Automatic Segmentation of Femoral Cartilage from MR Image Based on Hough Transform and Adaptive Canny Detection

Yu Cao[1], Xia Liu[1], Yang Cao[1] and Yu-nan Liu[2]*

[1]*School of Automation Harbin University of Science and Technology*
Harbin, China
[2]*School of Foreign Languages Harbin University of Science and Technology*
Harbin, China
cyhit@163.com

Abstract

Medical image segmentation has important significance for thickness estimation of the articular cartilage and joint disease diagnosis. In this study, a novel automatic segmentation method based on Hough transform and edge detection was proposed to divide femoral cartilage in human hip joint from MR images. MR image was interpolated, smoothed and enhanced in preprocessing to improve the image quality. Hough transform was employed to find out the center position of the femoral head and the anatomical constrain of the hip joint was considered to estimate the area of interest (AOI). Furthermore, the rough segmentation range was extracted. To figure out the border of the cartilage, the adaptive thresholding Canny detector was exerted. The detected edges were then labeled and filtered in a custom one by one manner to remove the noise edges and acquire the exact inner and outer edges of the femoral cartilage, according to the properties of the pixel on femoral cartilage edge. Image data between the two edges were finally extracted to achieve the femoral cartilage segmentation. Experiment on 120 MR image slices proved that the method can automatically segment the femoral cartilage fast and accurately.

Keywords: *Automatic segmentation; MR image; Hough transform; Canny detection; femoral cartilage*

1. Introduction

Many hip joint diseases begin from articular cartilage damage on femoral in their early time, such as rheumatoid arthritis, osteoarthritis and so on. Protecting and rehabilitating cartilage from destruction are the fundamental indicators of the effect of these diseases treatments [1]. Fast and accurate articular cartilage segmentation is the important prerequisite for accurate cartilage thickness estimation, joint diseases diagnosis and determination of the therapeutic method.

Compared with the X-ray, CT, and ultrasound detection technologies, MRI is the most effective non-invasive technology to detect and evaluate articular cartilage injury and repair, with excellent resolution and contrast [2]. Many scholars have researched on computer-aided processing in articular cartilage MR image. McWalter compared segmentation effects of articular cartilage in MR images in three types of human-computer interaction, and the result showed that the accuracies of segmentation in the different interactive modes did not make much difference [3]. Brem improved segmentation accuracy by using semiautomatic method to match and split adjacent projective slice MR images of knee cartilage [4]. Khanmohammadi achieved automatic edge extraction of human hip joint space, which

Supported by the Youth Foundation of Harbin University of Science and Technology (2011YF038).
*Corresponding author.

provided the premise to extract centerline of joint space and split hip joint space [5]. Most of researchers focused their analysis on parts of heart and brain. Research on the articular cartilage is still infancy [6].

Human hip joint is composed of femoral head and acetabulum. The outer surface of femoral head and the inner surface of acetabulum are covered with a layer of cartilage tissue, with the synovial fluid filled between two layers of cartilage as lubricant. Usually in the MR images, it's difficult to distinguish two layers of cartilage because they integrate closely. By traction technology to stretch hip joint, the femoral head and acetabular cartilage can be seen clearly in MR images. Figure 1 shows MR projective image of a hip joint after traction, and articular cartilage in the figure is displayed as a high-brightness. Addition to the femoral head and acetabular cartilage, some of surrounding soft tissue and noise are also shown as a high brightness. In this paper, edge-based segmentation method is proposed to achieve automatic segmentation on femoral cartilage in MR images. Firstly, image pretreatment was done by interpolation, smoothing and enhanced processing. Then the Hough transform was used to find center position of femoral head. Furthermore, anatomical structure knowledge was considered to select target range of femoral head and figure out coarse segmented region. Secondly, adaptive Canny edge detector was used to extract the edge of the cartilage within the region of the coarse segmentation. According to the properties of the pixel on femoral cartilage edge, these edges were labeled and screened in a one by one manner to remove the noise edges and acquire the exact inner and outer edges of the femoral cartilage. Finally, the image data between inner and outer edges were extracted to achieve the automatic segmentation of femoral cartilage. The whole process did not require manual intervention and the efficiency of segmentation process was improved.

