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Morphological Detection of Carotid Intima-Media Region for Fully Automated Thickness Measurement by Ultrasonogram

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Abstract

In this paper, we propose a method of detecting the region for measuring intima-media thickness (IMT). The existing methods for IMT measurement are automatic, but the region used for measuring IMT is not detected automatically but often set by the user. Therefore, research on detecting the intima-media region is needed for fully automated IMT measurement. The proposed method uses a morphological feature of the carotid artery visible as two long high-brightness horizontal lines at the upper and lower parts. It uses Gaussian blurring, ends-in search stretching, color quantization using a color-importance-based self-organizing map, and morphological operations to emphasize and to detect the morphological feature. The experimental results for evaluating the performance of the proposed method showed a 97.25% (106/109) success rate. Therefore, the proposed method can be used to develop a fully automated IMT measurement system.

Index Terms: Image processing, Intima-media thickness, Medical imaging system, Ultrasonogram

I. INTRODUCTION

The carotid artery is the artery originating from the aortic arch, and it supplies blood to the head and brain. When carotid stenosis, which is narrowing of the inner surface of the carotid artery caused by arteriosclerosis or vasculitis, occurs, the blood supply to the brain is reduced and the risk of stroke increases.

Stroke is the second leading cause of adult death in Korea and is the leading cause of death in a single disease [1]. According to statistics released by the Korea National Statistical Office in 2013, 50.3 deaths per 100,000 people are attributed to stroke. One in six people in the world experience a stroke in their lifetime, and one person is killed by the stroke every 6 seconds [2]. It is very important to prevent and predict these strokes because if they occur once they cause very serious aftereffects such as facial paranoid, hemiparesis, speech disorders, and so on [1].

The intima-media thickness (IMT) of the carotid artery is known as a predictor of long-term stroke or ischemic heart disease even without the presence of a common atherosclerotic plaque in the carotid artery [3, 4]. Therefore, accurate measurement of IMT is a very important task for stroke prediction.

Various imaging techniques such as ultrasound, CT, and MRI can be used to measure IMT. Among them, ultrasound is the most commonly used diagnostic method because it has the advantages of obtaining the carotid artery images most easily and quickly, being able to be performed repeatedly, and not having the risks associated with radiation.

However, the IMT measurement gives different results

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depending on the examiner because one examiner may measure a different location from another examiner. Therefore, it is necessary to automate IMT measurement using image processing techniques. The automated method will provide a more objective IMT.

The existing studies on IMT measurement show that IMT measurement is performed automatically, but the region for measuring IMT is not detected automatically but is often set by the user. That is, not all parts of the process of IMT measurement are fully automated [5-8].

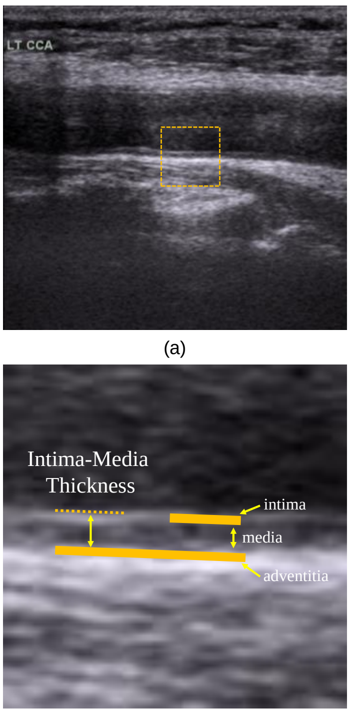
Therefore, in this paper, we propose a method of detecting the region of the carotid intima-media for measuring IMT in ultrasonogram. The proposed method uses the image processing techniques such as noise reduction, intensity stretching, color quantization, and morphology method to find out the feature of the carotid artery, and locates the region of the carotid intima-media based on the feature.

Fig. 2. Process of carotid intima-media region detection.

II. AN IDENTIFYING CHARACTERISTIC OF THE CAROTID ARTERY IN ULTRASONOGRAMS

The location and shape of the internal organs in CT and MRI images are relatively similar [9]. This is because the images are consistently taken at a constant angle with high resolution. However, ultrasonograms show a wide variety of locations and shapes of an organ, even when it is the same organ in different patients. Therefore, it is difficult to find the features of a specific organ in ultrasonograms.

