Hybrid Edge Detection for Real-time Kalman Filter Based Left Ventricle Tracking in 3D+T Echocardiography

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Endocardial border segmentation in 3D echocardiography is a challenging problem, since the trabeculated structure of the endocardium leads to intensity profiles that change over the cardiac cycle. This study introduces a novel Max Flow/Min Cut based edge detector (MFMC), and its combined usage with an existing step edge detector (STEP) for improving edge detection throughout the cardiac cycle.

The real-time left ventricular tracking framework uses an extended Kalman filter to recursively predict and update a deformable subdivision surface, based on a combination of edge measurements and a kinematic model. Edge detection is performed using normal-displacement measurements in sampled intensity profiles, and are processed using an information-filter formulation of the Kalman filter. For a given set of intensity profiles, MFMC based normal displacements are found as; (1) a graph is formulated where each voxel of each profile is represented by a node, (2) edges are set between consequential voxels within the same profile and, the neighboring profiles same-index voxels, with weights inversely proportional to the intensity gradients, (3) nodes corresponding to innermost and outermost profile voxels are connected to source/sink super-nodes respectively, (4) The minimal cut corresponding to maximum flow between source/sink is used to determine MFMC normal-displacements. Since MFMC solves the normal-displacement problem simultaneously for all profiles, results are smooth and consistent. Also, MFMCs low-order polynomial computational complexity does not threaten real-time tracking.

MFMC outperforms STEP for endocardial border detection at end-diastole (ED), while STEP works best at end-systole (ES). A hybrid method based on a weighted sum of MFMC and STEP, where the weight factors are set based on mesh size, outperforms both pure MFMC and STEP.

10 manually segmented 3D echocardiograms are used for validation. For ED, surface errors are, Hybrid: 2.50 ± 1.61(mm), STEP: 3.07 ± 1.93(mm), MFMC: 2.62 ± 1.58(mm). For ES, Hybrid: 3.02 ± 1.70(mm), STEP: $3.11 \pm 1{,}82$(mm), MFMC: 3.70 ± 1.81(mm). For ejection fraction, the percentage errors are, Hybrid: 3.83 ± 5.88(%), STEP: 6.29 ± 7.15(%), MFMC: 8.36 ± 5.97(%).