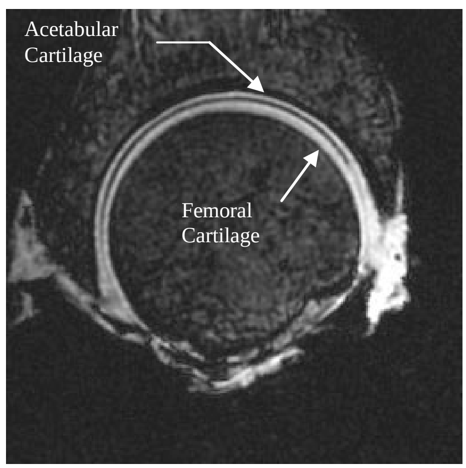


Figure 1. The MR Image of Human Hip Joint after Traction

2. Image Preprocessing

MR images were taken from the right side of the pelvis hip specimens of adult man (35 years old), using fast spoiled gradient-echo sequence to projective image on the sagittal direction of the hip joint specimens by 1.5T HDe MR system from the GE company. Projective imaging parameters were as follows: repetition time(TR)/echo time(TE)= 10.4/4.8 ms; flip angle = 15º; filed of view(FOV)= 160 mm x 160 mm; matrix = 256 x 256; section thickness = 1.6 mm; number of signals acquired = 2; acquisition time = 4 min 38 s.

Image preprocessing included interpolation, smoothing and enhancement. The image interpolation was implemented to enhance the accuracy of image segmentation, which improving the resolution from 256 x 256 to 512 x 512 and making the size of each image pixel change from 0.625mm x 0.625mm to 0.3125mm x 0.3125mm. Due to the Sinc function can be a good fit to the point spread effects of MR projective process [9], Sinc interpolation is used to improve the resolution of MR image in our study. The image smoothing processing was performed after the interpolation by using Gauss filter to reduce the noise on the image. In order to improve the contrast of the articular cartilage and background, fuzzy enhancement method was utilized.

Histogram equalization method was exerted to obtain image *P(x, y)*, and calculate the gray gradient on each pixel to be the Characteristic boundary as follow:

$$d(x,y)=\sqrt{\left[\frac{\partial}{\partial x}p(x,y)\right]^2+\left[\frac{\partial}{\partial y}p(x,y)\right]^2} \tag{1}$$

The membership function transforming the image from spatial domain to fuzzy domain is:

$$\mu(g,a,b,h)=\begin{cases}0 & ,\ g\le a\\ \dfrac{(g-a)^2}{(h-a)(b-a)} & ,\ a<g\le h\\ 1-\dfrac{(g-b)^2}{(b-h)(b-a)} & ,\ h<g<b\\ 1 & ,\ g\ge b\end{cases} \tag{2}$$

where a, b, h —— parameters which decide the fuzzy domain;
g —— gray level in spatial domain.

The minimum value of the image gray level is *a* and the maximum value is *b*. *h* is determined by the main trough. When *a, b* and *h* determined the membership function can be recorded as $\mu(g)$. The image is divided into four parts by the membership function, which is $0<a<h<b<255$. *h* is the threshold. The part higher than the threshold value will be enhanced and the lower part will be dark.

The average value of fuzzy membership was used to enhance the image in the specified window. The average membership value calculation is:

$$\overline{\mu}_w(d_{ij})=\frac{1}{w^2}\sum_{m=i-\frac{w-1}{2}}^{i+\frac{w-1}{2}}\sum_{n=j-\frac{w-1}{2}}^{j+\frac{w-1}{2}}\mu(d_{mn}) \tag{3}$$

where w —— window size;
d_{ij} —— pixel value on the location (i, j) of the image.

