Directional Analysis of 2D Cardiac Motion Slices Using the Discrete Helmholtz Hodge Decomposition

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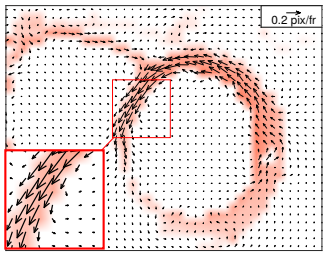
Aims: Quantification of the left ventricular (LV) motion vector field (MVF) from 2D cardiac image sequences can assist diagnosis through computation of cardiac indicators such as LV torsion, calculated from the difference between apical and basal rotation. The proposed study proposes the 2D Discrete Helmholtz Hodge Decomposition (DHHD) for extracting rotation from 2D cardiac MVF slices.

Method: MVFs were created by applying differential operators to Gaussian 2D potentials. MVF(i) consisted of rotational and radial components, MVF(ii) of rotational, radial and linear. Field smoothness was changed by varying standard deviation, σ. First, motion field smoothness was investigated by measuring normalised RMSE (NRMSE) against σ using MVF(i). Next two sets of boundary conditions (BCs) were compared. NRMSE values were computed for two versions of the DHHD: DHHD(i), using zero BCs on domain boundary nodes, and DHHD(ii), applying a zero BC to the first node. Finally, curl-free (F_{CF}) and divergence-free (F_{DF}) fields were estimated from a short axis slice of the Extended Cardiac Torso phantom (XCAT) MVF.

Results: A minimum NRMSE=0.92% was found for F_{CF} when $\sigma = 9.00$. The BC investigation showed that DHHD(i) decomposes both MVFs with 0.92% NRMSE, whereas NRMSE for DHHD(ii) is 0.88% and 230%, the larger error caused by failure to separate the linear field from F_{CF} and F_{DF}. We conclude that applying zero BCs to all nodes on the domain boundary achieves the required decomposition.



F_{DF}, calculated from 2D XCAT MVF slice

When the DHHD was applied to the XCAT MVF slice, F_{CF} was seen to represent the circumferential component of the MVF, as shown in the figure. The DHHD is a candidate for isolating the rotational component of the LV MVF and could be used for automated estimation of torsion if applied to 2D MVFs at the LV base and apex, such as those obtained from speckle tracking.