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Extraction of Fine Blood Vessels from an Ultrasound Image by an Image Processing

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Abstract: This paper discusses some useful image processing techniques for an ultrasound image using adaptive morphological operations. They are defined in such a way that the used structuring element is a function of local image to respond its characteristics. The defined mathematical morphology has almost the same mathematical structure and properties as the conventional one. Besides, the former has an advantageous image processing to others. For example, this technique to ultrasound images to extract blood vessel and showed its useful function. We discussed parameter evaluation and setting, from a statistical point of view. Experimental results are also demonstrated.

Key words: Mathematical morphology has almost % The simultaneous smoothing and enhancement can be implemented

INTRODUCTION

In order to extract diagnostic information from an ultrasound image, we need many kinds of image processing techniques. Among them, preprocessing is indispensable and is particularly important to extract diagnostic information.

Our research objective is to extract very fine blood vessels of a few hundred microns (0.5 to 2mm) in diameter from an ultrasound image and to develop a diagnostic system. In this paper, we discuss an effective preprocessing method using adaptive morphological operations and some techniques to extract 3D diagnostic information. The entire process is as follows. We use a set of successive 128 cross section ultrasound images, stored from the developed prototype diagnostic system. We process them to reduce speckle noise and enhance the edge of the blood vessels using adaptive morphological operations with locally variable structuring elements. Blood vessels are extracted from a binary image afterpreprocessing.

Then we display necessary 3D diagnostic information such as the position and the direction of blood vessels, showing the blood vessels in a three dimensional way. Speckle noise appears in an ultrasound image, resulting in unclear contour of the region of interest, such as organ or a blood vessel. Speckle should be removed and the edge is preferable enhanced in the preprocessing stage. Various kinds of smoothing techniques have been reported from linear to nonlinear filters [1-4]. Morphological filters are useful for ultrasound image preprocessing in many aspects [5, 6]. Among them are smoothing techniques such as median filter, edge preserving smoothing [7] andadaptive morphological filter [8]. These methods may eliminate noise effectively, but the blurred edges still remain in the processed image. We proposed morphological operations by locally variable structuring elements [9]. We compared some conventional techniques with our method using a two dimensional ultrasound image and and evaluated them. Useful results are reported using a morphological filter [5, 6, 9]. All of these are concerned with two dimensional processing and a three dimensional adaptive morphological filter is discussed in [10]. Since the image of blood vessels are represented as a set of cross sections, the image processing should done in a three dimensional way rather than in a two dimensional one. Adaptive morphological operations are implemented on the set of gray-scale ultrasound images using a structuring element of ellipsoidal shape. The value of the structuring element is defined to varydepending on the characteristic of the local sub image.

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They smooth and enhance the image simultaneously, owing to this peculiar property. Several parameters are evaluated to obtain an optimal image.

Morphological Operations: System C. There are other similar approaches.

Review: Four fundamental morphological operations aredefined using, so called structuring elements. The value of a structuring element is usually set constant. Here the proposed structuring element is a function of the sub image on the defined domain so that it takes an adaptive value according to the characteristic of the image. The variable structuring element g(f (X),Z)

is defined as

g(f(X),Z) = "~(sup–inf) + $~max(sup–f (X), f (X) –inf} (1)

where

sup max { ( )}
X Z F
Z G
f X Z+ ~ ~ = + (2)
inf min { ( )}X Z FZ Gf X Z+ ~ ~ = + (3)

parameters and they must satisfy the conditions "$0, $#0 and "+ ($/ 2) $0 . The structuring element g(f (X), Z) reacts to the intensity difference in the local image. It becomes small if the difference between a maximum value and a minimum one in the local image covered under G is small. On the otherhand it becomes large if the difference is large. Such cases occur when f (X)takes either a maximum or a minimum value at X. Generally, it becomes large at the boundary, since a large difference is possibly expected.

Since G covers a local image for morphological operation, the size of G is also an important parameter to decide.

Let the operation symbols 1, ~,o and Cdenote erosion, dilation, opening and closing, respectively. Four mathematical morphological operations are defined as follows [5].