Build a contrast ratio of matrix *K* between membership value and average value. Matrix element in the pixel position (i, j) is:

$$K_{ij}=\frac{\left|\mu(d_{ij})-\overline{\mu}_w(d_{ij})\right|}{\left|\mu(d_{ij})+\overline{\mu}_w(d_{ij})\right|} \tag{4}$$

Improve the rate of comparison to matrix *K* through the power transform. We can get $\hat{K}_{ij}$

$$\hat{K}_{ij} = \left[K_{ij} \right]^{r(p_{ij})} \tag{5}$$

$$r\left(p_{ij}\right) = \left[1 + \mu_0 - \mu\left(p_{ij}\right)\right]^2 \tag{6}$$

where μ_0 —— threshold in fuzzy domain.

When $\mu\left(p_{ij}\right) > \mu_0$ take the zooming in operation, when $\mu\left(p_{ij}\right) < \mu_0$ take the zooming out operation. Take $\mu_0 = \mu(h)$. The revised value can be calculated by the following equation:

$$\hat{\mu}\left(d_{ij}\right) = \begin{cases} \dfrac{1+\hat{K}_{ij}}{1-\hat{K}_{ij}} \mu\left(d_{ij}\right) & , \ \mu\left(d_{ij}\right) \geq \overline{\mu}_w\left(d_{ij}\right) \\ \dfrac{1-\hat{K}_{ij}}{1+\hat{K}_{ij}} \mu\left(d_{ij}\right) & , \ \mu\left(d_{ij}\right) < \overline{\mu}_w\left(d_{ij}\right) \end{cases} \tag{7}$$

In equation (7), when $\hat{\mu}\left(d_{ij}\right) > 1$, take $\hat{\mu}\left(d_{ij}\right) = 1$.

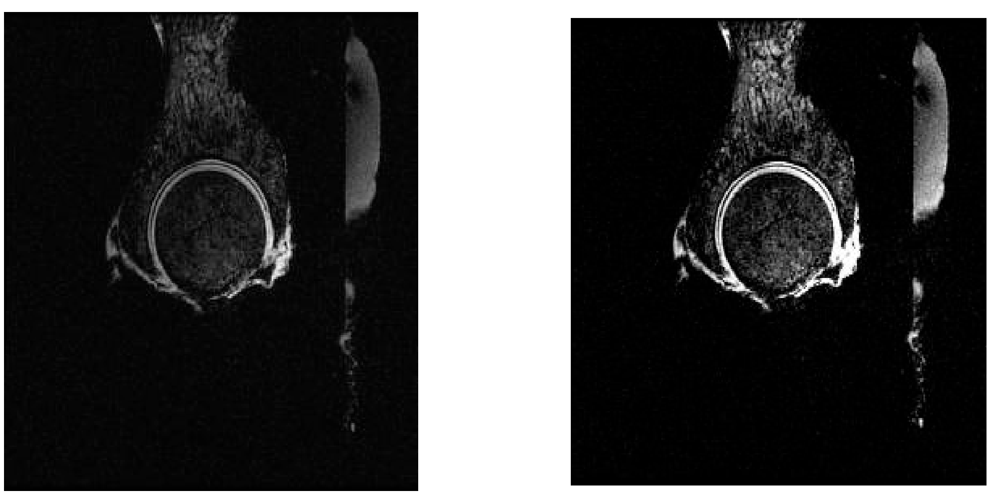
The modified value was transformed from the fuzzy domain into the spatial domain. The gray value in converted image in the position (i, j) is:

$$D_{ij} = \begin{cases} g_{\min} + \dfrac{g_{\max} - g_{\min}}{b-a} \sqrt{\hat{\mu}\left(d_{ij}\right)(h-a)(b-a)} & , 0 \leq \hat{\mu}\left(d_{ij}\right) \leq \dfrac{(h-a)}{(b-a)} \\ g_{\min} + \dfrac{g_{\max} - g_{\min}}{b-a} \left[b-a-\sqrt{\left(1-\hat{\mu}\left(d_{ij}\right)\right)(b-h)(b-a)} \right], & \dfrac{(h-a)}{(b-a)} < \hat{\mu}\left(d_{ij}\right) \leq 1 \end{cases} \tag{8}$$

where $g_{\min}$ —— the expected minimum gray value in enhanced image;

$g_{\max}$ —— the expected maximum gray value in enhanced image.

