Modified Hough Transform for Left Ventricle Myocardium Segmentation in 3-D Echocardiogram Images

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Problem

Segmentation of the left ventricular (LV) myocardium is an important first step in evaluating abnormalities in cardiac structure and motion. While blood pool segmentation alone allows the calculation of volumetric parameters (stroke volume, ejection fraction, etc.), other clinically important measurements, such as stress-strain, synchrony, and wall motion, require segmentation of the myocardium as well.

Contribution

We introduce a myocardial segmentation technique based on the circular Hough transform. By applying a simple constraint – that the LV myocardium is approximated by an annulus in short-axis cross-section – this technique takes advantage of both endocardial and epicardial image information. The segmentations generated are compared to expert manual segmentation of 3D+t echocardiogram data and evaluated for their appropriateness to initialize a subsequent segmentation step.

Formulation

Directional gradient images G_x and G_y are calculated from short-axis slices. Our two-step voting algorithm is a modified Hough transform, with the first accumulator:

$$H(c_x, c_y, r) = \sum_{\theta} \left[\begin{array}{l} \cos\theta \cdot G_x(x', y') + \\ \sin\theta \cdot G_y(x', y') \end{array} \right]$$

$$\{\, x' = c_x + r\cos\theta, \quad y' = c_y + r\sin\theta$$

For potential center (c_x, c_y), the best endocardial and epicardial radii r_1 and r_2, are:

$$r_1(c_x, c_y) = \arg\max_{r} H(c_x, c_y, r)$$

$$r_2(c_x, c_y) = \arg\min_{r > r_1} H(c_x, c_y, r)$$

Each potential center has likelihood score:

$$s(c_x, c_y) = k\, H(c_x, c_y, r_1) - H(c_x, c_y, r_2)$$

The annular approximation of the LV myocardium in the short-axis slice has the center (c_x, c_y) that maximizes s, and corresponding radii $r_1(c_x, c_y)$ and $r_2(c_x, c_y)$.

Data Set

Twenty-five 3D+t echo sequences were recorded on a Philips iE33. Resolution was $0.88 \times 0.88 \times 0.81\,\mathrm{mm}^3$. Each sequence consisted of 11 - 20 3D frames. The first 11 frames of each sequence were used.

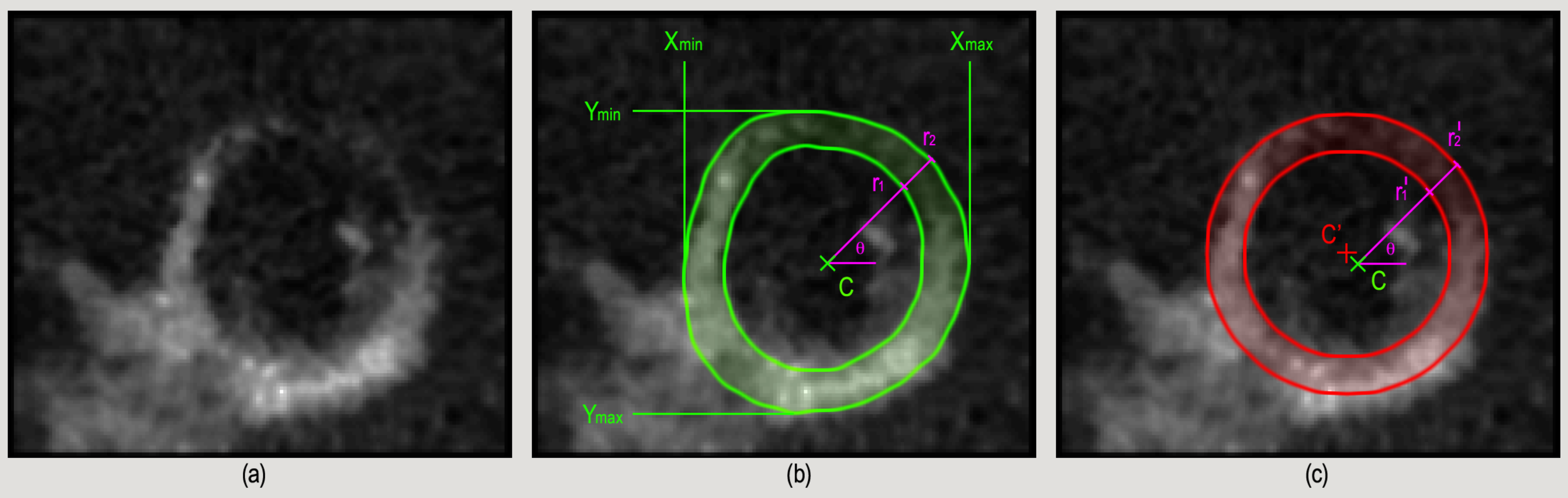
Manual segmentation was performed by three experts without knowledge of the algorithm. Every fifth short-axis slice of each image was segmented by one expert using long-axis views for guidance. A total of 5641 short-axis slices were used.

