Gabor Filter-Based Automated Strain Computation from Tagged MR Images

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Abstract. Myocardial tagging is a non-invasive MR imaging technique; it generates a periodic tag pattern in the magnetization that deforms with the tissue during the cardiac cycle. It can be used to assess regional myocardial function, including tissue displacement and strain. Most image analysis methods require labor-intensive tag detection and tracking. We have developed an accurate and automated method for tag detection in order to calculate strain from tagged magnetic resonance images of the heart. It detects the local spatial frequency and phase of the tags using a bank of Gabor filters with varying frequency and phase. This variation in tag frequency is then used to calculate the local myocardial strain. The method is validated using computer simulations.

1 Introduction

Conventional tag analysis techniques, such as finite element and B-spline models, require tag tracking [1-2] that often rely on active contours. The purpose of this study was to develop an automated Gabor filter-based tag analysis method. Previously, Gabor filters have been used for quantifying displacement and to enhance or suppress either the tags or the non-tagged regions of the image [3-5].

2 Methods

In image domain, a set of 2D Gabor filters is used for convolution with tagged image. A two dimensional Gabor filter (Fig. 1) h(x,y) is mathematically defined as

$$h(x,y) = g(x',y').s(x,y) \ . \quad (1)$$

$$g(x',y') = 1/(2\pi\, \sigma_{x'} \sigma_{y'}) exp\,(-\,((x'/\sigma_{x'})^2 + (y'/\sigma_{y'})^2)/2) \ . \quad (2)$$

$$s(x,y) = sin(2\pi d/\lambda + \Phi),\ d = x\,cos(\xi) + y\,sin(\xi) \quad (3)$$

$$x' = x\,cos(\theta) + y\,sin(\theta), y' = x\,sin(\theta) + y\,cos(\theta) \quad (4)$$

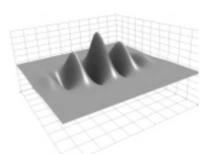

Fig. 1. *2D Gabor filter*

where $\sigma_{x'}$, $\sigma_{y'}$ are the standard deviations of the 2D Gaussian envelope along the *x* and the *y* directions, θ is the orientation of the Gaussian envelope, ξ is the orientation of the sinusoid and Φ

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is the phase offset of the sinusoid. The spatial wavelength and phase of the Gabor filter are determined by the wavelength, λ, and phase, $(2\pi d/\lambda+\Phi)$, of the sinusoidal function. The response of each individual filter centered at a given image pixel measures how well the wavelength and phase of the filter match with the spatial tag spacing and phase of the tags in the vicinity of this pixel. For strain calculations, we used a numerically generated annular 2D phantom with superimposed sinusoidal tags as an approximation of a tagged short axis image slice of the human heart (Fig. 2(a)), and applied a radially symmetric deformation with known longitudinal strain, E_{YY}, (Fig. 2(c)) to generate a sequence of nine images that simulates ventricular contraction (Fig. 2(b)). The Gaussian envelope was made eccentric so that it was elongated in a direction θ. The orientation, θ, of the Gaussian envelope and the orientation, ξ, of the sinusoid were set normal to the direction of the tags. The longitudinal strain in y-direction in each of these images was computed at every pixel as

$$E_{YY} = (\ L / L) . \quad (5)$$

where L is the original tag spacing and L is change in tag spacing (as detected by Gabor filter)

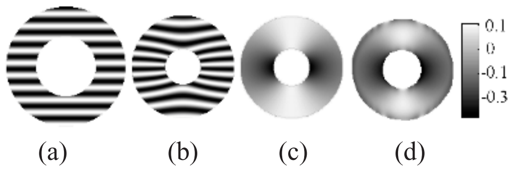

Fig. 2. (a) 2D numerical phantom (b) the phantom after a series of radial contractions (c) known longitudinal strain E_{YY} applied to simulate these ventricular contractions (d) strain calculated from Gabor filter-observed tag spacing

3 Results and Discussion

We calculated the percentage error and the standard deviation in Gabor filter-observed tag spacing (Fig. 3) for the phantom deformation sequence. This error was observed to be less than 5%. In this study we have demonstrated that Gabor filter-based detection of tag spacing and phase allows us to locally analyze the tag pattern in simulated tagged MRI. The study indicates that this technique may be useful for fast and automated strain calculations. Future work will apply this technique to analyze *in-vivo* cardiac images.

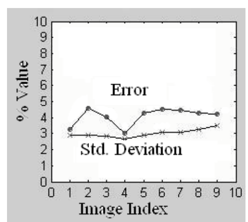

Fig. 3. *Error and std. deviations* in the Gabor filter-observed tag spacing values

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