Extraction of Chondromalacia Knee Cartilage Using Multi Slice Thresholding Method

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Abstract. The paper deals with design of segmentation method for extraction special types of pathological changes of knee cartilage. Those changes are called chondromalacia of knee cartilage. These pathological changes unfavorable influence cartilage's surface and significantly deteriorate their structure. Knee cartilage is typically investigated by Magnetic resonance imaging (MRI). MRI is very effective method which is able to differentiate individual knee structures. On the other hand some tiny tissue's changes are not clearly recognizable because MRI generates image outputs in shade gray levels. Chondromalacia in early stage is manifested by weak contrast compared to its surroundings and therefore it is very complicated to recognize and locate spots where this change is. The proposed segmentation method is able to precisely differentiate individual cartilage structures and perform extraction of cartilage structure and adjacent pathological changes. Furthermore the proposed segmentation method transform MRI data to contrasting color map which is more effective approach then gray shade levels. The proposed algorithm is being tested on sample 30 patient's records and results are discussed with radiological experts.

Keywords: Multi slice thresholding · Image segmentation · MRI · Chondromalacia · Articular cartilage · MATLAB

1 The Structure of Articular Cartilage

Covering the surface of bone in all joints is articular cartilage. Articular cartilage is smooth white and glistening. This type of cartilage is very specialized and has several functions. One of the most important functions is force distribution. If a load is placed on the joint the cartilage spreads the load out so that it is distributed over a large surface area. This protects the bone and makes it so that the underlying bone is not subjected to large forces. Normal cartilage also is very smooth and slippery. A joint is able to bend and straighten with very little resistance because of the low coefficient of friction of articular cartilage which is less than that of ice. Lastly the shape of the bone and cartilage surface provides stability to the joint.

The composition of articular cartilage is very complex and is made up of collagen (protein in skin and nails), water and various other proteins. These proteins and water are in a compressed state and because of this balance are able to resist load. When a

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load is placed on the joint the cartilage surface will compress and the water and protein will be pushed closer together. Water and protein have opposite charges (positive and negative) and repel each other as they are compressed and therefore resist load. The load is also spread out over a large area to dissipate the force. This is the way that articular cartilage is able to decrease the load on the underlying bone and protect it. The most frequent used sequences for examination of articular cartilages are spin-echo sequence (Fig. 1) and fast spin echo sequence with fat saturation (Fig. 2) [1–6].

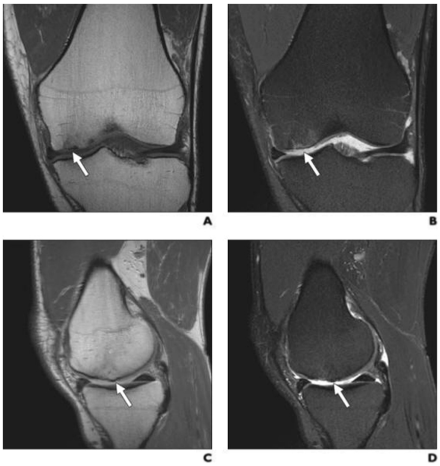

Fig. 1. Multiple planes of fast spin-echo (FSE) images show cartilage damage in 54-year-old man

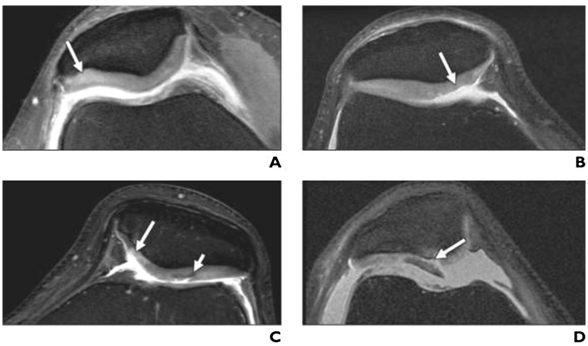

Fig. 2. Axial fast spin-echo (FSE) images with fat saturation of cartilage damage

2 The Design of Multi Slice Segmentation Algorithm

After loading input image it is necessary defining region of interest (RoI). This step is needed for localization area where cartilage structure should be. By this procedure it is increased analyzed area, there is a disadvantage because it is focused smaller part of image which contains less pixels. Therefore it is needed to perform pixel's interpolation for achieving better image contrast. For this task, linear interpolation method is used.

The core of segmentation method is based on the Otsu method. Otsu method normally uses just one thresholding. Segmentation method with only one thresholding is not suitable for processing of medical images. In this area, it is much better to use which is based on the multi slice thresholding approach, which increases sensitivity of recognition individual structures in cartilage images. Furthermore segmentation procedure transforms shade level pixels to contrasting color map with high level of contrast scale.

Proposed thresholding method finds specific levels for a image based on the histogram distribution into equally large areas. Specific thresholding level is used for each area. The analyzed image is consequently segmented according to all thresholding levels.