Figure 2 shows the original MR image on hip joint and image after preprocessing.



(a) Original image (b) Enhanced image

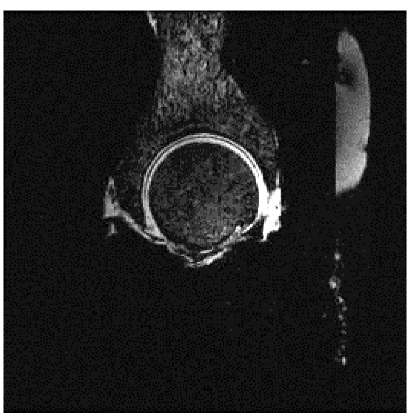
Figure 2. Comparison of Original Image and Enhanced Image

3. Image Segmentation

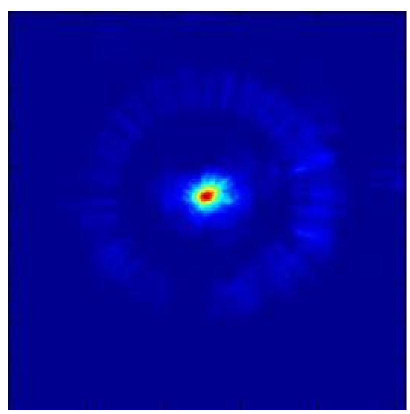
Depending on imaging mechanism and segmentation target, researchers have proposed many different medical image segmentation methods, such as segmentation algorithm based on regional growth, segmentation algorithm based on edge detection, segmentation algorithm based on neural networks, watershed segmentation algorithm, level set segmentation algorithm, map-guided segmentation algorithm and so on. Each method has its own advantages and disadvantages and special applicable detection site. In order to achieve the automatic segmentation without manual intervention, features of cartilage in MR images which were stable position, high gray and good connectivity had been considered. Based on it, an optimized segmentation algorithm using Canny edge detection operator was developed in our study. Considering that the edge detection method are sensitive to noise, we segmented the coarse region first to reduce noise, and then eliminate noise by labeling and screening the edges in one by one manner. The femoral cartilage inner and outer edges would be accurately extracted according custom rules, and accurate segmentation of the femoral cartilage would be realized.

3.1. Center Extraction based on the Hough Transform

The anatomical research shows that approximately 2/3 of the femoral articular surface is spherical surface. The radius is normally between 20mm to 25mm. There are lunate swivels as contact surface between the femoral head and acetabulum [10]. In this paper we assumed that the femoral cartilage has a spherical structure. In order to select the target area of interest automatically, Hough transform method was employed to take out of the center position of the femoral head in the MR slice image by finding out the center of the sphere. Cartilage near the edge pixel in the image has following features: (1) the gradient vector of pixel is arranged along the direction from center point to pixel; (2) the modulus of gradient vector is very large. According to these characteristics and the known radius constraint, the cumulative array satisfied the adaptive threshold conditions of the gradient vector can be calculated. The largest element in the accumulation array position is the center position of the femoral head.