Comparison Criteria

Parameter distance. Distance ΔC between the center C of the manual segmentation bounding box and the center C' by modified Hough transform was measured. For $\theta = \frac{n\pi}{4}$, the inner and outer radii by manual segmentation (b) were compared to the corresponding radii of the Hough segmentation (c). Both were were measured from the manual center C.

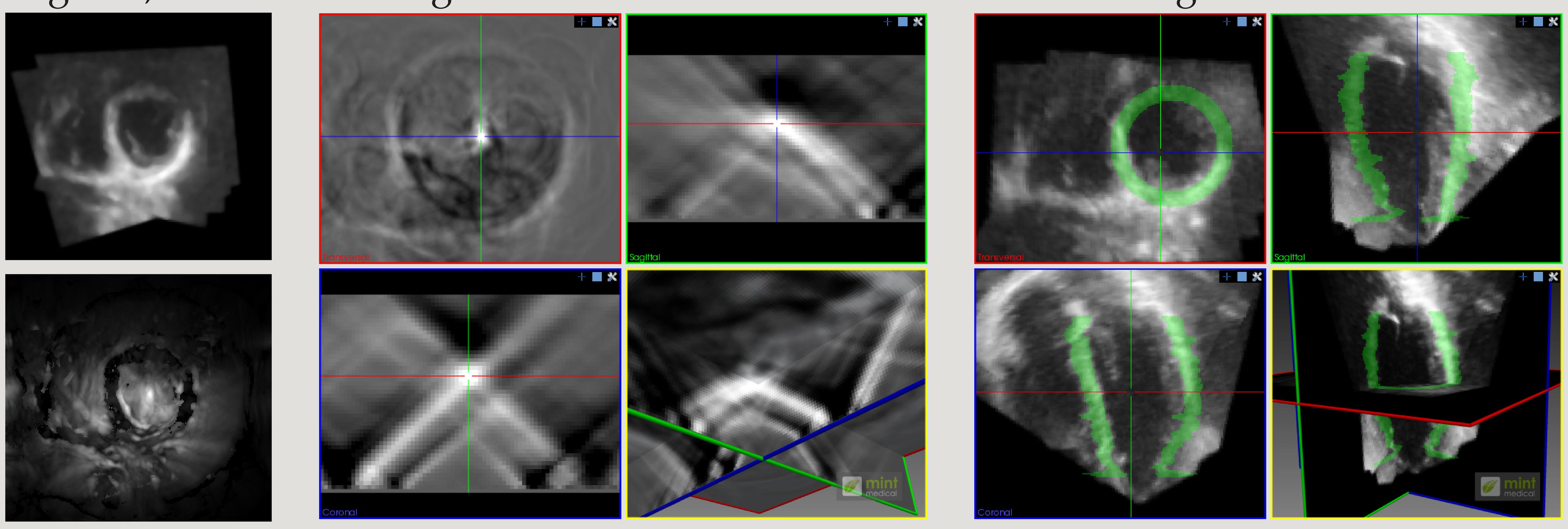
Dice's coefficient. The segmentations were compared using Dice's coefficient d.

Initialization suitability. When the Hough segmentation is used to initialize a second segmentation step (e.g. level set or active contour method), that step is more likely to converge if its boundary does not have to cross an image feature edge, i.e. $r_1' < r_2$ and $r_2' > r_1$.