Individual pixels with different shade levels are labeled as L with range: [0,1,…,L]. Number of thresholding levels is given as p. The size of one segmented area is given by equation:

$$a = \frac{L}{p} \tag{1}$$

Between class variance σ^2 is calculated similarly as Otsu method:

$$\sigma^2 = W_0 * W_1 * (\mu_0 - \mu_1)^2 \tag{2}$$

The number of divided regions of the histogram is equal to the number of thresholding levels p. Optimal thresholding levels for individual areas are given:

$$P_p = max_p(\sigma^2) \tag{3}$$

For the validity of the above formulas is necessary that the number of pixels in different shades of gray L is equal to 256 * j. Number of thresholding levels p must be from set: [2*j, 4*j, 8*j], where j belongs to set: [1,2,…,∞]. According to practical results, it is recommended to use set: [1,2,…,8].

The segmentation output would be normally generated by shade gray levels. This way is it not appropriate because gray scale is not obviously recognizable. Due this fact transformation to color spectrum is performed. Each output segmentation class is coded by one number which represents individual structure. This transformation assigns to each class unique color. By this procedure is achieved contrasting map when individual colors reflect detected structures. [7–9] (Fig. 3)

The proposed algorithm for chondromalacia extraction is described by following diagram: [10–12]

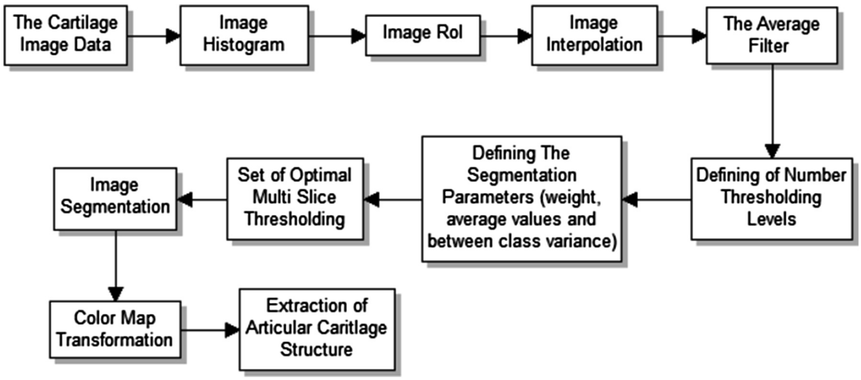

Fig. 3. The block diagram of multi slice algorithm for chondromalacia extraction

3 Data Analysis and Segmentation Results

The proposed algorithm has been tested on the sample of 30 patient's records. For examination of articular cartilage are normally used two types of MRI sequences: spin-echo sequence and fast spin echo sequence with fat saturation. There are four stages of chondromalacia:

- Degree 0 – physiological cartilage.
- Degree I – cartilage with swelling and softening.
- Degree II – partial rupture with a crack on the surface that does not interfere with the subchondral bone.
- Degree III – a crack extending to the subchondral bone with a diameter of up to 1.5 cm.
- Degree IV – exposed subchondral bone.

Physiological cartilage is normally represented by single colour spectrum (usually by white color but it depends which imaging sequence is used). If some color changes are registered on cartilage surface, it indicates pathological lesions. In Terms of image processing Degrees II – IV are not so interesting because those disorders are manifested by significant contrasting changes. Degree I is usually manifested by weaker change of color spectrum in comparison with adjacent structures. Those changes are badly recognizable by human eye. Therefore is for clinical practice really needed image processing tool for automatic recognizing areas of pathological spots. Significant advantage of the proposed software solution is expanding of interesting area to maximum size for better view (Fig. 4).

The proposed algorithm has been tested on sample image data which contain cartilage structure. Cartilage is corrupted by chondromalacia of first degree. At the first view those pathological changes are not clearly visible.

Fig. 4. Example of analyzed data

- Case 1

The articular cartilage is represented by darker-white color. Physiological cartilage would have been shown by white color. At the first view it is not obvious any changes on cartilage surface. After detailed investigation it is a little viewed weaker contrasting change on the cartilage surface. It is indicated first degree of chondromalacia. It is going to loss (delamination) of cartilage's dorsal part medial condyle of femur. In the square window area of interest is focused. Segmentation results create color map which differentiate individual tissue's structures (Fig. 5. left image). Physiological cartilage is represented by red color. It is obvious interruption on cartilage's surface (Fig. 5. right image).

