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Automatic classification of left ventricular wall segments in small animal ultrasound imaging

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ABSTRACT

Multiple statistics show that heart diseases are one of the main causes of mortality in our highly developed societies today. These diseases lead to a change of the physiology of the heart, which gives useful information about characteristic and severity of the defect. A fast and reliable diagnosis is the base for successful therapy. As a first step towards recognition of such heart remodeling processes, this work proposes a fully automatic processing pipeline for regional classification of the left ventricular wall in ultrasound images of small animals. The pipeline is based on state-of-the-art methods from computer vision and pattern classification. The myocardial wall is segmented and its motion is estimated. A feature extraction using the segmented data is realized to automatically classify the image regions into normal and abnormal myocardial tissue. The performance of the proposed pipeline is evaluated and a comparison of common classification algorithms on ultrasound data of living mice before and after artificially induced myocardial infarction is given. It is shown that the results of this work, reaching a maximum accuracy of 91.46%, are an encouraging base for further investigation.

1. Introduction

According to the Framingham Heart Study, arterial hypertension, coronary artery disease, and chronic heart failure are the leading cardiovascular causes of mortality in the industrialized world reaching epidemic extent in the aging societies [11]. Heart failure hereby is caused by a vicious circle in which an original insult leading to mechanical cardiac dysfunction initiates multiple morphological, biochemical, and molecular pathological alterations of myocardial structure and function referred to as *cardiac remodeling*, which needs extensive clinical follow-up of original cardiac history and post-interventional changes by clinicians [5].

Echocardiography resembles the initial and most frequently used non-invasive diagnostic imaging modality for heart failure patients [14]. The frequent use of non-invasive ultrasound images for clinical decision making in cardiovascular medicine on the one hand and the lack of highly trained, skilled sonographers under economic pressure in the healthcare system on the other hand demands for more sophisticated echocardiographic examination tools for minimal cardiac changes during the remodeling process [7].

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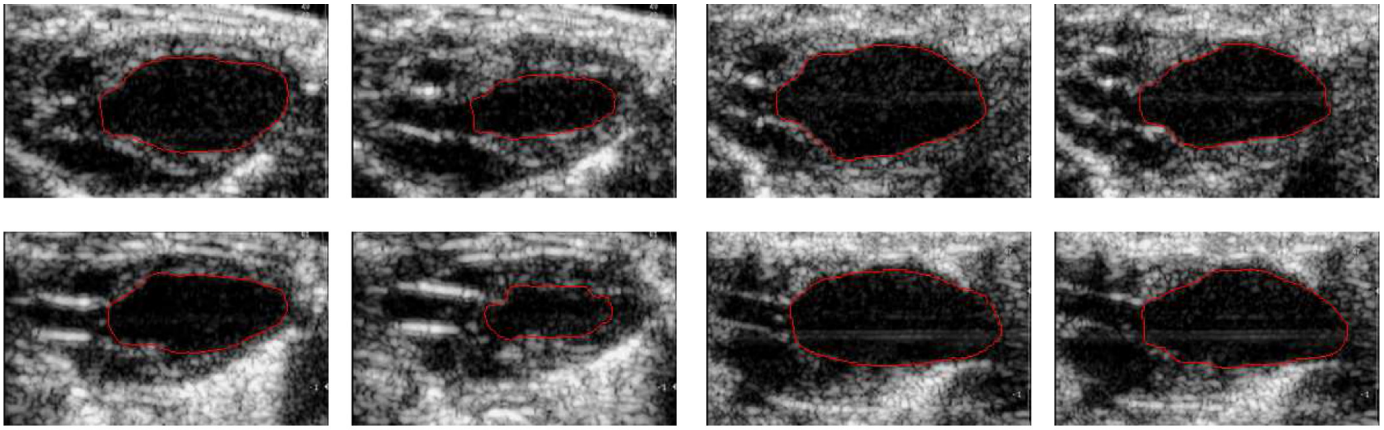

(a) d0: End-diastole (b) d0: End-systole (c) d14: End-diastole (d) d14: End-systole

Fig. 1 – Results of automatic high-level segmentation of the murine left ventricle for two different mice before (d0) and after (d14) artificially induced myocardial infarction.

Aiming for facilitated early identification of heart remodeling processes and trying to minimize inter-observer variability when interpreting regional and global heart pathologies, our goal is to develop standardized automated classification algorithms which provide parametric image encoding of left ventricular regional tissue properties.

In the field of ultrasound (US) tissue characterization it is of interest to differentiate between healthy and diseased tissue. Traditionally, the received radio frequency data of ultrasound imaging systems is analyzed. Features which are extracted from this data are used to characterize different classes of tissue, e.g., tumor tissue. Since these features are not directly correlated to certain diseases, classification techniques have to be employed. Tissue classification has already been investigated for different important anatomical subjects, i.e., breast, liver, heart, eyes, and skin. For a comprehensive review of tissue classification methods we refer to [13].

As said before, tissue characterization approaches are typically based on low-level features computed from radio frequency signals or image intensities in ultrasound B-mode images, e.g., the integrated backscatter coefficient or the attenuation coefficient [13]. To the best of our knowledge, the incorporation of higher order features derived from motion estimation or segmentation into regional tissue characterization of the left ventricular wall has not been investigated in the literature so far. For this reason, we propose in this work a novel processing pipeline for automatic classification and regional differentiation of the left ventricular wall, on the basis of features computed with robust segmentation and motion estimation methods from computer vision.

This paper is an extended version of [20] and represents an expansion in technical details, methodology and experimental work. From a methodological point of view the Bayes classifier already has been used in [20]. In this work we extend the methodology by exploring and comparing the potential of four other common classifiers. In addition, we introduce a relaxation postprocessing step to further enhance the classification performance.

The remainder of this paper is organized as follows. In Section 2.1 we give details about our ultrasound image acquisition setting. Section 2.2 describes a novel high-level segmentation method to perform accurate estimation of the left ventricular endocardial border in the presence of heavy noise perturbations. Subsequently, we shortly present a robust method for motion estimation between the end-diastolic and end-systolic phase of myocardial motion based on local statistics in Section 2.3. With the help of these information we are able to compute features for the classification of left ventricular segments introduced in Section 2.4, while for classification we utilize state-of-the-art classifiers as described in Section 2.5. After classification we propose the application of a relaxation process in Section 2.6. We show experimental results of the proposed processing pipeline and a comparison of the different classifiers in Section 3 and evaluate the methodology on real data of living mice. We conclude this work with a discussion in Section 4.

2. Methods

In this section we present a fully automatic processing pipeline for regional classification of the left ventricular wall in small animals. The performed small animal experiment serves as a simplified model for human myocardial infarction of the left anterior descending coronary artery. Here, motion abnormalities after operatively induced myocardial infarction show up rapidly within a few minutes and subsequently alter to a paper thin dyskinetic aneurysm within two weeks depending on the size of the infarcted myocardium. The reproducibility of this well described process in mice gives the opportunity of scanning multiple equally old infarctions in parallel for bigger scan numbers. Evidently, this is not applicable for human patients. Furthermore, remodeling processes of the human heart can take between 90 days to 1 year which make them even harder to study. However, the cascade of wall motion abnormalities from hypokinesia to akinesia to dyskinesia proceeds equally in both models. Thus, observed