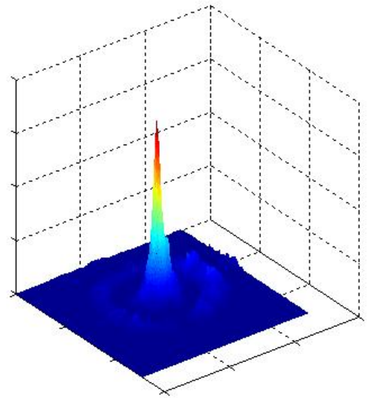


(a) MR image after preprocessing



(b) Femoral center position estimated by Hough transform

(b) The original MR image with the estimated femoral center overlay



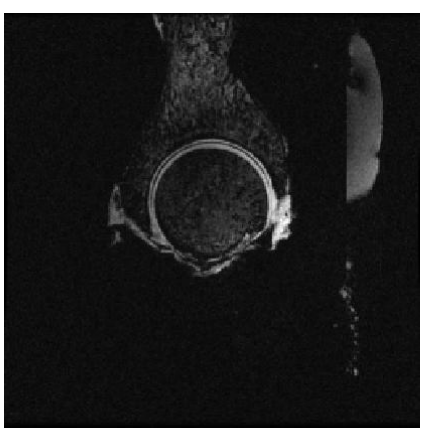
(c) 3D view of the femoral center estimated by Hough transform

Figure 3. Process of Estimating Femoral Head Central Position by Hough Transform

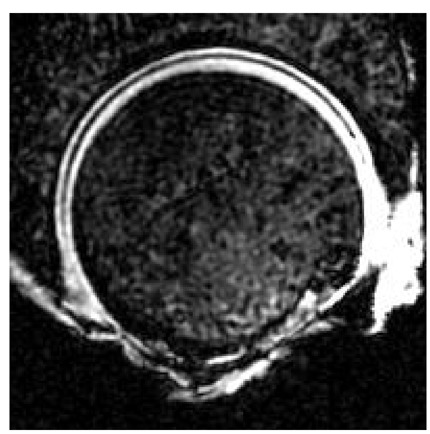
The radius of the constraints in the algorithm will be expanded from 15mm to 30mm in order to avoid omissions and enhance the algorithm adaptability. According to the center position and anatomical size constraint of femoral head, the target area of interest can be automatically selected in MR image. The selection standard can be extended to other MR slice images to achieve overall segmentation of the target area. Figure 3 shows the selection process and the extracted target area of the femoral head center.

3.2. Select Rough Region

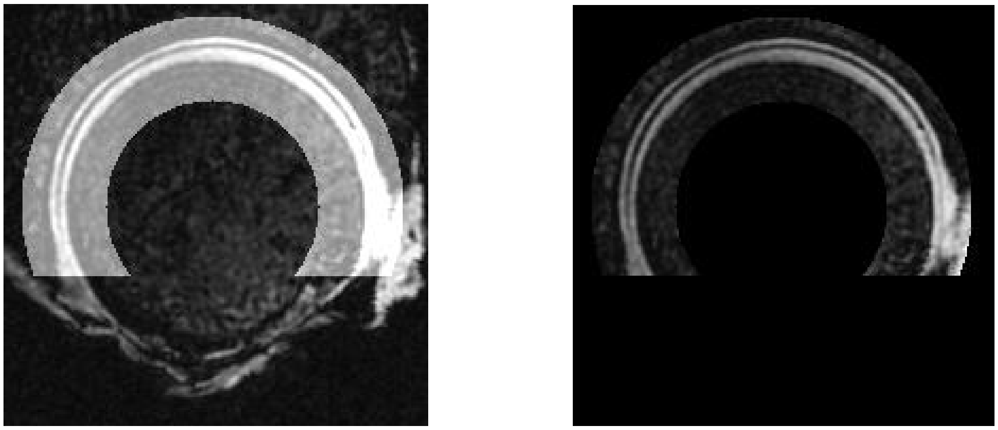
Hough transform can not only calculate the center position of femoral head, but also fit the circular boundary of the femoral cartilage inner edge to get approximation of the inner edge radius in a single image. According to the approximate radius of the edge and the anatomical femoral cartilage thickness range, a coarse femoral cartilage area can be divided. This step can greatly reduce the noise in the area outside of the scope and provide condition for accurately extract the cartilage inside and outside edges. Figure 4 shows the rough region of a hip MR image slice.



(a) Original MR image



(b) The area of interest



(d) Rough segmentation region of MR image

(e) Extracted region of rough segmented

Figure 4. The Hip MR Image Crude Divided Regions

3.3. Accurate Edge Extraction and Segmentation

In order to achieve the accurate segmentation of femoral cartilage, the edges of cartilage need to be accurately extracted. Adaptive threshold Canny edge operator was employed to detect the image edges in target area. The Canny operator need to set two thresholds to achieve edge detection. To realize non-manual intervention an adaptive dynamical threshold selection method was employed.