Nevertheless, the carotid artery has a certain morphological feature compared to other organs. This feature can be described as two long horizontal lines with high brightness due to the upper and lower parts of the blood vessel being shown brightly with ultrasound. For this reason, the method proposed in this paper uses these two horizontal lines with high brightness as a morphological feature that can yield consistent and objective IMT measurement results.



(a)

(b)

Fig. 1. Carotid artery and intima-media thickness in ultrasonogram. (a) Carotid artery as shown in an ultrasonogram. (b) Intima-media thickness.

Fig. 1 shows the carotid artery in an ultrasonogram. In Fig. 1(a), we can see the high-brightness horizontal lines mentioned above. The space between the two high-brightness lines is the carotid artery, and IMT will be measured in the region located in the lower part of the carotid artery. Fig. 1(b) shows the intima, media, and adventitia, and the region for measuring IMT.

The proposed method detects this carotid artery region, positioned between the long high-brightness horizontal lines, in order to determine the intima-media region for IMT measurement.

III. INTIMA-MEDIA REGION DETECTION USING MORPHOLOGICAL METHODS

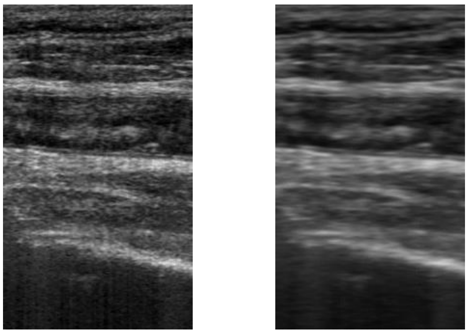
Fig. 2 shows the entire process of detecting the optimal region of the carotid artery for IMT measurement. The proposed method emphasizes the morphological feature of the carotid artery that appears as bright horizontal lines. To do this, it uses morphological operations and preprocessing, such as noise reduction, contrast enhancement, quantization, and so on.

At first, the proposed method uses Gaussian blur to remove many noises in ultrasonogram. To emphasize the feature of the carotid artery, it uses a Gaussian mask with a large width. In this paper, a 31×9 mask is used.

Fig. 3 shows an example of noise reduction using Gaussian blur. In Fig. 3(b), it shows that uneven textures, which is unique to the ultrasonogram, are removed and the horizontal lines are connected together smoothly. Generating these connected horizontal lines is equivalent to emphasizing the morphological feature of the carotid artery.

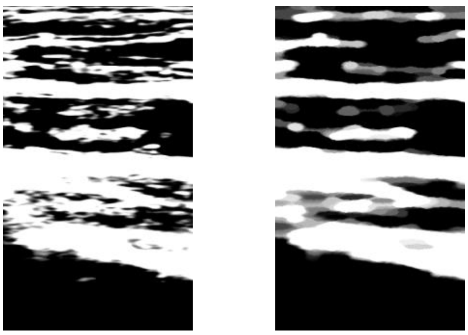
The proposed method enhances the contrast of noise-reduced images to emphasize the morphological feature. To do this, the proposed method uses the end-in-search technique of contrast stretching [10].

End-in-search stretching is a contrast stretching methods in which a certain number of pixels are set to white (255) or black (0) and the remaining pixels are stretched to a value between 0 and 255. End-in-search stretching is suitable for stretching the brightness of ultrasonograms with uneven brightness because it a ratio to determine dark and light pixels [10]. Eq. (1) explains end-in-search stretching.



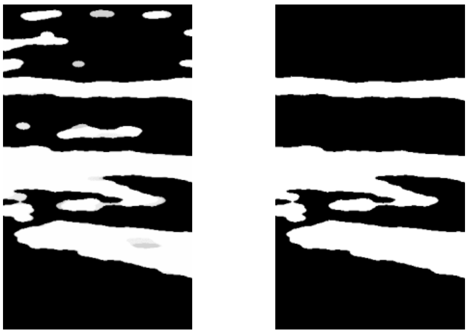
(a) (b)

Fig. 3. Example of noise reduction. (a) Original, (b) with noise reduction.



(a) (b)

Fig. 4. Example of contrast stretching (a) and morphological operation (b).