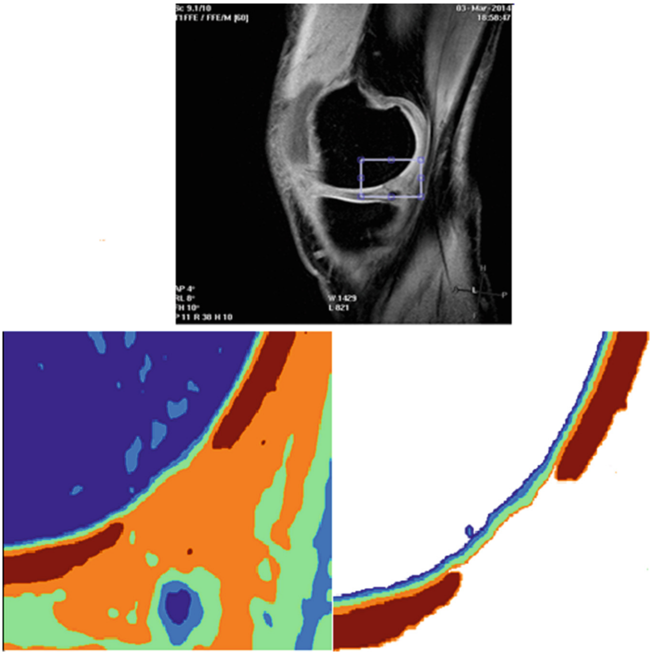

Fig. 5. Original MRI image data (up), segmentation results (left) and detected cartilage's surface with pathological interruption (right)

- Case 2

There are two images of articular cartilage which is suffered from chondromalacia of first degree. It is again needed to perform extraction of articular cartilage and pathological interruptions (Figs. 6, 7 and 8).

- Case 3

The third case deals with detection of inhomogeneity on cartilage of medial condyle's femur and tibia. These changes are very difficult recognizable in standard shade levels imagining. In segmentation output it is obvious changes of cartilage's structure. Those changes are accompanied by color changes from yellow to lightly blue color spectrum (Fig. 9).

Fig. 6. Original image data with RoI

Fig. 7. Segmentation results (left), cartilage surface with interruption (right)

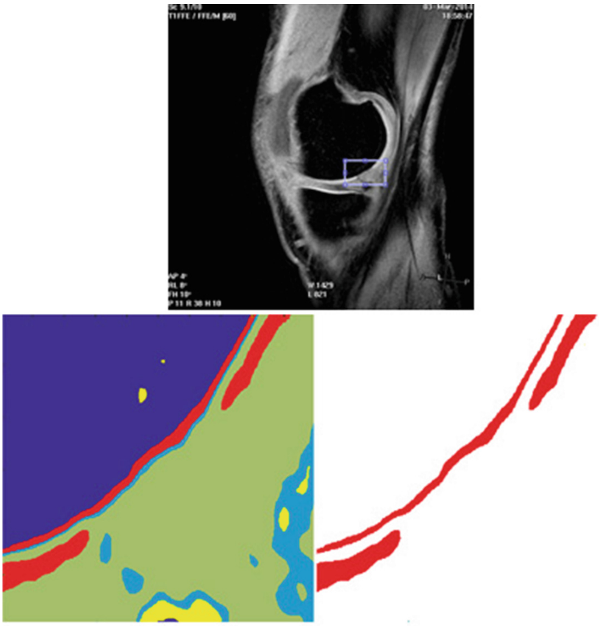

Fig. 8. Original MRI image data (up), segmentation results (left) and detected cartilage's surface with pathological interruption (right)

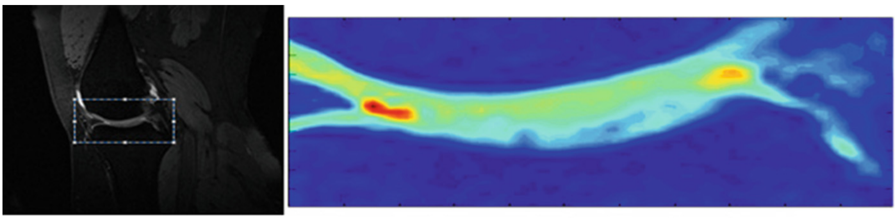

Fig. 9. Original MRI image (left) and segmentation output (right) (Color figure online)

4 Conclusion

The Article deals with design and testing of multi slice thresholding method for chondromalacia detection. The proposed algorithm is able to perform color mapping of individual structures from MRI images. The significant benefit is separation those structures to isolated classes and consequent selection interested structures. By described procedure it is possible to extract specific tissues from original MRI data. Benefit of proposed solution is deep sensitivity of classification even for the structures which are accompanied by badly visible contrast. This feature is needed especially for extraction of early stage chondromalacia. This disorder is manifested by weak contrast changes and therefore it is practically impossible to recognize and locate those pathological areas. On the base segmentation procedure articular cartilage is represented by single color spectrum (usually red color) and pathological interruptions are clearly indicated unlike from native MRI images. In clinical practice, there is no any other alternative for assessing articular cartilages. Those structures are assessed by human's eyes. This process is influenced by relative significant subjective error. The proposed software solution has been tested on the sample real patient's data and for now gives satisfactory results because it is able to reliably separate physiological cartilage and chondromalacia's changes. It is very favorable assumption for using it in clinical practice.

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