For the image with gray level L, the number of pixel with gray value i is n_i. The all pixel can be shows as:

$$N = n_1 + n_2 + \cdots + n_L \tag{9}$$

The gray probability distribution is:

$$p_i = \frac{n_i}{N} \tag{10}$$

The threshold l, h divided the image into three categories: $C_0 \in [1, l]$, $C_1 \in [l+1, h]$, $C_2 \in [h+1, L]$. The probability for each category is:

$$\omega_k = \Pr(C_k) = \sum_{i \in C_K} p_i \ , \quad K = 0,1,2 \tag{11}$$

Similarly, the mean value for each category is:

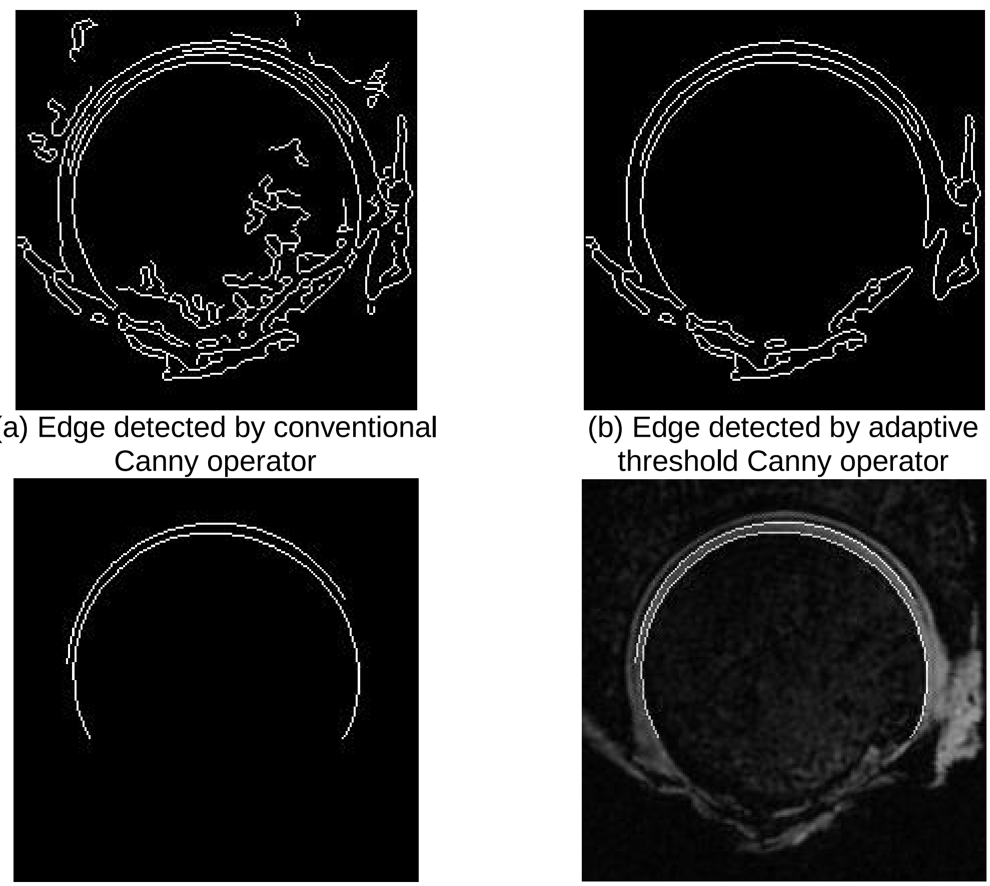
$$\mu_K = \sum_{i \in C_K} \frac{ip_i}{\Pr(C_K)} = \sum_{i \in C_K} \frac{ip_i}{\omega_K} \ , \quad K = 0,1,2 \tag{12}$$

According to the category variance sum minimization principle [11], we can prove the equation as follow:

$$\begin{cases} 2l - \mu_0 - \mu_1 = 0 \\ 2h - \mu_1 - \mu_2 = 0 \end{cases} \tag{13}$$

By the equation (13) the two thresholds l, h could be obtained. The whole process did not require manual intervention. Edge detection compare between conventional Canny operator and the adaptive threshold Canny operator was shown in Figure 5 (a) and (b). The threshold proportion coefficient in conventional Canny operator is [0.4, 0.7].

