Examination of the number of classes required for arteriosclerosis detection

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Abstract

The number of arteriosclerotic patients has been increasing on account of Japanese Westernization. A diagnostic method using echocardiography is a simple and easy method to diagnose arteriosclerosis. The method measures the intima-media thickness (IMT), which is the thickness of the carotid artery wall. Accordingly, the method employs this thickness as a diagnostic index.

When using this method, however, it is difficult to detect arteriosclerosis in its early stages when the artery wall has not yet thickened. Therefore, we propose a method that can be used even in these early stages by employing echocardiogram brightness as a diagnostic index. Because the artery wall hardens in arteriosclerosis progression, the echo brightness shows a large numerical value. In addition, in the possible case of an artery wall exploding, the echo brightness shows a small value because the vascular wall is soft. Nevertheless, we do not know the number of classes in advance. Thus, we must automatically change the number of classes for each image that is obtained.

1 Introduction

Arteriosclerotic detection methods using echocardiography have been previously proposed [1][2]. One method uses the stiffness parameter, which is the stiffness of the artery wall. This requires measurement of the blood vessel diameter for a single heartbeat, and it finds the stiffness of the artery wall based on the change. If the artery wall is rigid, a large value is calculated because there are few

changes in the blood vessel diameter. However, when applying this method for the displacement of the diameter, it is necessary to detect wall precision for a single heartbeat. Moreover, the edge must be extracted because it is part of the bloodstream and artery wall border in the animation image. Consequently, echocardiography cannot determine the correct stiffness parameter without the possibility of clearly imaging all parts in accordance with an incidence angle and tissue constitution.

IMT can perform arteriosclerotic distinction using only one good image; it does not employ a method using many frames. It thus measures the thickness of the artery wall. However, detection is difficult if arteriosclerosis does not progress. We therefore propose a detection method for the whole interest domain, which includes cases in which only some surface of the vascular wall has changed [3]. However, the method can evaluate only a change that occurs on the surface of the vascular wall. It remains difficult to detect arteriosclerosis (e.g., the case in which an artery wall may explode) produced inside the vascular wall. Therefore, the proposed method of arteriosclerotic detection uses only one frame based on echo brightness.

The echocardiogram is typically divided into six tissue domains based on brightness levels in the image. These domains include (1) calcification, (2) adventitia, (3) fibrotic intima, (4) normalcy wall, (5) fresh thrombosis, and (6) blood and lipid core. In a normal case, these brightness categories are classified into four domains of 0~15, 15~50, 50~150, and 150~255, except in the cases of (1) and (5). These classifications are not absolute conditions. This

is because a doctor can change the echo level when obtaining the image. It is thus difficult to only use these numerical values, and the threshold must be changed for each image. Accordingly, we classify images using the distinction threshold methods suggested by Otsu and others [4][5].

These methods determine the class in advance, and they complete their processing when the desired class is achieved. It is thus necessary to first decide the number of the classes. This number has a significant influence on the result. Specifically, if the image is one of a physically unimpaired person, an arteriosclerosis part does not exist; accordingly, the number of classes is four. In addition, the number of the classes becomes five or six when arteriosclerosis occurs. Therefore, a change of the number of the class is necessary if the number is not that of one of the most suitable classes after having been divided.

Based on the above, we employ our proposed method using least squares criteria for determining the number of the most suitable classes [6].

2 Target image

(a) Illustration of artery

(b) Illustration of blood vessel

Figure 1. Illustration of atherosclerotic plaque
Figure 1(a) depicts a common carotid artery,

while an artery cross section is depicted in (b). The echo brightness shows the same tissue. It is additionally observed in Figure 2 by coordinating the echo gain. We employ the threshold choice method because the threshold of each image must be determined without fixing the echo gain.

(a) 50% gain

(b) 60% gain

Figure 2. Difference of gain

3 Classification of Tissue

3-1 Classification by Histogram

Figure 3 shows the image that we used for division. The central thickened area is an arteriosclerosis part. The image is a 256 echo level.

Figure 3. Image with arteriosclerosis
(363×308)

The histogram of the above image is shown in Figure 4. We divide the six domains using the echo level histogram [4]. Because we are given the class number, we know the arteriosclerosis part. We divide the domain using the threshold method. The result is shown in Figure 5; the threshold is presented in Table 1. The domain in red represents arteriosclerosis, the most rigid part. The domain in blue likewise denotes arteriosclerosis; however, it specifically represents the soft domain that may explode.

