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Automatic Segmentation of Brachial Artery based on Fuzzy C-Means Pixel Clustering from Ultrasound Images

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ABSTRACT

Automatic extraction of brachial artery and measuring associated indices such as flow-mediated dilatation and Intima-media thickness are important for early detection of cardiovascular disease and other vascular endothelial malfunctions. In this paper, we propose the basic but important component of such decision-assisting medical software development – noise tolerant fully automatic segmentation of brachial artery from ultrasound images. Pixel clustering with Fuzzy C-Means algorithm in the quantization process is the key component of that segmentation with various image processing algorithms involved. This algorithm could be an alternative choice of segmentation process that can replace speckle noise-suffering edge detection procedures in this application domain.

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1. INTRODUCTION

Brachial artery is the main arterial supply of the upper limb providing the blood supply to nearly all of its structures. It is a medium sized artery and is actually a continuation of the axillary artery from the region of the axilla into the arm [1]. Brachial artery injuries are diagnosed by physical examination, with the help of Doppler sonography. If there is associated bone fracture with brachial artery injury, repair of the artery is always done first, and then attention is focused on the bone reconstruction and repair of the soft tissue and muscles [2].

The existing methods for assessing endothelial dysfunction and atherosclerosis in humans are based on functional tests in the brachial artery. With high-resolution ultrasound, the diameter of the superficial brachial arteries is measured, while at rest, during reactive hyperaemia, and then assessed with Doppler ultrasonography, a well-tolerated, noninvasive and low-risk procedure. It is currently the most widely investigated method and shows the greatest promise for clinical application [3].

Automatic extraction of brachial artery and measuring associated indices such as flow-mediated dilatation (FMD) and Intima-media thickness (IMT) are important for early detection of cardiovascular disease [4] and other vascular endothelial malfunctions [5] without operator subjectivity. However, automated techniques still underperform semi-automated IMT measurement methods. Automated techniques cannot reproduce human expertise in selecting the optimal point where IMT should be measured. Hence, superior intelligence must be embedded into automated techniques in order to overcome the performance limitations. A possible solution is to extract more information from the image, which could be obtained by an accurate analysis of the image at pixel level [6].

Thus, accurate segmentation of artery region is quite important basic building block of the goal software that computes clinically important parameters such as IMT and FLD for further analysis. The basic idea of the automatic artery segmentation is the structure of the input image that has the dark region (lumen: space where blood circulates), comprised of two bright stripes (the near and far wall artery layers). Therefore, the artery is recognized when the boundaries of the near and far wall endothelium have been traced [3].

There have been efforts to extract the target vessel automatically with feed-forward active contour (snake) [7] or with a probabilistic approach to the computerized tracking of arterial walls [8] among others. However, those based on edge detection, are particularly vulnerable to speckle noise.

Generally, edge is detected according to algorithms such as Sobel, Roberts, Prewitt, Canny, and LOG (Laplacian of Gaussian) operators [9]. However, the drawback of such method is also well studied as they consist of high pass filtering, which are not appropriate for noise ultrasound image edge detection [10]. An ultrasound image includes more noise content, especially speckle noise, than any other imaging modality. Speckle is the artifact caused by interference of energy from randomly distributed scattering objects which reduces image resolution and contrast and blurs essential details. Therefore, speckle noise suppression is an important requirement whenever ultrasound imaging is used [11]. Within the limitations of such edge detection based algorithms, a study tries to find the best combination of detection algorithm, with speckle reducing anisotropic diffusion [12].

In this paper, we focus on extracting brachial artery automatically with more noise-tolerant intelligent algorithm. We propose a pixel clustering strategy in extracting target brachial artery area from ultrasonography with Fuzzy C-means (FCM) algorithm. Fuzzy C-Means (FCM) clustering is an unsupervised technique that classifies the image by grouping similar data points in the feature space into clusters. This clustering is achieved by iteratively minimizing a cost function that is dependent on the distance of the pixels to the cluster centers in the feature domain. FCM has shown its effectiveness especially in segmentation in many engineering areas as well as medical domain. A special type of FCM has been applied to carotid artery segmentation [13] but that algorithm is coupled with other special image processing strategies thus may not be used in other areas of application. Thus, we keep the FCM version of our own application used in other medical imaging analysis [14].

