Improved Myocardial Tissue Tracking and Strain Accuracy in Cine-DENSE using Temporal Fitting

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Introduction: Displacement encoding with stimulated echoes (DENSE) (1) provides a means of monitoring myocardial motion and deformation at a pixel resolution. This abstract introduces a method for computing the trajectories of discrete points in the myocardium as they move through the cardiac cycle for cine-DENSE (2) data. The nature of the DENSE displacement fields allows the error in individual displacement measurements to be reduced by fitting a time series to sequential displacement measurements. This improvement is in turn reflected in the strain maps.

Methods: In DENSE, the displacement of each voxel is encoded as a phase shift that has accrued since the time that the displacement encoding was initiated (t_0). Two dimensional cine-DENSE thus provides a succession of independent displacement fields that all reference the material position of the myocardium at t_0. The individual vectors in a 2D DENSE displacement field are visualized as having heads pointing to the centres of the pixels at the current cardiac phase, and tails originating from the positions of these material points at t_0. This arrangement of displacement vectors can be used to obtain the 2D trajectory of each element of myocardium as follows: It is assumed that no motion has taken place between t_0 and the first cardiac phase of the image series. The centres of all pixels on the myocardium at the first cardiac phase are designated as the starting points for the point-to-point tracking. Consider the centre of one of these pixels. For each cardiac phase, the N vector tails (N=4 is used for this study) closest to this starting position are identified. These N vectors are used to 2D linearly interpolate for an estimate of the vectors stemming from the chosen pixel centre at the first cardiac phase. By subtracting successive interpolated vectors from each other, one obtains the point-to-point trajectory. A number of such trajectories are shown in Figure 1(a).

The characteristic that successive displacement measurements are independent provides a framework suited to temporal fitting. The accuracy of the estimate of a point's position can thus be improved based on its estimated positions at preceding and/or following cardiac phases. This is implemented here by fitting curves to each of the spatial coordinate components as a function of time. Figure 1(b) shows the trajectories of Figure 1(a) after being fitted using 5th order polynomials. Many of the trajectory discontinuities seen in Figure 1(a) are inconsistent with physiological motion. The trajectories in Figure 1(b) give a more realistic portrayal of cardiac motion.

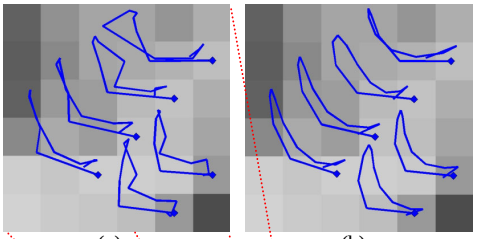
By noting the positions of the arrow tails in the original DENSE displacement fields, it is possible to obtain maps of Lagrangian strain. A map of circumferential strain at end-systole for a patient with an infarct centred at 4 o'clock is shown in Figure 2(a). If all of the myocardial pixel centres for the first phase are tracked, then the resulting corrected trajectories can be used to reduce errors in the original DENSE displacement fields. This requires 2D back-interpolation of vectors from the point-to-point trajectories to the centres of all myocardial pixels at all cardiac phases. Figure 2(b) shows the improved strain map corresponding to Figure 2(a). The location of the infarct is more apparent in Figure 2(b).

An ECG-gated 2D EPI cine-DENSE sequence (2) was run on a 1.5 T Siemens Sonata scanner. Imaging parameters included FOV = 360 mm; percent phase resolution = 84.4 %; TE = 11 ms; TR = 22 ms; slice thickness = 8 mm; matrix size = 128×104 pixels; pixel size = 2.81×2.81 mm; cardiac phases = 15; and displacement encoding frequency = 0.1 cycles/mm. In accordance with protocols approved by our institutional review board, and with informed consent, five healthy volunteers and two infarct patients were studied using cine-DENSE. Histograms of the values of circumferential strain (*Ecc*) at end-systole were analyzed.

Results: For the volunteers, **t**he mean and standard deviation of *Ecc* before and after temporal fitting were -0.17±0.14 and -0.20±0.08, respectively. The range of *Ecc* values after correction more closely matches those predicted using conventional (3) processing of tagged images. The *Ecc* histograms of the two infarct patients are shown before correction, in Figure 3(a), and after correction, in Figure 3(b). Here the correction reduces the standard deviation of *Ecc* from 0.50 to 0.11. The regions of infarct are, in these examples, evident as a distinct peak in Figure 3(b) (arrow).

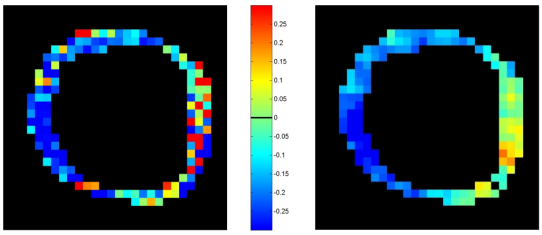
Conclusions: A technique for point-to-point tracking using cine-DENSE data has been introduced. The error of the tracking is reduced by fitting curves to the temporal evolution of the trajectories, and the corrected trajectories result in less variability in the strain estimates. Using sets of 5th order polynomials to describe the trajectories over the majority of the cardiac cycle significantly reduces the noise in the strain maps, while still retaining sufficient information to distinguish anomalies. The improvement in the strain maps is evident both visually and in a comparison of histograms. The corrected values of strain also more closely match those predicted using myocardial tagging methods. The accuracy of the point-to-point tracking still needs quantification, as does the effect of the correction on the strain values. This will be done using a deformable phantom.

The ability to track discrete points through time means that rates of change of strain can also be investigated using cine-DENSE. A further potentially useful feature stemming from this tracking is a pixel-wise map of kinesia, which portrays the sum of the vector magnitudes along each trajectory.



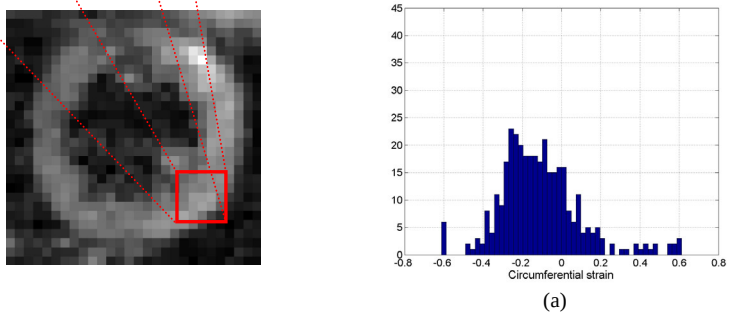
(a) (b)

Figure 1 (a) Tracking selected points in a short axis slice through the LV. (b) The same trajectories as (a), but with temporal fitting using 5th order polynomials.



(a) (b)

Figure 2 (a) Map of *Ecc* at end-systole of a patient with an infarct centred at 4 o'clock. (b) The same strain map calculated using the fitted displacement field.



(a) (b)

Figure 3 (a) Histogram depicting *Ecc* at end-systole for two infarct patients. (b) Histogram obtained using fitted DENSE displacement fields. A peak depicting the low strain region of the infarct is clearly apparent (arrow).

1. Aletras A.H *et al.* JMR 1999; 137: 247-252. 2. Kim D. *et al.* Radiology 2004; 230:862-871. 3. Moore C.C. *et al.*Radiology 2000; 214:453-466.