Figure 4. Histogram of image showing arteriosclerosis

Figure 5. Domain division

Table 1. Standard of threshold

Threshold	1st	2nd	3rd	4th	5th
Value	17	42	64	90	132

As shown in Figure 5, adventitia and an arteriosclerosis portion of the highest brightness are detected in an equivalence domain while being unable to be effectively divided into a high domain. Many areas of low brightness exist as bloodstream domains; accordingly, the histogram shows an imbalanced distribution. Nevertheless, both especially firm and soft domains are respectively extracted for arteriosclerosis detection, and good results are produced. In addition to the above approach, the method proposed by Kittler [5] reduces the influence of the partial histogram, such as the one shown here.

3-2 Determination of Numbers of the Most Suitable Classes

3-2-1 Evaluation Equation Bias

Figure 5 shows the image we used in which the development of arteriosclerosis was depicted. As mentioned, a domain is divided into six classes. However, it is necessary to automatically distinguish the number of the classes for each image, where it is unknown if arteriosclerosis is occurring. In this study, we employ a histogram for the class distinction method.

However, in this method, the threshold is decided when the interclass variance is the largest (i.e., the most separability). Furthermore, if the number of the classes increases, the interclass variance likewise increases. Therefore, the number of the classes is chosen regardless of the existence or nonexistence of the arteriosclerosis part, particularly when we compare only the separability and intend to decide the number of the classes. This is because a significant separability is calculated even if the same image is used when dividing it into many classes.

Because this method has a bias for each threshold, the same histogram varies in accordance with the value of the evaluation function by the numbers of the classes [6]. Below is an example using the uniform distribution $\{p_i = \frac{1}{256} : p_i \text{ is the probability distribution}\}$. We divide the uniform distribution in the domain of M levels. Let the pixels of a given picture be represented in N echo levels $\{0, 1, \dots, N-1\}$. The value of the mean at level i is denoted by μ_i . The value of the frequency at level i is denoted by ω_i . The evaluation function (selectivity) for the threshold is given by the ratio of the interclass variance (σ_B^2) and the overall variance (σ_T^2). Therefore, the evaluation function is calculated using these two values.

In the case of uniform distribution, the mean (μ_i) is defined in Expression (1).

$$\mu_i = \frac{N(2i-1)}{2M} \quad (1)$$

The overall mean (μ_T) is defined in Expression (2).

$$\mu_T = \frac{N}{2} \quad (2)$$

Furthermore, the frequency of each level is defined in Expression (3).

$$\omega_i = \frac{1}{M} \quad (3)$$

Expression (4) is calculated when we compute the interclass variance using these values.

$$\begin{aligned} \sigma_B^2 &= \sum_{i=1}^M \omega_i (\mu_i - \mu_T)^2 \\ &= \frac{N^2}{12} - \frac{1}{12} \left(\frac{N}{M} \right)^2 \end{aligned} \quad (4)$$

In addition, the overall dispersion is given in Expression (5):

$$\begin{aligned} \sigma_T^2 &= \sum_{n=0}^{N-1} \frac{1}{N} (n - \mu_T)^2 \\ &= \frac{N^2}{12} + \frac{1}{6} \end{aligned} \quad (5)$$

The evaluation function (η_M^*) (Equation (6)) is calculated by Expressions (4) and (5).

$$\begin{aligned} \eta_M^* &= \frac{\sigma_B^2}{\sigma_T^2} = \frac{\frac{N^2}{12} - \frac{1}{12} \left(\frac{N}{M} \right)^2}{\frac{N^2}{12} + \frac{1}{6}} \\ &\cong \frac{\frac{N^2}{12} - \frac{1}{12} \left(\frac{N}{M} \right)^2}{\frac{N^2}{12}} = \frac{M^2 - 1}{M^2} \end{aligned} \quad (6)$$

It should be noted that we use an approximation because N is 256 in the echo level, which is sufficiently larger than $1/6$.

Equation (6) shows the change of the evaluation function value from one level to another. Here, we use Expression (7) for the quantity of new evaluation. This quantity is $-\infty$ of the supposed minimum 0 and ∞ is the supposed maximum 1 in the conventional method. In addition, as in a uniform distribution, this value is the same as the evaluation quantity in Expression (6) and is equal to 0.

$$\begin{aligned} Q_M &= \log \frac{\eta_M}{1 - \eta_M} - \log \frac{\eta_M^*}{1 - \eta_M^*} \\ &= \log \frac{\eta_M}{1 - \eta_M} - \log(M^2 - 1) \dots (7) \end{aligned}$$

where η_M is the evaluation quantity in the conventional method.

3-2-2 Simulation of Class Number Determination

We show three wave patterns, which we use for the simulation in Figure 6. The value of the wave in that figure is presented in Table 2. Results from these data are given in Table 3.