2. PROPOSED METHOD OF BRACHIAL ARTERY SEGMENTATION

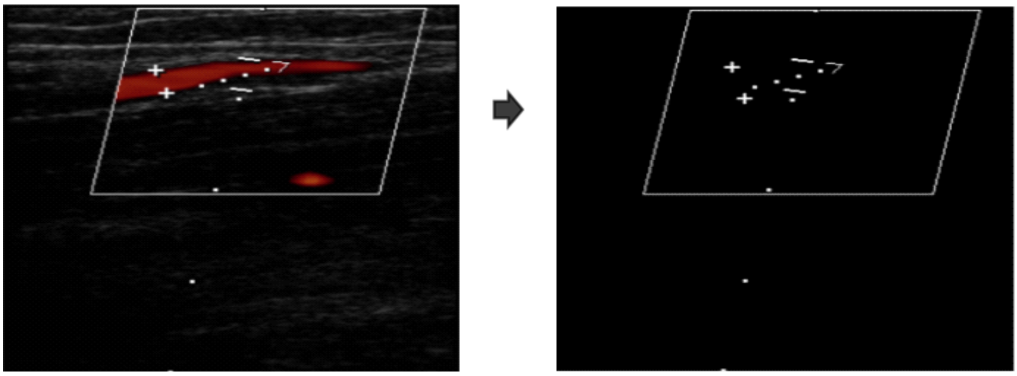
In order to extract the brachial artery, we need to enhance the intensity contrast to differnciate the target area from other area. The process can be summarized as shown in Figure 1.

The region of interest (ROI) where the brachial artery exists is marked as a trapezoid as shown in Figure 2(a). In order to enhance the intensuty contrast, we apply Min-Max binarization and the input omage is changes as shown in Figure 2(b).

Figure 1. Process for extracting brachial artery

In order to extract the object in the image, we apply 4-directional contour tracking algorithm with masks shown in Figure 3. Then the labeling algorithm is applied to form a set of obhects found in the ROI. Only the largest object in that area can be the candidate of brachial artery. Small objects in the area are removed as noise.

After applying Min-Max binarization and contour tracking algorithm, we can localize the candidate region of target brachial artery as shown in Figure 4(a). From there, we apply FCM in quantization procedure.



(a) ROI (b) Max-Min binarization

Figure 2. The effect of binarizarion

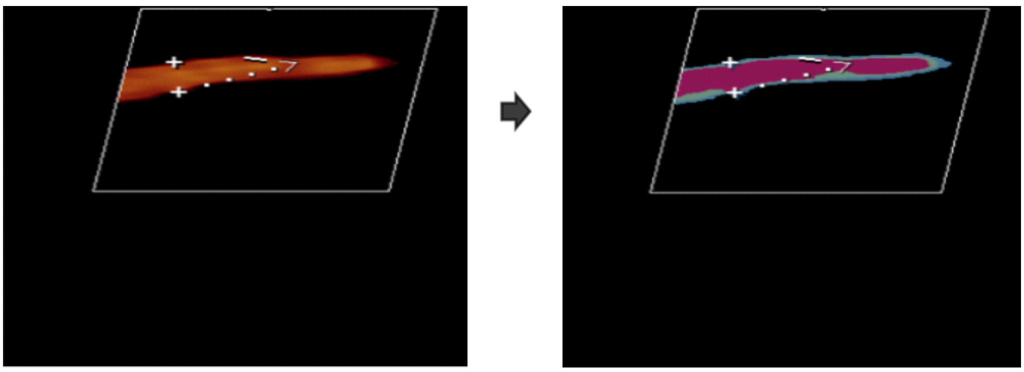
A	B
X	Y

(a) 2×2 mask

Direction	A	B	X	Y
Forward	1	0	A	B
Right	0	1	B	Y
Right	1	1	A	X
Left	0	0	X	A

(b) 4-diectional contour proceeding rules

Figure 3. Settings for contour tracing



(a) Candidate Input (b) After FCM

Figure 4. Object extraction by FCM

FCM is a clustering method which allows one piece of data to belong to two or more clusters depending on the degree of membership to each cluster. For n data vectors, we may have c fuzzy clusters ($c < n$) and each vector is classified into the cluster whose membership degree is the highest.

Let U^r be the r^{th} version of the membership function and m be the weighting exponent then FCM procedure can be summarized as follows;

Step 1: Compute the centroid of a cluster is the mean of all points, weighted by their degree of belonging to the cluster as shown in formula (1).

$$v_{ij} = \sum_{k=1}^{n} (u_{ik})^m x_{kj} / \sum_{k=1}^{n} (u_{ik})^m \quad (1)$$

where i denote the cluster number, j denotes the node number on input x of total n data.

Step 2: Then compute the distance between the data point and each centroid point of the cluster as shown in formula (2).

$$d_{ik} = \left[\sum_{j=1}^{l} (x_{kj} - v_{ij})^2 \right]^{1/2} \quad (2)$$

where l denotes the number of nodes.

