Evaluation of heart wall motion from tagged MRI using Gabor filter bank

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Introduction:

Cardiac cine MRI with magnetization tagging produces images with tag lines that move with underlying heart wall during the heart cycle. One approach for automated quantitative analysis of the tag motion is the use of HARP analysis [1], which uses a single-sided bandpass filter in the Fourier domain. We have developed an alternative automated tag analysis approach, using Gabor filters [2], which can also be carried out in the Fourier domain, using double-sided bandpass filters. The response to a pair of filters equivalent to sine and cosine modulations is used to find the local phase relative of the periodic tag pattern. After the heart starts to contract, the corresponding changing local phase gives a 2D displacement map, from which we can derive the local strain deformation of the heart wall. In addition, the magnitude of the output can be used for the purpose of thresholding for segmentation of the wall. In this paper we also validate the Gabor results by comparing its performance to the ground truth (given by a predefined displacement field on a synthetic phantom) and a tag tracking approach [3] based on deformable models.

Method:

A Gabor filter is a sinusoidally modulated Gaussian, and is split into its real and imaginary components (even and odd functions, respectively). In the Fourier domain, each component of a Gabor filter consists of the sum of two Gaussian functions centered at the corresponding frequencies. After tags are deformed, the local tag spacing and orientation may change. A set of Gaussian filters with different spacing and orientation can be used to recover corresponding information on the local tag pattern and motion. The response to a bank of Gabor filters may be more robust to large deformations or rotations than HARP. Previously [4], the maximum response to the filter bank was used as the final output, which might not be accurate for the limited number of elements of the filter bank. We now interpolate among the strongest filter responses to estimate the local (unwrapped) phase of the tag pattern at each point in the image. From the temporal evolution of these phases, we can estimate the local eulerian displacement fields without phase aliasing. By tracking the location of pixels having the same phase over time and suitably combining data from orthogonal families of tag lines, we can reconstruct the 2D Largrangian displacements, and then calculate the 2D strain during the heart cycle. The motion of the tag locations can be recovered from the phase distributions by tracking the locations having the phase π . Synthetic grid-tagged phantoms and real MR tagged heart images of normal volunteers and patients have been used to test the methods.

Results:

Representative analysis results on synthetic phantoms and real tagged MR data are shown in Figure (1) and (2), respectively. The annular numerical phantom, with darker synthetic grid tags, is deformed under a predefined displacement to simulate the contraction and dilation of the heart. The predefined displacement field is used as the ground truth to evaluate the performance of each approach. The Gabor-based segmentation, reconstructed displacement field, and the strain distribution agree well with the ground truth (below 0.015 strain error for circumferential strain with the peak magnitude at -0.25) similarities to the ground truth. See Figure. (1). Gabor results for both normal and patient data are comparable with deformable model-based tag tracking, as shown in Figure (2).

Conclusion:

The improved Gabor filter bank provides rapid and automated analysis and can accurately reconstruct the cardiac displacement and strain. In comparison to the deformable model-based tag tracking methods, it is able to capturing local motion from the tag images. In particular, the quantitative validation results show its robustness to tag deformation.

References:

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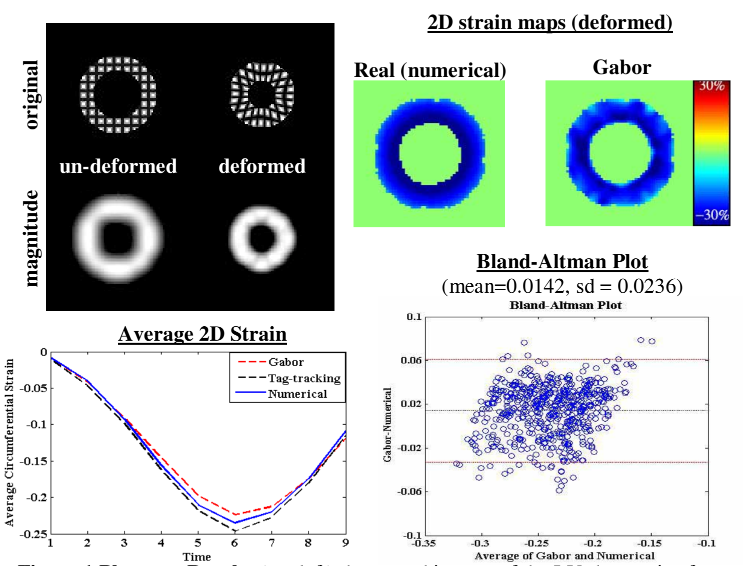

Figure 1 Phantom Results (top left) the tagged images of the LV short-axis of numerical phantom in un-deformed and deformed states and their corresponding magnitude images from Gabor filtering (top right) 2D numerical and Gabor strain maps of the deformed image (bottom left) average 2D circumferential strain of gabor, tag-tracking and numerical results throughout systole (bottom right) Bland-Altman plot of differences vs means for numerical and Gabor strain variables at time 6

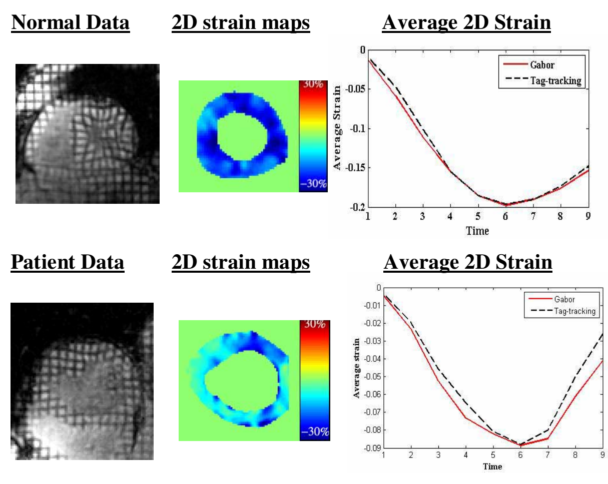

Figure 2 Normal and Patient Data (top) the deformed normal heart image, its corresponding 2d circumferential strain map and average 2D strain plots of Gabor and tag-tracking results, and same with the deformed patient heart image (bottom). Due to high level of noise and lack of motion in the septum, the average strain plotted (bottom right) only includes the free wall region. Also notice that the strain magnitude in the patient’s heart wall is much lower than that in the normal heart (above 50% lower). Both methods capture this weakness in contraction and agree well with each other.