Automated image analysis techniques for cardiovascular magnetic resonance imaging

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CHAPTER 1

General introduction and outline

1.1 Background

Assessment of quantitative parameters describing the status of the cardiac system is of eminent importance for the diagnosis and follow-up of patients with cardiac disease. Cardiac Magnetic Resonance Imaging (CMR) is one of the many imaging modalities used in clinical practice. CMR can be used to study multiple aspects of the cardiac system in a single examination, such as information on the cardiac anatomy, function, perfusion, flow and tissue characteristics. This would otherwise require multiple studies with different imaging modalities, and the subsequent difficulty in combining these data from the different unregistered modalities each with their spatial and temporal scales. As a three-dimensional (3D) technique, highly accurate volumetric measurements can be obtained without relying on the use of geometrical assumptions, making CMR a powerful technique to study complex structures such as the left and right ventricle. Repeat CMR examinations can be obtained without exposing the patient to harmful radiation or contrast agents. This makes CMR an ideal technique to perform repeat examinations on a patient for quantitative evaluation of the effects of medical treatment.

Visual and quantitative interpretation of a typical MR study requires review and processing of a huge number of images. For quantitative analysis image segmentation is required. The process of image segmentation involves the definition of the myocardial boundaries and other structures in the images. For the assessment of left ventricular function, imaging is usually preformed using a cine-MR acquisition in the short-axis view, in which the heart is imaged in eight to ten imaging sections from apex to base at 20 to 30 time points within the cardiac cycle. As a result, quantitative assessment of the ventricular volume over the cardiac cycle requires the definition of the endocardial (inner) contour of the myocardium in 160 to 300 images. For the assessment of left ventricular mass and regional assessment of the ventricular wall thickness over the cardiac cycle an additional set of epicardial (outer) contours is required. Furthermore, for more extensive quantitative analysis, such as the assessment of right ventricular function, myocardial perfusion, flow and myocardial scar tissue, additional image segmentation is needed. Clearly, manual contour tracing for all these CMR acquisitions is too demanding for routine clinical use. Consequently, the availability of automated or semi-automated contour detection techniques is demanded to fully exploit the information provided by a CMR examination.

1.2 Scope of this thesis

The work described in this thesis is inspired by the clinical needs as described above. Quantitative image analysis has advantages over visual image interpretation as it provides objective numbers which can be used to decide upon the appropriate treatment. The use of automated contour detection potentially has several benefits as it may result in a considerable decrease in the image analysis time and produces objective and reproducible results. Moreover, since automated contour detection is much faster, it also enables assessment of additional quantitative parameters which are derived by taking into account all the available image data. An example of such parameter is the regional rate of wall thickening and wall thinning from short-axis Cine MR. This parameter requires endocardial and epicardial contours in all time frames, which is only practical when automated contour detection is available.

The goal of the research described in this thesis is therefore:

- To investigate automated and semi-automated contour detection techniques for the assessment of quantitative indices of cardiac function
- To develop and evaluate techniques for the assessment of cardiac parameters from CMR image data
- To validate the developed algorithms on clinical CMR studies 7by comparing automated results to results obtained by expert observers.
- To investigate the feasibility of applying an automated contour detection algorithm on images acquired on MR scanners from different vendors using different MR pulse sequences.

1.3 Thesis outline

The remainder of this thesis is structured as follows.

Chapter 2 provides an overview of image processing techniques developed for quantitative analysis of cardiac MR image data. While the other chapters are mainly focusing on assessment of left ventricular function, this chapter also provides a summary of CMR image analysis techniques for other cardiac parameters, such as perfusion and viability.

Chapter 3 describes a method for semi-automated detection of the myocardial boundaries in multi-slice short-axis cine-MR imaging studies. The method described in this chapter uses low-level image processing techniques such as adaptive thresholding and edge-detection combined with usage of *a priori* information in order to optimize the robustness of the algorithm.

Chapter 4 describes an automated contour detection method for assessment of aortic flow throughout the cardiac cycle from velocity-encoded MR imaging studies. By exploiting the temporal coherence of the image data, the described algorithm provides accurate results, also in the presence of image frames with poor image quality.

In **Chapter 5** a new approach for quantitative assessment of myocardial wall thickness is presented. In contrast to pre-existing methods, the new method explores the three-dimensional nature of multi-slice short-axis studies to obtain improved accuracy of the wall thickness measurements.

Chapter 6 describes a contour detection method for short-axis cine MR studies based on Active Appearance Models. In this chapter the concept of Active Appearance Models was used to develop a 2D+time model. Based on a training set of pre-segmented short-axis MR image series, the left ventricular shape and image appearance is modeled, including the temporal variation from the end-diastolic phase to the end-systolic phase. This information is described in a statistical frame work and used as *a priori* information during the segmentation of new image series. The main advantage of this approach is that the complete time-sequence of images is used to obtain a consistent time-continuous segmentation result. This improves the robustness compared to a single-image (2D) Active Appearance Models implementation.

Chapter 7 describes an alternative contour detection approach for the detection of left ventricular endo- and epicardial contours, which exploits the temporal continuity of cardiac contraction and relaxation. The presented algorithm is an extension to the minimum cost contour detection algorithm which is frequently used in various medical image segmentation problems in 2D images. The method requires an accurate segmentation of a single frame and temporally propagates this segmentation based on local similarity properties and enforcing temporal continuity.

As segmentation algorithms get more complex, it becomes nearly impossible to guarantee that the various parameters controlling the behavior of the algorithm are defined optimally. In addition, it can be observed that images acquired with different pulse-sequences or obtained with different MR scanners do have varying image characteristics. The existence of these image characteristics variations were the motivation for developing an automated parameter optimization procedure, which is described in **Chapter 8**.

Finally, general conclusions of the thesis are presented in Chapter 9.