(a) (b)

Fig. 5. Example of color quantization (a) and labeling and size filtering (b).

$$output(i(x,y)) = \begin{cases} 0 & , \text{ for } i(x,y) \le low \\ 255(i(x,y) - low)/(high - low) & , \text{ for } low < i(x,y) < high \\ 255 & , \text{ for } high \le i(x,y) \end{cases} \quad (1)$$

where $i(x, y)$ is the brightness of the pixel at the coordinates x and y, *low* is the threshold of brightness below which pixels are set to black, and *high* is the threshold of brightness above which pixels are colored white.

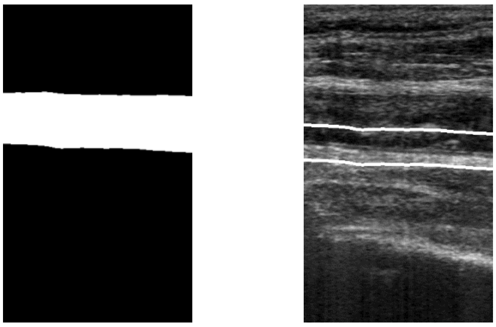
Fig. 4(a) shows the contrast-enhanced image. It shows that a lot of noise has been removed and the morphological feature is therefore enhanced.

Additionally, morphological operations are used to emphasize the morphological features much more. First, the opening operation is performed to remove noise, and then the closing operation is performed to connect high-brightness horizontal lines to each other. For the morphological operation, a wide mask is used to emphasize the feature for the same reason as Gaussian mask used. In this paper, the proposed method uses a 29×5 mask for the opening operation and a 17×9 mask for the closing operation.

Fig. 4(b) shows the result of the morphological operation on the contrast-enhanced image. Now, the morphological feature of the carotid artery is shown more clearly.

The proposed method uses color quantization and a size filter as the last step to remove noise. Color quantization is used to determine areas of high brightness. Clustering the brightness of pixels using color quantization and selecting the largest clusters can determine which areas have the high brightness. These steps are more adaptive than simple binarization because only the high-brightness areas are set to white (255), and all other areas are set to black (0). In this paper, color quantization with a color-importance-based self-organizing map (SOM) [11] is used to group the brightest pixels into sixteen clusters, and the top four clusters were set to correspond to high brightness.

Fig. 5(a) shows the results of clustering using color quantization. It shows that much of the noise in Fig. 4(b) has been removed.



(a) (b)

Fig. 6. Example of detected carotid artery (a) and detected intima-media region (b).

Table 1. Success rate of the proposed method

	Success	Failure
Number of image	106	3
Rate (%)	97.25	2.75

Then the proposed method uses connected-component labeling and size filtering to leave only the long labels. This step removes noise by eliminating features outside the morphological feature. In this paper, if the width of label was less than 90% of the image width, then the label was removed. Fig. 5(b) shows the results of the size filtering. With the small labels removed, the morphological feature remains as the dominant region among just a few regions.

Now the carotid artery can be found in the image shown in Fig. 5(b). The regions bordered by the long white horizontal lines are selected as candidates for the carotid artery. Then, the candidate corresponding to the following conditions is determined as the carotid artery.

1. Lowest average brightness
2. Lowest average variance
3. Height < 40% of the image height
4. Vertical position of center point >10% of the image height

Fig. 6(a) shows the results of this method of carotid artery detection. Because, usually, the IMT is measured from the lower part of the carotid artery, the intima-media region can be set as shown in Fig. 6(b).

If the carotid artery is not detected, the proposed method tries to detect the carotid artery, this time changing the *low* and *high* parameters of the end-in-search contrast stretching.

IV. EXPERIMENTAL RESULTS

The experimental environment for evaluating the proposed method is as follows. We used PC with Intel i7-7500U 2.70 GHz CPU and 8.0 GB RAM, and the method is implemented in Microsoft Visual Studio Community 2015 with MFC-based C++ language. OpenCV 3.10 was used as an image processing library.

