6117	0.2308
04	0.3328	1.2604	0.2686	0.3460	1.1534	0.2686	0.3356	0.6558	0.2368



(a) (b) (c)

Figure 1. Simulated tagging MR images and motion field. (a) end-diastolic image (b) end-systolic image (c) motion field using squared cosine bandpass filter.

Discussion

We have compared the SinMod technique performance on simulated tagged MRI data using three different types of bandpass filters. They all produced correct motion field with slightly different error levels. Overall, squared cosine bandpass filter on log frequency coordinates outperformed the disk and Butterworth filters. Applying finely tuned bandpass filter will result in improved performance for frequency-based motion tracking techniques.

References

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