STRAIN RESOLUTION FROM HARP-MRI

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Introduction: Harmonic phase (HARP) MRI is used in the analysis of tagged MR images to automatically and rapidly produce two-dimensional images of myocardial strain [1]. The premise of HARP is that information about tissue motion lies in the phase of the complex harmonic image, which is constructed by bandpass filtering one of the spectral peaks in the Fourier spectrum of the tagged image. The use of bandpass filter to extract the spectral peaks suggests that the resolution of HARP strain images is equal to the intrinsic Fourier resolution defined by the filter. The concept of intrinsic Fourier resolution fundamentally assumes that the system is linear and that superposition of impulse functions holds. But strain is computed as a nonlinear function of the data, which can recover resolution in theory [2], and the notion of an impulse in strain defies the principles of continuum mechanics (even in a limiting sense). In fact, there is no simple closed form expression for the resolution of strain in HARP, and it cannot be immediately concluded that HARP strain resolution is given by the Fourier resolution of its bandpass filter.

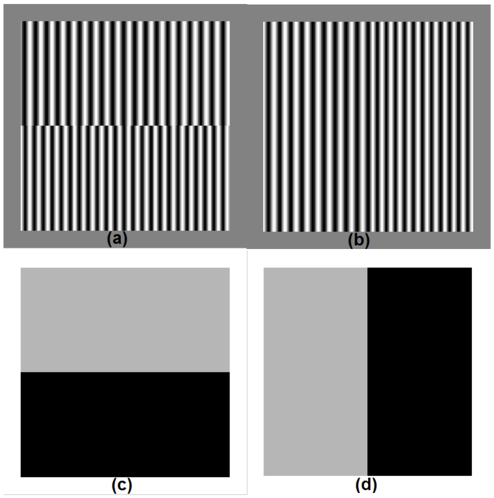

Fig. 1

In this abstract, we use an approximate -- yet intuitive -- relationship between strain and Fourier frequencies to develop an understanding of strain resolution. In order to verify the theory, we develop two new analytical models. In a previous work [3] we proposed a hypothetical model, which showed that under certain circumstances the resolution of strain and the resulting HARP magnitude can be better than the intrinsic Fourier resolution. In this abstract we propose a better and more practical model that will be able to answer basic physiological questions regarding the extent of diseased myocardium.

Theory: We start by interpreting the underlying sinusoidal tag pattern as a *carrier* signal. The carrier signal is amplitude modulated (AM) by the anatomy (when the tags are applied) and frequency modulated (FM) by strain [1]. Hence, we interpret a harmonic image as a 2-D AM-FM signal. Since the strain (Eulerian) frequency modulates the tags, it is identified as the instantaneous frequency (IF) of the AM-FM signal. Wei et. al. [4] noted that if an AM-FM signal is a so-called monocomponent signal (signal with one carrier frequency), then the IF at every point is the average of the Fourier frequencies in a small region around that point. Since each harmonic image deals with unidirectional tags, our signal is monocomponent and hence the relation between strain and regional Fourier frequency holds.

Methods: Figs. 1(a) and (b) show two simulated vertical tag pattern models with two different directions of strain variation. In Fig. 1(a) the strain variation is perpendicular to the direction of the tagging vector and in Fig. 1(b) the variation is along the direction of the tagging vector. In both configurations, the transition from one strain region to the other is abrupt; simulating an edge or step function in strain (red line in Figs 2(a) and (b)). For concreteness, we think of Fig. 1(a) as a model of an abrupt transmural change in strain and Fig. 1(b) as a model of circumferential changes in strain. Resolution is characterized by the blurring of strain computed in these directions with respect to the ideal "step" strain transition. In order to compare with intrinsic Fourier resolution, we simulated the step functions in magnitude images (AM) (Figs 1(c) and (d)) and used the same size filter around the origin of their spectrum. In these simulations we used a FOV = 28 cm and filter size of 33x33 (having a Fourier resolution of 8.48 mm).

Results: Figs. 2(a) and (b) show of the response of HARP to a step function in strain (green) and to a step function in magnitude or AM (blue). The responses are along the midline section of the image; the midline vertical profile in Fig. 2(a) and the midline horizontal profile Fig. 2(b). Even though the responses of strain and magnitude are a little different, the blurring of the edge is similar in both cases; suggesting that the resolution is the same.

Discussion: We know that the blur in magnitude can be explained using traditional Fourier resolution theory. To explain the blur in strain, consider the IF at the edge of the two regions in either case (Fig. 1(a) or 1(b)). From the theory, the IF must be equal to the average Fourier frequency around that point. The Fourier frequencies in a small region around the point must be within pass band of the bandpass filter, so the average frequency must also be within the bandpass filter. Therefore, the highest IF frequency achievable is limited by the bandpass filter. Hence, it turns out that the HARP resolution is almost equal to Fourier resolution.

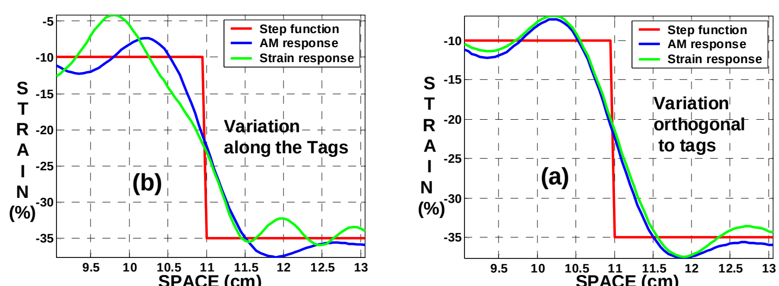

Fig. 2

Conclusion: Strain resolution cannot be determined using normal Fourier theory. In this paper, we use an approximate relationship between IF and Fourier frequencies to explain the idea of HARP strain resolution. We test the theory using computer simulations and demonstrate that under normal conditions HARP computes strain almost at the same resolution as the intrinsic Fourier resolution predicted by the bandpass filter.

References: 1. N. F. Osman and J. L. Prince, "Visualization of Myocardial Function using HARP-MRI", *Phys. Med Biology*, 45:1665-1682, 2000

2. A. Van Des Bos and A.J. Den Dekker., "Resolution reconsidered", *Adv. in Imaging and Electron Physics*, 117:241-360, 2001

3. V. Parthasarathy and J. L. Prince, "On the Resolution of HARP-MRI", *Proceedings of ISMRM*, 2003

4. D. Wei and A. Bovik, "On the instantaneous frequencies of multicomponent AM-FM Signals", *IEEE Signal Processing letters,* 6(4),81-83,1999