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Model-based Strategies for Automated Segmentation of Cardiac Magnetic Resonance Images

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Abstract

Segmentation of the left and right ventricles is vital to clinical magnetic resonance imaging studies of cardiac function. A single cardiac examination results in a large amount of image data. Manual analysis by experts is time consuming and also susceptible to intra- and inter-observer variability. This leads to the urgent requirement for efficient image segmentation algorithms to automatically extract clinically relevant parameters. Present segmentation techniques typically require at least some user interaction or editing, and do not deal well with the right ventricle.

This thesis presents mathematical model based methods to automatically localize and segment the left and right ventricular endocardium and epicardium in 3D cardiac magnetic resonance data without any user interaction. An efficient initialization algorithm was developed which used a novel temporal Fourier analysis to determine the size, orientation and position of the heart. Quantitative validation on a large dataset containing 330 patients showed that the initialized contours had only ~ 5 pixels (modified Hausdorff distance) error on average in the middle short-axis slices.

A model-based graph cuts algorithm was investigated and achieved good results on the midventricular slices, but was not found to be robust on other slices. Instead, automated segmentation of both the left and right ventricular contours was performed using a new framework, called SMPL (Simple Multi-Property Labelled) atlas based registration. This framework was able to integrate boundary, intensity and anatomical information. A comparison of similarity measures showed the sum of squared difference was most appropriate in this context. The method improved the average contour errors of the middle short-axis slices to ~ 1 pixel. The detected contours were then used to update the 3D model using a new feature-based 3D registration method. These techniques were iteratively applied to both short-axis and long-axis slices, resulting in a 3D segmentation of the patient's heart. This automated model-based method showed a good agreement with expert observers, giving average errors of $\sim 1-4$ pixels on all slices.

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Glossary of Abbreviations

| | |
|-------|-----------------------------------------------|
| AAM | Active Appearance Models |
| ACC | Accuracy |
| AMIR | Automatic Multi-modality Image Registration |
| AMRG | Auckland Magnetic Resonance Research Group |
| ASM | Active Shape Models |
| CAR | Capture Range |
| CMR | Cardiac Magnetic Resonance |
| CO | Cardiac Output |
| CR | Correlation Ratio |
| CSS | Chi Square Statistic |
| CT | Computed Tomography |
| DC | Direct Current |
| DICOM | Digital Imaging and Communication in Medicine |
| DOG | Distinctiveness of the Global Maximum |
| ECC | Entropy Correlation Coefficient |
| ECG | Electrocardiogram |
| ED | End-diastolic |
| EDI | Entropy of Difference Image |
| EDV | End-diastolic Volume |
| EF | Ejection Fraction |
| EH | Energy of Histogram |
| EM | Expectation Maximization |
| ES | End-systolic |
| ESV | End-systolic Volume |
| FFD | Free-form Deformation |
| FOV | Field of View |
| FT | Fourier Transform |
| GCC | Gradient Cross Correlation |
| GMI | Gradient Mutual Information |
| GVF | Gradient Vector Flow |
| H1 | First Harmonic |
| HD | Hausdorff Distance |
| ICA | Independent Principle Component Analysis |
| ICP | Iterative Closest Point |
| JE | Joint Entropy |
| LA | Long Axis |
| LM | Levenberg-Marquardt |
| LV | Left Ventricle |

| | |
|----------|----------------------------------------------------------------------------------|
| LVEF | Left Ventricle Ejection Fraction |
| LVM | Left Ventricle Mass |
| MAP | Maximum a Posteriori |
| MHD | Modified Hausdorff Distance |
| MI | Mutual Information |
| MR | Magnetic Resonance |
| MRA | Magnetic Resonance Angiography |
| MRF | Markov Random Fields |
| MRI | Magnetic Resonance Image |
| MRIU | Modified Ratio of Image Uniformity |
| NCC | Normalized Cross Correlation |
| NMI | Normalized Mutual Information |
| NOM | Number of Minima |
| NP-hard | Nondeterministic Polynomial-time Hard |
| ONTARGET | Ongoing Telmisartan Alone and in combination with Ramipril Global Endpoint Trial |
| PCA | Principal Component Analysis |
| PDM | Point Distribution Models |
| PET | Positron Emission Tomography |
| PNI | Pattern Intensity |
| RIU | Ratio of Image Uniformity |
| ROI | Region of Interest |
| RON | Risk of Non-convergence |
| RV | Right Ventricle |
| SA | Short Axis |
| SI | Similarity Index |
| SMPL | Simple Multi-Property Labelled |
| SPECT | Single Photon Emission Tomography |
| SPM | Statistical Parametric Mapping |
| SSD | Sum of Squared Difference |
| SSFP | Steady State Free Precession |
| SV | Stroke Volume |
| WD | Wood Method |
| WT | Wall Thickness |
| ZEST | New Zealand Eplerenone Aortic Stenosis Trial |

