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 ~ 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