Aiming at interference of noise in the image, edges out of the coarse segmentation area were removed, and then the edges in the coarse segmentation area were filtered by investigation as follows: (1) According to continuity of the edges, the shorter length edge would be removed as noise; (2) According to smoothness of the edge gradient, the edge with large gradient change would be removed as noise; (3) If the number of edges left is larger than 2, take the two pieces of edge near the center. Ultimately the inside and outside edges of the femoral cartilage could be extracted exactly. Figure 5 shows edge extraction and process of removing the noise. Because the femoral head and acetabular cartilage can get only limited separation by traction, we cannot get the full femoral cartilage edges, but only get the edges separated by pulling effect. So in Figure 5 (c) the edges are non-closed. However, the human hip cartilage area function is mainly concentrated on the 1/3 top spherical cap and various joint diseases area focused on this area, so the image segmentation still has its important significance. MR image data between the inner and outer edges were extracted as the final segmentation result. Figure 6 shows the effect of femoral cartilage segmentation.



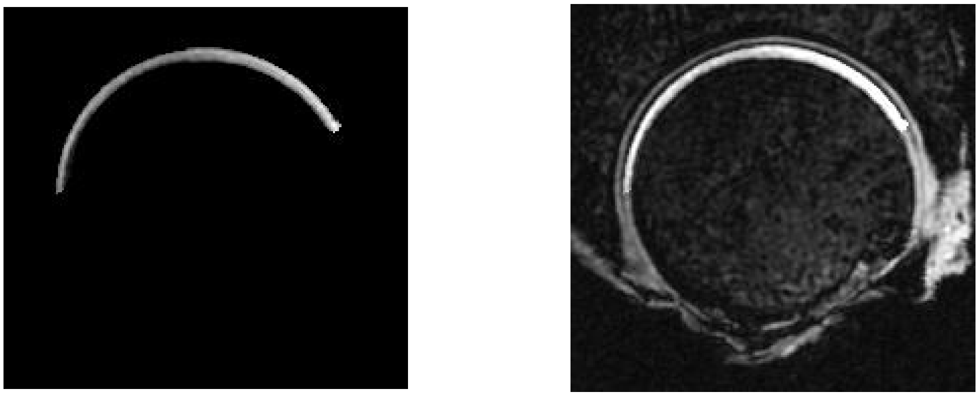
(a) Edge detected by conventional Canny operator

(b) Edge detected by adaptive threshold Canny operator

(c) Inner and outer edges of femoral cartilage

(d) Original MR image with the inner and outer edges overlay

Figure 5. Edge Detection and Noise Removal



(a) Segment femoral cartilage image

(b) Dividing the image with an original MR projective image overlay

Figure 6. Automatic Segmentation Image

4. Experiment

Image processing program developed in the Matlab7.6.0 environment on laboratory computer (Pentium IV 2.66G, 1GB RAM). In the segmentation experiment femoral cartilage in 117 images had been successfully segmented from total 120 images in three groups MR projective sequence, which mean the success rate was better than 97%. The reason for the failure of three images segmentation was that they were far from the location of sphere center and the traction effect was not obvious and the femoral cartilage had no effective separation to the acetabular cartilage. Even if segmentation of such images by manual is also difficult. The successful segmentation images were compared with manual segmentation images and the results showed that the average matching rate between two sets of images is 95.3%.