Note here that the opening and closing operations are slightly different from those by normal definitions [1]. The newly defined opening and closing morphological operations smooth and enhance an image at a time, while the conventional opening and closing ones smooth an image but do not enhance it simultaneously.

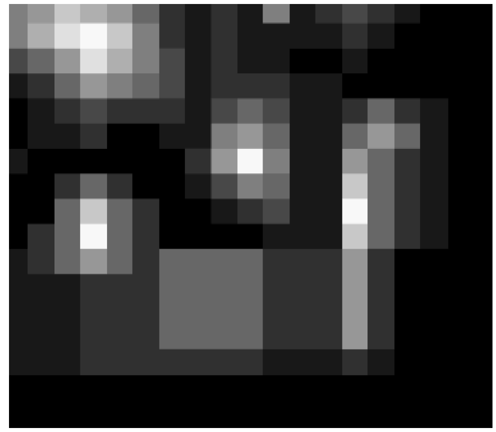

Fig. 1: A horizontal profile

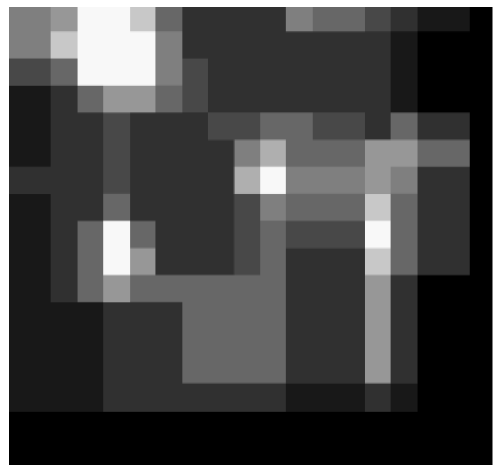

Fig. 2: Closed image of Fig. 1

Fig. 1 is a horizontal profile, i.e., the data of a horizontal line in the original image.

Now we close the original image by an adaptivemorphological operation using a structuring element defined as in (1), where the size is 3x3 and "=3, $=-2. Fig. 3 is the horizontal profile of the same line as before. We see the image is smoothed and the edge is enhanced as shown in Fig. 3(a). We can observe the same property in the opened image.

Evaluation of the Structuring Element's Parameters: We have several parameters to be set in advance toapply the adaptive morphological operations toultrasound images. They are the shape and the size ofthe structuring element and the weighting coefficients "(>0) and $.(<0). Figure 4 shows an ultrasonically scanned image of blood vessels, where low-intensitycircular regions are blood vessels. The scanning area is 1[cm] x 1 [cm] and is displayed as theimage of 512x512 pixels with 8-bit intensity.

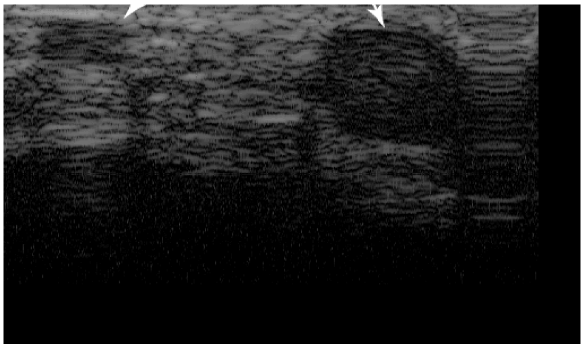

Fig. 4: An ultrasound image of blood vessels.

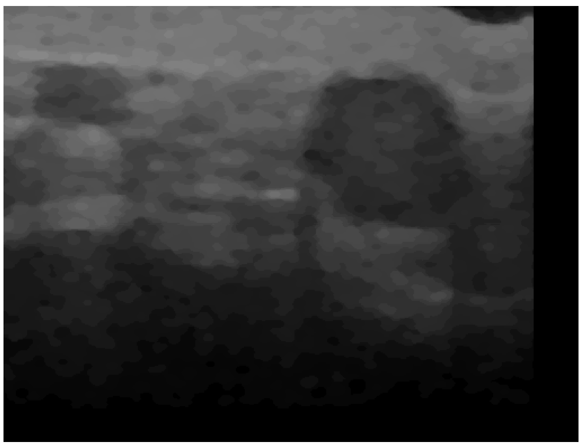

Fig. 5: Close-opened image of Figure 4.

