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Original Research Article

A new computer-based approach for fully automated segmentation of knee meniscus from magnetic resonance images

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ABSTRACT

Menisci are tissues that enable mobility and absorb excess loads on the knee. Problems in meniscus can trigger the disorder of osteoarthritis (OA). OA is one of the most common causes of disability, especially among young athlethes and elderly people. Therefore, the early diagnosis and treatment of abnormalities that occur in the meniscus are of significant importance. This study proposes a new computer-based and fully automated approach to support radiologists by: (i) the segmentation of medial menisci, (ii) enabling early diagnosis and treatment, and (iii) reducing the errors caused by MR intra-reader variability. In this study, 88 different MR images provided by the Osteoarthritis Initiative (OAI) are used. The histogram of oriented gradients (HOG) and local binary patterns (LBP) methods are used for feature extraction from these MR images along with the extreme learning machine (ELM) and random forests (RF) methods which are used for model learning (regression). As the first step of the pipeline, the most compact rectangular patches bounding the menisci are located. After this, meniscus boundaries are revealed by the morphological processes. Then, the similarities between these boundaries and the ground truth images are measured and compared with each other. The highest score is acquired with Dice similarity measurement with a success rate of 82%. A successful segmentation is performed on the diseased knee MR images. The proposed approach can be implemented as a decision support system for radiologists, while the segmented menisci can be used in classification of meniscal tear in future studies.

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1. Introduction

Osteoarthritis is a joint disorder and generally characterized by pain, stiffness, and limitation of movement. Osteoarthritis occurrence increases with age. Knee osteoarthritis (OA) is accompanied by the loss of function due to the degeneration of joint cartilage. Meniscus tears may also lead to OA. On the other hand, OA can also cause meniscus tearing because of the deterioration and weakening of the meniscal structure. There are important functions performed by the meniscus such as carrying the load on the knee and the reduction of friction in the knee joint. So, the damage on meniscus can lead to the knee cartilage disorder and further the limitation of mobility, as well. Thus, it is very important to detect the damages on meniscus region for the early diagnosis.

Magnetic resonance imaging (MRI) is one of the most commonly used techniques for this purpose. MRI is an extensively preferred imaging alternative due to being a noninvasive and harmless method that works in a low energy radio frequency band, and provides high quality imaging to distinguish tissues. Besides, MRI is ideal for quantitative image analysis of meniscus, because it allows detailed imaging of the inaccessible tissue by radiographs [1]. Compared to the arthroscopic and clinical examination, the detection of meniscal injuries by MRI has an accuracy of 85%, and this, very well supports the use of automated methods for the diagnosis and treatment of acute injured knees [1]. Motivated from these findings, MRI is also used in this study as the most commonly used imaging modality for the studies conducted on the knee joint in relevant literature.

The knee joint consists of the tibia and femur bones, joint cartilages and menisci. All these structures directly affect the ability to move. Many studies in the literature focus on the automatic segmentation of these structures which directly affect the movement on the knee. Tibia and femur bones enable the segmentation of cartilage and meniscus. In bone segmentation, many methods such as statistical shape model approach [2,3], active contour method [4], and deformable model approach [5] have been successfully applied.

Some of the studies conducted on the knee MR images are about segmentation of the articular cartilage. OA is the most common joint disease that is caused by the gradual erosion of articular cartilage. Although there is no certain treatment, the early diagnosis is aimed in most relevant studies. Some studies about the articular cartilage perform a semi-automatic segmentation [6,7], while another part of studies perform fully automatic segmentation [8–12]. Apart from the studies about cartilage segmentation, there are also many studies about the detection and diagnosis of the menisci. The first of these studies conducted by Sasaki et al. employed an automatic meniscus segmentation by using fuzzy logic [13]. In this study, the segmentation of cartilage tissue according to the intensity values with thresholding methods were firstly carried out. Then menisci were determined according to the *fuzzy if then rule* by observing the cartilage tissues. The authors applied the method on five MR images. The small number of data instances was the weakness of the study. Another leading work of the same team diagnoses the tears in medial or lateral menisci in a fully automatic manner on the proton density knee MR images [14]. Boniatis et al. intended to uncover a distinction between the normal and degenerated meniscus at the T1-weighted sagittal plane [15]. This study detected only the medial meniscus posterior horn on 55 different MR images. The region growing algorithm was used to identify the meniscus location. Bayes classifiers with texture features were employed for the classification process in this study, providing a success rate of 89%. Another study used statistical methods for meniscus segmentation and the detection of meniscal tears from sagittal plane knee MR images [16]. Here, the histogram-based and template-matching methods were used for segmentation of menisci and the detection of tears, respectively. The use of region specific assumptions in determining the meniscus may cause problems on different types of MRs, and diminish the generalization of this work.

Ramakrishna et al. has implemented an automated computer-assisted detection system to detect meniscal tears and their levels from MR images [17]. Although it was a detailed study in this field, low specificity values and the need for a priori knowledge in identifying slices constitute the weaknesses of this study. Swanson et al. performed a semi-automated method to examine and evaluate the lateral menisci in normal and osteoarthritis-caught knees, and stated that their goal was to reduce the segmentation time and errors caused by the MR intra-reader variability [18]. The average success rate obtained was 80% from the healthy volunteer images, based on the disease level. Swamy et al.'s comprehensive study was applied in all three planes (sagittal, coronal and axial) and varying MR scanners, operating both in low-field (1.5 T) and high-field (3.0 T), were used [19]. Femur and tibia bones were segmented with the Canny edge detector method [20] in this study. After that, menisci were determined between tibia and femur bones by region of interest (ROI) based masking. Another study on OA knee MR images detected cartilage thickness and meniscus tear [21]. Many image processing techniques, such as histogram equalization, thresholding and Canny edge detection is used in this study. The weaknesses of the study lies in the fact that it does not report any performance measures, hence the efficacy is not validated. Fripp et al. developed a system which has automatic meniscus segmentation in the sagittal plane knee MR images [22]. In this study, they used previous bone and cartilage segmentation results as the preliminary information and performed the labeling of meniscus voxels accordingly. Using the Dice similarity measure, they achieved an accuracy rate of 75% for lateral meniscus, and 77% for medial meniscus. Its only weakness is that the study is conducted on healthy people, and is applied in a small dataset. Nedmark conducted an automatic meniscus segmentation for MR images obtained from low field MRI scanner [23]. In this work, bone segmentation was followed by meniscus localization. Finally, meniscus segmentation was carried out.

Some of the studies related to menisci were performed in three dimensions (3D). Kim et al. have carried out the 3D meniscus segmentation with the integration of statistical active shape models [24]. As a result, a success rate of 54% for the medial meniscus, and 73% for the lateral meniscus were obtained. Yin et al. have performed a 3D meniscus segmentation using random forest (RF) classifiers with the previous study results about bone and cartilage [25]. They measured