Automatic Human Knee Cartilage Segmentation from Multi-contrast MR Images Using Extreme Learning Machines and Discriminative Random Fields

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Abstract. Accurate and automatic segmentation of knee cartilage is required for the quantitative cartilage measures and is crucial for the assessment of acute injury or osteoarthritis. Unfortunately, the current works are still unsatisfactory. In this paper, we present a novel solution toward the automatic cartilage segmentation from multi-contrast magnetic resonance (MR) images using a pixel classification approach. Most of the previous classification based works for cartilage segmentation only rely on the labeling by a trained classifier, such as support vector machines (SVM) or k-nearest neighbor, but they do not consider the spatial interaction. Extreme learning machines (ELM) have been proposed as the training algorithm for the generalized single-hidden layer feedforward networks, which can be used in various regression and classification applications. Works on ELM have shown that ELM for classification not only tends to achieve good generalization performance, but also is easy to be implemented since ELM requires less human intervention (only one user-specified parameter needs to be chosen) and can get direct least-square solution. To incorporate spatial dependency in classification, we propose a new segmentation method based on the convex optimization of an ELM-based association potential and a discriminative random fields (DRF) based interaction potential for segmenting cartilage automatically with multi-contrast MR images. Our method not only benefits from the good generalization classification performance of ELM but also incorporates the spatial dependencies in classification. We test the proposed method on multi-contrast MR datasets acquired from 11 subjects. Experimental results show that our method outperforms the classifiers based solely on DRF, SVM or ELM in segmentation accuracy.

1 Introduction

Magnetic resonance (MR) imaging has emerged as the most promising imaging modality to detect structural changes in cartilages, as it can provide direct and noninvasive images of the whole knee joint. Since the assessment of acute injury or osteoarthritis (OA) requires exact quantitative cartilage measures such as the cartilage’s thickness and volume, accurate cartilage segmentation as the key to these measures has gained considerable attention in recent years. In general, Manual and semi-automatic segmentation is laborious and time consuming. Moreover, they are prone to inter/intra-observer variability rendering the analysis of the results very complicated. Therefore, it is
desirable to automate the segmentation. Unfortunately, automatic cartilage segmentation from MR images is a challenging task due to the thin variable morphology of cartilages, intensity inhomogeneity, the low contrast between cartilages and other soft tissues, and MR artifacts. In this work, we address the problem of automatic human knee cartilage segmentation from multiple sets of MR images taken with different sequences (referred to as multi-contrast MR images). To the best of our knowledge, the research on cartilage segmentation from multi-contrast MR data is sparse.

1.1 Related Works

In recent years, several automatic approaches to cartilage segmentation have been proposed. Glocker et al. [1] utilized a nonrigid registration scheme to segment the patellar cartilage by fitting a statistical atlas to MR data. Fripp et al. [2] used a hierarchical cartilage segmentation scheme based on a hybrid deformable model. Dodin et al. [3] developed a hierarchical automatic segmentation algorithm for knee cartilage volume quantification. At the 2010 MICCAI conference, a competition for knee segmentation was held at a workshop “Medical Image Analysis for the Clinic” [4]. Among these automatic segmentation methods, model-based works ranked in the highest quantile, such as the approach proposed in [5]. Besides, image segmentation can also be considered as a statistical classification problem in which each pixel belongs to a class. Folkesson et al. [6] employed a two step k-nearest neighbor classifier to automatically separate cartilages from non-cartilages. While all the aforementioned works are based on a single MR sequence, multi-contrast MR images provide different contrast mechanisms between tissues and help separate different tissues. Koo et al. [7] proposed to segment cartilage automatically with multi-contrast MR images using support vector machines (SVM). However, these classification based works [6, 7] assumed that data instances were independent, which may not be appropriate for the cartilage segmentation task. As pointed out by [8], class labels are not independent in most real-world spatial classification problems, where correlations in labels of neighboring instances exist in data with multi-dimensional structure, such as images and volumes. This motivates one to incorporate contextual information in the form of spatial dependencies in the classification for cartilage segmentation, which generally yields smoother and more reliable results.

1.2 Overview of the Work Presented

Extreme learning machines (ELM) [9, 10] were proposed as the training algorithm for the generalized single-hidden layer feedforward networks (SLFN), which can be used in various regression and classification applications. Works on ELM have shown that ELM for classification not only tends to achieve good generalization performance, but also is easy to be implemented since ELM requires less human intervention (only one user-specified parameter needs to be chosen) and can get direct least-square solution. Unfortunately, ELM does not consider spatial information which is necessary and beneficial to the cartilage segmentation. Probabilistic graphical models such as discriminative random fields (DRF) have been used to incorporate spatial contextual constraints in many applications [8].