We can assume here that echo signals are relatively weak in blood vessels and relatively large in other regions. Opening the closed image of Fig. 4, using an ellipsoidal structuring element, we have a smoothed image as shown in Fig. 5. This smoothing processing is carried out for all the set of cross sectional images Figs. 6(a) and 6(b) show data how speckle noise is reduced with respect to parameters represented as quintuple (a, b, c, ", $), where a, b and c are each radius of the ellipsoid. Coefficients " and $. Are weighting factors. “Orig” means the original raw ultrasound image. For example, (3-2-1-10-08) means that a, b, c, ", $are 3, 2, 1, 10 and -8, respectively. The average intensity increases in almost every region of the smoothed image. The variance is large in every region of the original image, whereas it decreases after close-opening of the image by an adaptive morphological operation. Here close-opening is to close the image followed by opening. Fig. 5 is the close-opened image of Fig. 4 with parameters 5-3-1- 10-5, where we can observe that speckle noise is reduced to large amount. We know that two regions are easily separable when the inter-class variance is large and inner-class variance is small. For this purpose, an evaluation function called separable index or separability, is defined as the ratio of the inter-class variance of the two regions to the variance of the entire region [11]. 0= b (10). Here a large number of evaluation samples are collected along the boarder(s) of the blood vessels by placing a circle window to calculate statistically. The averaged (mean) measured data are shown in Figure 7. Setting "=$=0, the conventional morphology operation can be implemented. Among these data, the most effective parameter values were a=3, b=2, c=1, "=10, $=-5.

We can conclude that the proposed adaptive morphological filters result in more effective

Preprocessing and Segmentation: Ultrasound images are neither independent of machine nor living body. They vary from person to person and from region to region. The reflected ultrasound signal becomes weak as it penetrates in the body. Besides, we want to display blood vessels of different sizes from a few hundred microns to a few millimeters. We need ultrasound image processing, which is independent of those influences as mentioned above as much as possible. The adaptive morphological operation plays an important role at the preprocessing stage. Blood vessels are generally displayed as regions of low intensity in an ultrasound image, but the intensity difference to other areas is not large enough to yield binary image easily. Here we introduced a method to enhance the contour of blood vessel in such a way that the successively obtained edges in the small divided sub images are summed up to enhance the contour. By a stepwise move of a small window, sub images are each prepared for local binary processing. Adding all the binary sub images produce an edge-enhanced image shown in Fig.8. Now the enhanced image of Fig. 8 is easy to be segmented. Fig. 9 is the inverted B/W picture, which contains blood vessels, extra noisy components and artifacts too. Now we extract blood vessels from a set of binary cross sections followed by after-processing such as the removal of extra components and artifacts. We apply a space-filling filter to Fig. 9 in order to remove a boundary produced in a low-level area such as in a blood vessel. Fig. 10 is an image processed through the filter. Using the fact that the neighbor cross sections of blood vessel must have connected common regions and thus, connected components in the neighbor are to be extracted. Morphological opening of this set of connected components by a spherical structuring element gives a candidate image component of a blood vessel. Among of these, the component having the highest circularity (a relative large blood vessel in Fig