5. Conclusion

To achieve automatic femoral cartilage segmentation on MR image, an automatic segmentation method based on Hough transform and adaptive Canny edge detection has been proposed. Interpolation, smoothing and enhancement were implemented in the image preprocessing to improve the image quality. Hough transform was employed to determine the center position of femoral head. The area of interest was selected and the target area for the rough segmentation was figured out by considering the anatomical structure constraint of hip joint. Edges in the rough region were extracted out by the adaptive threshold Canny edge detector. According to the properties of the pixel on femoral cartilage edge, these edges were labeled and filtered in a custom one by one manner to remove the noise ones and acquire the exact inner and outer edges of the femoral cartilage. Finally the accurate segmentation was achieved by extracting the image data between the inner and outer edges. Segmentation experiment validates the method.

Acknowledgements

Thanks to Dr. Zhang Tong and Dr. Liu Fang, Department of Medical Imaging, the Fourth Hospital of Harbin Medical University, for providing the MR image data. Also thanks to Hou Tao, the Senior Technician teacher of human specimens in the Harbin Municipal Health School, for providing the body structure.

References

[1] Y. Bin and Y. Liu, "MRI studies of the articular cartilage", Chinese Journal of Sports Medicine, vol. 1, no. 27, **(2008)**.

[2] P. R. Kornaat, S. B. Reeder, S. Koo, J. H. Brittain, H. Yu, T. P. Andriacchi and G. E. Gold, "MR imaging of articular cartilage at 1.5T and 3.0T: Comparison of SPGR and SSFP sequences", Osteoarthritis and Cartilage, vol. 4, no. 13, **(2005)**.

[3] E. J. McWalter, W. Wirth, M. Siebert, R. M. von Eisenhart-Rothe, M. Hudelmaier, D. R.Wilson and F. Eckstein, "Use of novel interactive input devices for segmentation of articular cartilage from magnetic resonance images", Osteoarthritis and Cartilage, vol. 13, **(2005)**.

[4] M. H. Brem, P. K. Lang, G. Neumann, P. M. Schlechtweg, E. Schneider, R. Jackson, J. Yu, C. B. Eaton, F. F. Hennig, H. Yoshioka, G. Pappas and J. Duryea, "Magnetic resonance image segmentation using semi-automated software for quantification of knee articular cartilage-initial evaluation of a technique for paired scans, Skeletal Radiol., vol. 38, **(2009)**.

[5] M. Khanmohammadi, R. A. Zoroofi, Y. Sato, T. Nishii, K. Nakanishi, H. Tanaka, N. Sugano, H. Yoshikawa, H. Nakamura and S. Tamura, "Automated segmentation of the articular space in MR images of the hip joint", IET International Conference on Visual Information Engineering, Osaka, Japan, **(2006)** September 26-28.

[6] F. Liu, J. You, L. Guo, P. Ann Heng, Z. Wei and D. Xia, "Automatic segmentation of the epicardium and endocardium from MR image based on hough transform and geodesic active contour model", Journal of Computer-Aided Design & Computer Graphics, vol. 10, no. 19, **(2007)**.

[7] Y. Wang, Y. Niu, Y. Tian, J. Dong and C. Hao, "More stable and accurate genetic algorithm (GA) for segmentation of 3D medical images", Journal of Northwestern Polytechnical University, vol. 3, no. 25, **(2007)**.

[8] T. Luo and Y.-Q. Chen, "Visual attention guidance and region competition for medical image segmentation", Journal of Zhejiang University, vol. 11, no. 41, **(2007)**.

[9] D. L. Parker, Y. P. Du and W. L. Davis, "The voxel sensitivity function in fourier transform imaging: Applications to magnetic resonance angiography", Magnetic Resonance in Medicine, vol. 2, no. 33, **(1995)**.

[10] Y. Wang, H. Wang and S. Zhang, "Human anatomy", Jilin Science and Technology Press, **(2000)**.

[11] M. Li, J. Yan, G. Li and J. Zhao, "Self-adaptive Canny operator edge detection technique", Journal of Harbin Engineering University, vol. 9, no. 28, **(2007)**.