Noise Suppression in Displacement Imaging Using an Adaptive Spatial Filter

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Introduction

In DENSE(1) imaging of myocardial wall motion the displacement vectors are proportional to phase differences between encoded and reference images. Phase noise leads to noise in the displacement vectors and the subsequent strain maps (Fig.1). Spatial or temporal smoothing reduces noise at the cost of spatial or temporal resolution. The standard low-pass spatial filter results in blurring of edges (Fig.1). An adaptive spatial filter (A.S.F.) is designed to improve upon the standard filter. A low-pass filter is equivalent to assigning to each pixel the weighted average of a neighborhood of a fixed shape, which is called the filter kernel. In A.S.F. the kernel is a flattened strip aligned with the contour of the ventricular wall, shown as red boxes in Fig.2. This shape prevents blurring across the wall(2) (Fig.1).

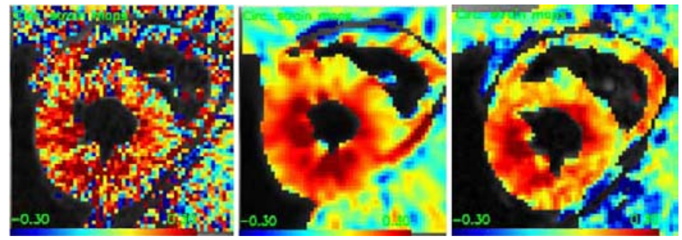

Fig. 1 No filter Low-pass Adaptive

Method

Human scans were performed on a 1.5T system (Sonata, Siemens). A 3-point phase-cycled DENSE sequence was used to acquire 3 displacement encode cine data sets in 18 heartbeats(3). These were respectively encoded with combined gradients of (Y,Z), (-Y,Z) and (X,Z) and noted as I_0, I_1, and I_2. Spatial and temporal resolutions of the images were 2.0x3.7 mm^2, 31ms. They were combined to complex images I_x and I_y which contain phase proportional to the X and Y displacement(4):

$$I_y = I_0 I_1^* (|I_0|/|I_1| + |I_1|/|I_0|), \quad I_x = I_2^2 I_0^* I_1^* /(4|I_0 I_1 / I_2| + |I_1 I_2 / I_0| + |I_2 I_0 / I_1|).$$

The adaptive filter was then applied to the complex images I_x and I_y. Their phase maps φ_x and φ_y then went through an auto-masking process which removed pixels that prevent proper phase unwrapping(5). They were unwrapped with a region-growth process in the three dimensions of (X,Y,t) to give the X and Y displacement maps.

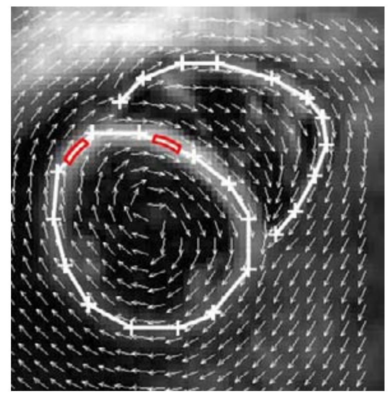

Figure 2

The A.S.F. procedure was as follows: On a magnitude image, landmarks are manually laid along the contours of the LV and RV (Fig.2), from which a set of tangent vectors (T.V.) of the contours are calculated with curve splining. The vectors are extrapolated from the contours to the entire image according to a summation weighted with the inverse of distance raised to the 4th power (Fig.2). The A.S.F. kernels are small curved sectors of 1.5 pixel width and L pixel length and aligned with the local T.V.. To calculate the A.S.F. of a scalar function, for each position the values in the local kernel is fitted to a linear function of the local tangent coordinate, and the zero intersect of the fitted function is assigned to the position.

The A.S.F. filter had a strong effect on the ability to follow a material pixel over time, or tissue tracking. Tissue tracking means that for each time frame the positions of the pixels at the initial time point are found by the displacement vectors, and the initial positions are interpolated to a fixed grid, so that the position of each grid point is known for all times. The A.S.F. procedure reduced the noise level in the displacement data and increased the number of pixels that were successfully tracked.

Results

In long-axis data from 4 volunteers, the number of successfully tracked pixels in the heart relative to un-filtered condition is dependent on the A.S.F. kernel length (Fig.3 left). At L = 4.5 there is an 59% improvement ($p < 0.01$). In data from a heart-failure patient the histogram of the peak E_{cc} strain in the LV reveals the bi-modal distribution of normal and dyskinetic zones after filtering (Fig.3 right).

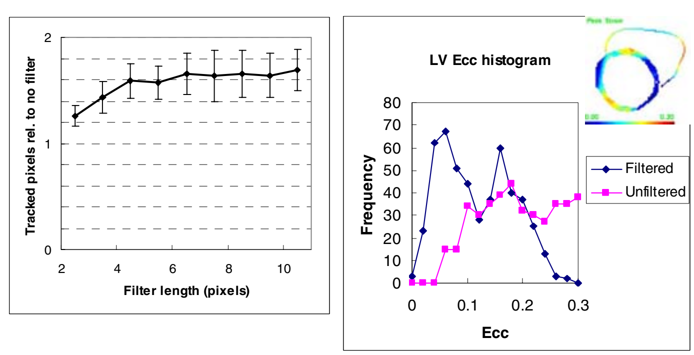

Figure 3

References

1. Aletras AH, Ding SJ, Balaban R, Wen H. Proc. ISMRM1998;p.281.
2. Wen H, Proc. ESMRMB 2005, p.469.
3. Bennett E, Spottiswoode B, Lorenz CH, Wen H, abstract submitted to ISMRM 2006.
4. Bernstein MA, Grgic M, Brosnan TJ, Pelc NJ. MRM 1994;32(3):330-334.
5. Wen H, Proc. ESMRMB 2005, p.259.