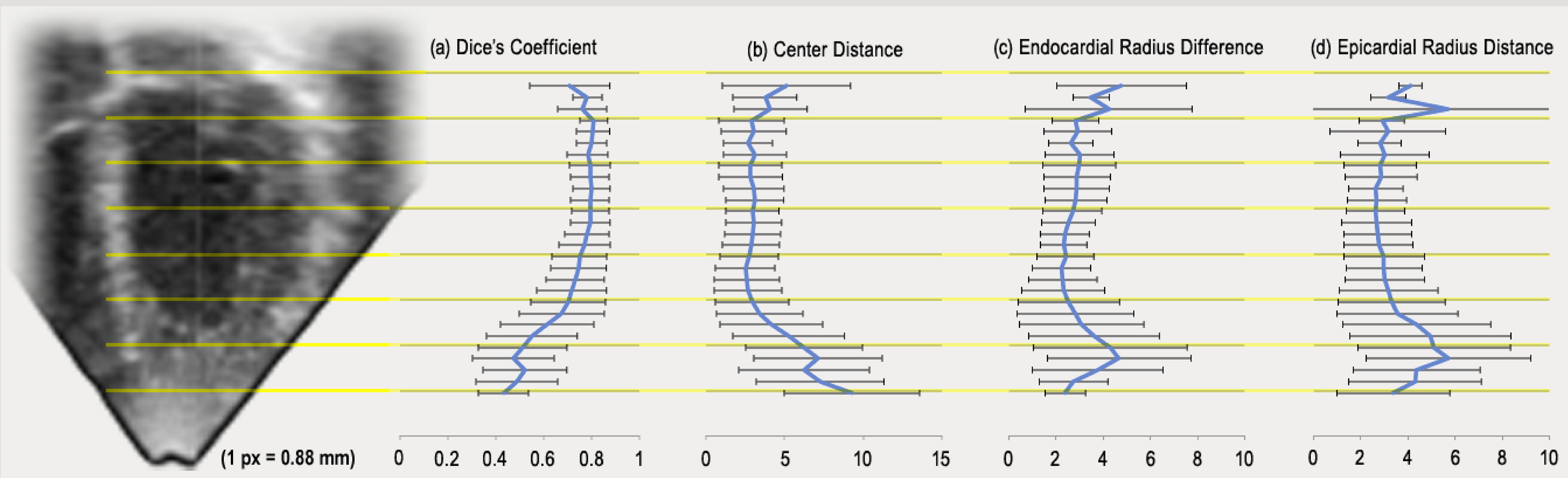


Results

A typical filtered short-axis slice, its accumulator H, its center likelihood score image s, and the segmentation results from its 3D image are shown below.



Experimental results are summarized in the figure below. The algorithm performs better in the basal LV compared to the apical area, due to the lack of meaningful image data in apical slices. Manual segmentation was performed with the benefit of long-axis views.



The parameter distance and Dice's coefficient results (mean ± StDev) are tabulated to the right. The initialization suitability criteria were met by 93.8% of segmentations, and 96.8% of non-apical segmentations.

	All Slices	Basal 80%
ΔC	3.31 ± 2.65 mm	2.65 ± 1.88 mm
Δr_1	2.57 ± 1.78 mm	2.34 ± 1.43 mm
Δr_2	3.04 ± 2.10 mm	2.68 ± 1.68 mm
d	0.70 ± 0.17	0.75 ± 0.13

Conclusions

The modified Hough transform method met the criteria for initialization of a subsequent segmentation in most cases, with better results for the basal LV. Performance as an initialization step remains to be evaluated.

State-of-the-art methods that consider speckle statistics and tissue characteristics achieve accuracy in the range of 1.4 - 1.8 mm [1]. Our relatively simpler modified Hough technique have accuracy of 2.5 - 3.0 mm. This may be acceptable in some scenarios.

Acknowledgements

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References

[1] Y Zhu et al. "A coupled deformable model for tracking myocardial borders from real-time echocardiography using an incompressibility constraint," *Medical Image Analysis*, 14(3), 429–448, June 2010.