(a) Same frequency of level

(b) Distribution in which only one peak is a high frequency, such as in an echo image

(c) Distribution with only one low frequency

Figure 6. Simulation wave

Table 2. Rate of simulation data
(unit: %)

	1st Peak	2nd Peak	3rd Peak	4th Peak
Fig.6(a)	25.00	25.00	25.00	25.00
Fig.6(b)	62.50	12.50	12.50	12.50
Fig.6(c)	31.25	31.25	6.25	31.25

Table 3. Quantity of evaluation

Division Number	Fig. 6(a)		Fig. 6(b)		Fig. 6(c)	
	η_M	Q_M	η_M	Q_M	η_M	Q_M
3	0.88	0.03	0.91	0.29	0.93	0.54
4	0.95	0.38	0.95	0.34	0.96	0.52
5	0.96	0.16	0.97	0.40	0.97	0.35

η_M of Table 3 is the quantity of evaluation in the conventional method. The number of the classification becomes five for all wave patterns in comparison with these values (η_M). We determine that a value of η is the most suitable for five classes, even though there are only four classes. However, for the quantity of the new evaluation, we use Q_M .

As a result, five classes do not necessarily become the maximum. Moreover, Figure 6(a), which shows the same variance wave pattern, is divided by four classes. In addition, three becomes the most suitable class in Figure 6(c), wherein the frequency includes a small one, and a small frequency is believed to be ignored. However, it is more likely to be determined that the number of the most suitable classes is four if the size does not differ between η_M of the four and three respective classes. However, even when using this method, the most suitable number may not be an option if there is a significant difference of quantities of η_M .

3-3-3 Echocardiography Application

The results from applying this method to echocardiography are shown in Figure 7 and Table 4. The number of the most suitable classes is four as a result of the data in Table 4. Therefore, the number of the correct classes has not been identified. However, the domain that is represented with blue and red in Figure 7 is displayed as an arteriosclerosis domain. Because the correct class has not been determined, the red and blue are distributed over a large domain. Furthermore, the results of dividing the six levels from Table 4 are shown in Figure 8.

Table 4. Threshold of each class

Division Number	Threshold					Q_M
	1	2	3	4	5	
4	24	60	111			-0.13
5	21	52	80	124		-0.14
6	17	42	64	90	132	-0.18

Figure 7. Result of division by η_M

Figure 8. Results of dividing six levels

3-3 Class Distribution Using Normalization

We believe the correct number of classes was not found from Table 3 because a large difference in frequency occurred. Therefore, we normalized the frequency of the histogram and believed that it could be divided into a correct class. We thus calculated the mean every ten

points from the histogram, which had low sequential brightness, and we normalized it by applying the mean to the frequency of the histogram. The results are shown in Table 5, which are η_M and Q_M using the data in Figure 6. Therefore, the result of η_M is calculated by the conventional method. In this case, five classes in total were selected. However, in the case of Q_M , we selected four classes as being suitable ones.

Table 5. Classification by normalization

	Number of classes	η_M	Q_M
Fig. 6(a)	3	0.90	0.12
	4	0.96	0.56
	5	0.97	0.51
Fig. 6(b)	3	0.91	0.34
	4	0.96	0.58
	5	0.97	0.56
Fig. 6(c)	3	0.92	0.44
	4	0.96	0.72
	5	0.97	0.61

In Figure 9 and Table 6, the results of applying this method to an echocardiogram are shown.

Figure 9. Results of dividing six levels by normalization

The number of classes from Table 6 determined to be the most suitable was four. As shown in Figure 10, this result does not produce six peaks in the brightness histogram of the echocardiogram. Based on the results, an arteriosclerosis domain is unified with the brightness distribution, such as of adventitia.

Table 6. Classification by normalization in the echocardiogram

	Number of classes	η_M	Q_M
Echocardiogram (Fig. 3)	3	0.87	-0.11
	4	0.93	-0.03
	5	0.95	-0.08
	6	0.96	-0.08

Figure 10. Echocardiogram histogram

From data in Figure 9, we could extract the domain that represents the most rigid part (red circle) as being an arteriosclerosis part. We could thereby choose the domain that was more likely to explode (blue circle).

4. Conclusion

In this study, we proposed a method that employs only a single image to detect arteriosclerosis. In the case of using only one section of the image, information of only the brightness exists. We obtain different results when using this information. In this study, because this brightness information varied according to the condition at the time of the imaging, we chose a histogram method. However, on account of using the histogram approach, it was necessary to determine in advance the number of the classes to divide. Nevertheless, the number was not known. Therefore, it was necessary to automatically determine the number of the classes of each image. However, we had to consider this influence because bias was included in the method using the histogram of each level. In addition, depending on the distribution of the histogram, the class division was not

definitively performed. This may have been caused by deflection of the frequency.

In future work, we will examine a review of the evaluation function or the removal of the bias ingredient using the method proposed by Kittler.

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