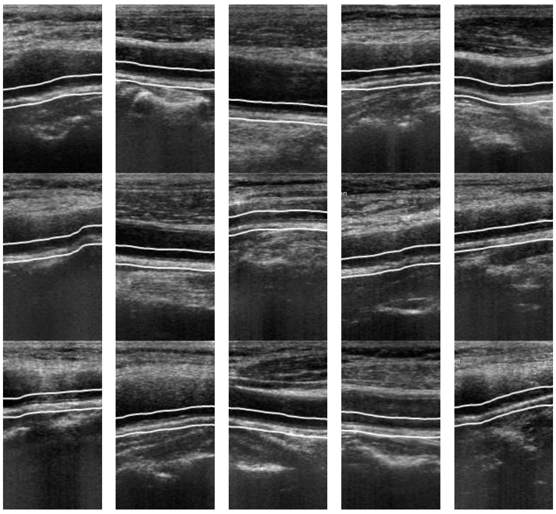
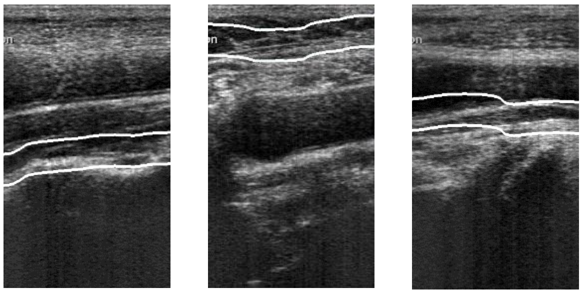


Fig. 7. Examples of successfully detected intima-media region.



(a) (b) (c)

Fig. 8. Failed cases: (a) case 1, (b) case 2, and (c) case 3.

There were 109 carotid ultrasonograms used in the experiment. The whole images have a resolution of 800×600, but in these images, the area containing the ultrasonogram itself has a resolution of 530×500.

Table 1 shows the success rate of the proposed method. It shows that 106 of 109 intima-media regions were detected successfully, and detection failed in only 3 cases.

Fig. 7 shows 15 of the 106 images in which the intima-media region was successfully detected. It shows that the intima-media regions are accurately detected even though they have various slopes and shapes, and the images have various noise levels.

Fig. 8 shows the three failures. Fig. 8(a) and (b) show that, in these failures, the carotid artery was not accurately detected. In Fig. 8(a), another region was determined as the carotid artery because the actual carotid artery had much more noise. In Fig. 8(b), the carotid artery was not detected because the morphological feature, the pair of long bright horizontal lines, is not long enough. In Fig. 8(c), the carotid artery has been correctly detected. However, the lower part was set incorrectly, so the intima-media region for measuring IMT is out of place in part of the image.

Experimental results show that the proposed method is 97.25% accurate and the region for measuring IMT is set correctly in most images.

However, there are some cases where the proposed method does not accurately detect the carotid artery. If there is not enough of the morphological feature visible, or if there is too much noise inside the carotid artery, the proposed method fails. Therefore, we can improve the proposed method by detecting additional features through analysis of carotid artery ultrasonograms and by adding a more efficient noise removal process.

V. CONCLUSIONS

In this paper, we have proposed a method of detecting the intima-media region of the carotid artery in other to perform fully automatic IMT measurements with ultrasonograms.

The proposed method uses a prominent morphological feature of the carotid artery visible in ultrasonograms. The feature appears as two long high-brightness horizontal lines at the upper and lower parts of the carotid artery. To enhance and detect the feature, the proposed method uses Gaussian blurring, end-in-search contrast stretching, color-mportance-based SOM color quantization, and a morphological operation.

To evaluate the performance of the proposed method, we used 109 carotid artery ultrasonograms. The proposed method had a 97.25% (106 out of 109) success rate of detecting the intima-media region of the carotid artery accurately these ultrasonograms. However, if the long horizontal line feature, the identifying morphological feature, is not long enough, or if the image of the carotid artery has too much noise, then the proposed method detects the region inaccurately. Therefore, to improve the proposed method, detecting other features of the carotid artery in ultrasonograms and using a more efficient noise-removal process would be required in further studies. Also, in the further studies, we will collect more carotid ultrasonograms and improve the experiments and the proposed method.

At the last, it is expected that if the proposed method is used with the existing IMT measurement techniques, it will be able to develop a fully automated IMT measurement and analysis system.

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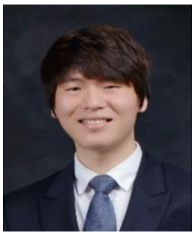

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