Step 3: Then update the membership function U of its $(r+1)^{th}$ repetition as follows;

$$u^{(r+1)_{ik}} = \frac{1}{\sum_{j=1}^{c} \left[\frac{d_{ik}^r}{d_{jk}^r} \right]^2}, \ for\ I_k = \phi \quad (3)$$

Repeat above steps until the difference between U^{r+1} and U^r becomes less than predetermined threshold value, i.e., there is no meaningful difference between two membership function versions.

3. RESULTS

The proposed method is implemented with .Net 2010 under Microsoft Visual Studio 2010 C# on the IBM-compatible PC with Intel(R) Core(TM) i5-6200 CPU @ 2.40GHz and 8GB RAM.

The experiment used 12 brachial artery images of 800 x 600 size and the method was successful in extraction judged by the field expert. We could also measure the thickness of the vessel as shown in Figure 5.

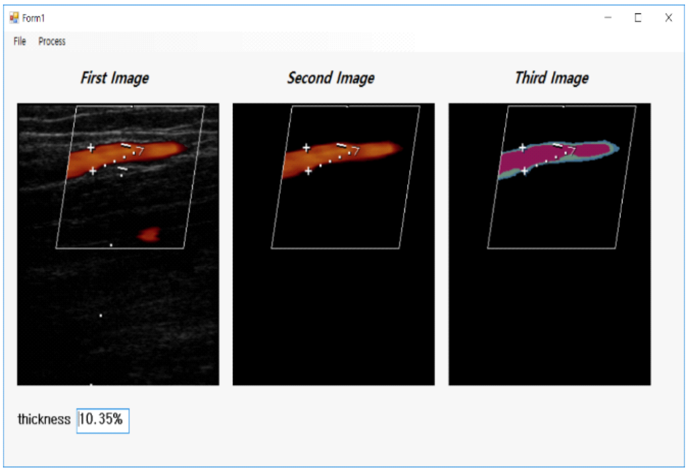


Figure 5. Examples of brachial artery extraction and measuring the thickness

Figure 5 is an example snapshot of the implemented software and Figure 6 also demonstrates various input images and extraction results by the proposed method.

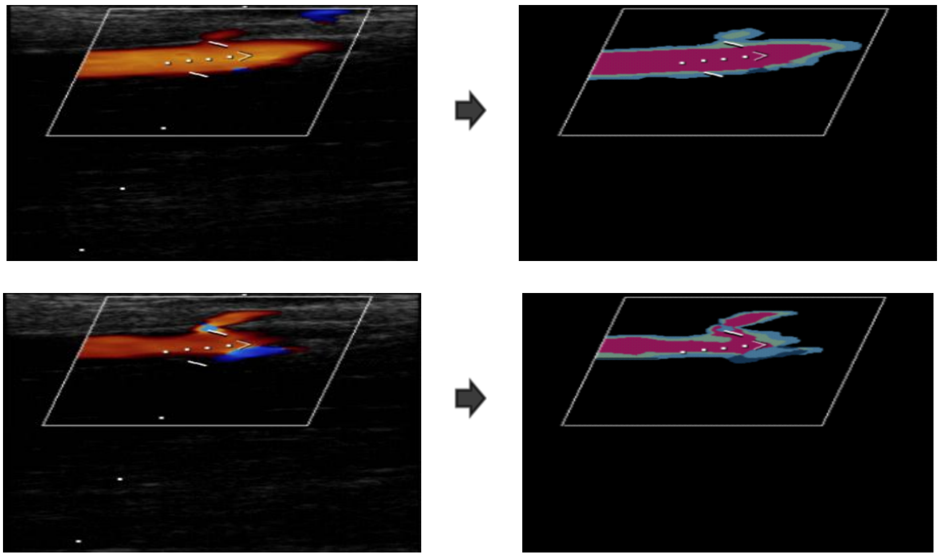


Figure 6. Various input images and artery extractions

4. CONCLUSION

In this paper, we propose a method to extract brachial artery from ultrasound images based on intelligent pixel clustering in quantization with other image processing algorithms. While edge detection base d mothods tried in this problem suffer from specle noise in segmentation, thus FCM based method is simpler and noise tolerant. Fuzzy clustering used to form information granulation is usually employed to overcome a possible curse of dimensionality. With such clear extraction of the target object, we can develop a useful decision making/automatic measuring performance patameters such as IMT for the next step.

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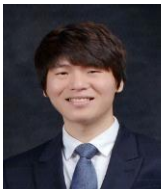

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