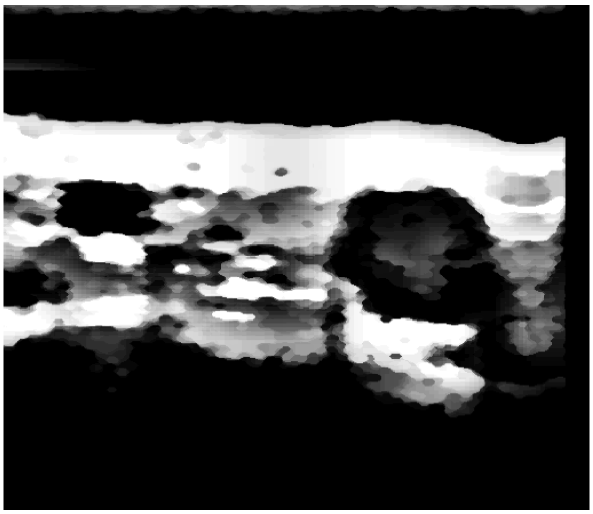

Fig. 8: An edge-enhanced image obtained by adding all the binary sub images

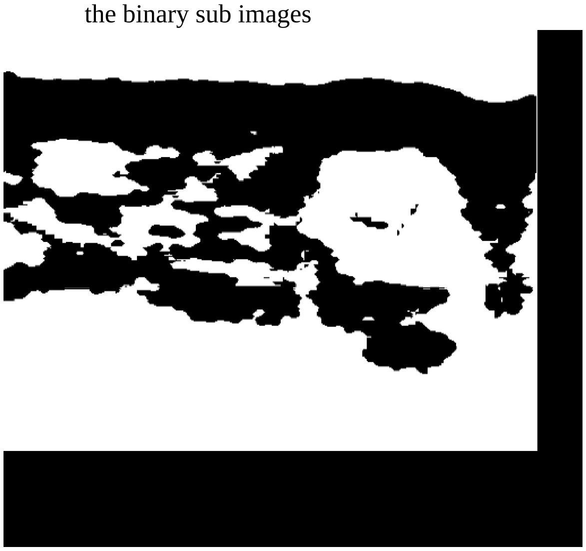

Fig. 9: Binary image of Fig. 8.

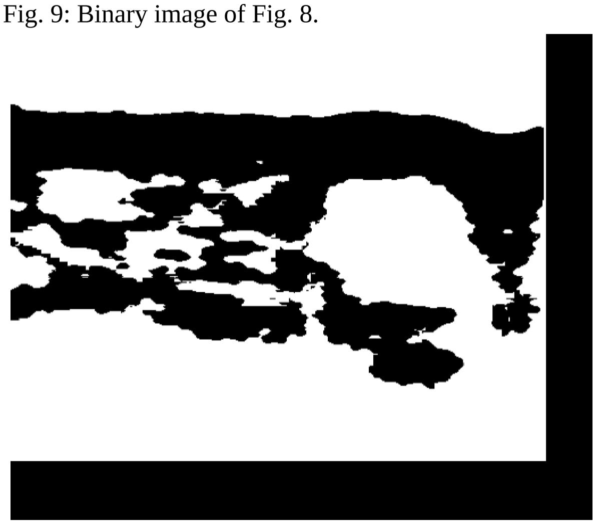

Fig. 10: Binary image through a space-filling filter.

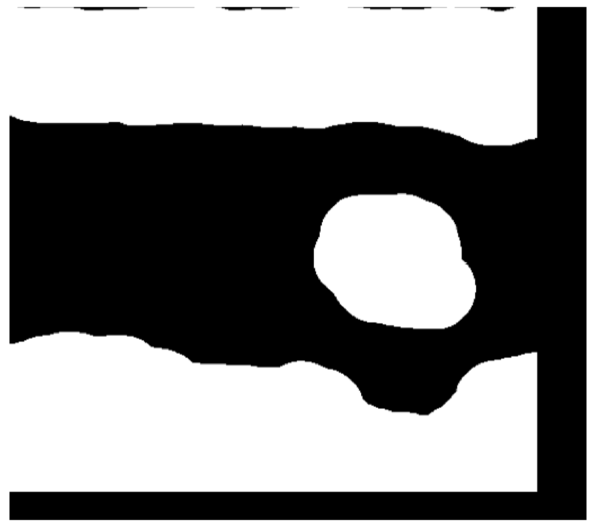

Fig. 11: Display of a resultant image of large blood vessel.

CONCLUSION

We discussed several useful ultrasound image processing techniques using an adaptive three dimensional mathematical morphological operations. The parameters of the structuring elements are evaluated statistically and optimal values are set in advance. We found the simultaneous smoothing and enhancing property makes the preprocessing easy and effective. We applied this method to an actual ultrasound image to extract very fine blood vessels, where local images are successively specified and processed stepwise. Furthermore, we must investigate an efficient and accurate method to extract small and large blood vessels simultaneously.

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