Automated analysis of 3D echocardiography

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8 Summary

research objective *FRU transducer*

The left ventricle of the heart is responsible for pumping oxygen saturated blood through the whole body. Assessment of left ventricular function is therefore very important in clinical decision making, evaluation of therapeutic effects and determination of prognosis. In the last decade, 3-dimensional (3D) echocardiography has evolved into a valuable imaging technique for evaluation of left ventricular function. This thesis, as posed in chapter 1, aims at automating the analysis of 3D echocardiography to reduce interobserver variability and analysis time, and to improve reproducibility of functional assessment of the left ventricle. In this way, diagnosis and treatment of cardiovascular disease may be improved and its costs may be reduced. In this chapter, an overview of the basics in ultrasound imaging is given. Current 3D echocardiography, including the fast rotating ultrasound (FRU) transducer and commercial matrix transducers, is put into historical perspective. Also, major issues in digital image analysis are discussed, with a focus on automated analysis of echocardiography.

semi-automatic full cycle analysis

Chapter 2 describes a method for endocardial border detection for reliable assessment of full cycle left ventricular volume, requiring minimal user interaction. In this chapter analysis focuses on data acquired with the FRU transducer. The method is based on detection of the endocardial border in the 2-dimensional (2D) slices using dynamic programming and pattern matching. 3D plus time (3D+T) patient specific shape and texture models were derived from four manually drawn contours for each patient, describing the approximate shape and texture of the endocardial border for this patient. Knowledge in these models was optimally combined using dynamic programming and pattern matching to detect the contours in all the required image slices throughout the entire cardiac cycle, such that the 3D endocardial surface could be reconstructed and volumes could be estimated over the full cardiac cycle. The performance of this semi-automatic technique was evaluated on 10 patients and compared to gold standard MRI determined volumes. A good correspondence to MRI volumes was shown. However, the main advantage of this method, being the possibility to manually correct automatically detected contours, was also evaluated and showed an improved correlation to MRI volumes. Also, a low interobserver variability was found for the semi-automatic method.

mitral valve tracking

Chapter 3 discusses one of the main disadvantages of the semi-automatic border detection: the poor model for mitral valve displacement throughout the cardiac cycle. Hence, an automated technique for tracking the mitral valve hinge points (MVHPs) was investigated. To enforce continuous and cyclic motion of the MVHPs while allowing displacements in horizontal and vertical direction, tracking was done using multidimensional programming with apodized block matching. The method was tested on VCR recorded 2D echocardiograms of clinical quality, to evaluate the robustness of the tracking, and compared to common tracking techniques. High accuracy and precision was found, comparable to interobserver variability of manual tracking, showing the value of this approach and promise for application in 3D echocardiography.

In chapter 4 reconstruction of the 3D+T data acquired with the FRU transducer is studied. The typical challenges in this reconstruction process are discussed. A solution that deals with irregularity and the sparseness of the data is presented, based on normalized convolution. The presented approach is demonstrated on simulated data and tested on in-vivo FRU data. The reconstruction shows advantages over the standard reconstruction technique, reducing multi-beat fusion artifacts and spurious edges in sparse regions. The method is generic and can be applied to a wide range of irregular 3D ultrasound data, such as freehand 3D ultrasound or mechanical 3D transesophageal echocardiography.

3D+T image reconstruction

Chapter 5 deals with a common problem in model-based segmentation approaches: the model initialization. To this extent, a skeletal feature detection approach is presented that fully automatically determines the left ventricular long axis and the position of the mitral valve plane. These two features may be very useful in initialization of model-based approaches. The presented method reliably detects the long axis using dynamic programming and a Hough transform for circles, based on detection of the LV center in slices perpendicular to the estimated long axis and tracking of these centers over the full cardiac cycle. Using the detected long axis, also a reliable estimate of the mitral valve plane position is generated based on a low level edge detection using dynamic programming. It is shown that this method performs well in FRU and commercial matrix transducer data with low computational costs, which promises great value as an initialization step for segmentation approaches.

automatic initialization

Chapter 6 aims at fulfilling the ultimate goal of our research objective, namely fully automatic segmentation of the left ventricle in 3D echocardiography. Our approach employs 3D active appearance models: statistical models that encompass typical shape and texture variations of the left ventricle in 3D echocardiography. The generalization of the shape and texture models is evaluated in relation to the number of patients in the study. For the texture model a nonlinear gray value normalization technique is presented, which improves the generalization capabilities of the texture model. Furthermore, the performance of the AAM detection is investigated with respect to the model's initialization, the a priori knowledge about the current patient and the optimization method used. It is shown that adequate automatic detection can be performed provided that the AAM is initialized within a certain lock-in range. Optimization using Jacobian tuning has shown to improve the matching accuracy and precision dramatically. In combination with automated initialization and proper postprocessing, 3D AAMs should be able to provide the desired automated analysis. This is a promising direction for future work.

fully automatic segmentation

Finally, chapter 7 briefly presents the research objective with the conclusions *discussion and conclusions*

of each of the chapters in this thesis. Furthermore, a general discussion on the presented work and recommendations for future work are given with respect to texture analysis, model-based segmentation and integration of the presented techniques. In the general conclusions the main contributions of this thesis are described, showing the relevance of this work, in reducing analysis time and interobserver variability, and improving the reducibility by automating the analysis of 3D echocardiography. Methods presented in this thesis may be of great value in related research areas such as freehand 3D ultrasound and 3D transesophageal echocardiography. Also research on automated analysis of cardiac MR or CT may benefit from the presented advances in analysis of 3D echocardiography, as 3D echocardiography does also benefit from advances on those fields. Integration of the presented techniques and technical improvements in 3D ultrasound imaging may soon lead to reliable fully automated analysis of 3D echocardiography.