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AUTOMATED DETECTION OF MICROCALCIFICATIONS ON MAMMOGRAM WITH MORPHOLOGICAL FILTER

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Abstract

This paper presents a new method for detecting microcalcifications on mammograms by using morphological filter. This filter is an extension of Top-hat transformation in morphological operations with multi-scale and multiple structuring elements. The proposed method makes it possible to detect geometrical structures considered to be microcalcifications on the basis of their size, shape and density. Experimental results to show the effectiveness of the proposed method are also presented.

1 INTRODUCTION

Mass screening of breast cancer has become popular in advanced countries, and the number of mammograms to be diagnosed is increasing year by year. The development of automatic screening system of breast cancer is urgently required. For reliable diagnosis of breast cancer, the identification of both malignant tumor and microcalcification is essential. There have been many researches on automatic diagnosis of breast cancer, most of which treat detection methods of microcalcifications[1]-[3]. Some researches on the mathematical characterization of calcifications have been performed to investigate shape discrimination and benign/malignant classification. Texture analytic approaches have been primarily applied to detect clustered microcalcifications[2]. Recently, Methods to detect each microcalcifications on mammogram have been proposed, in which

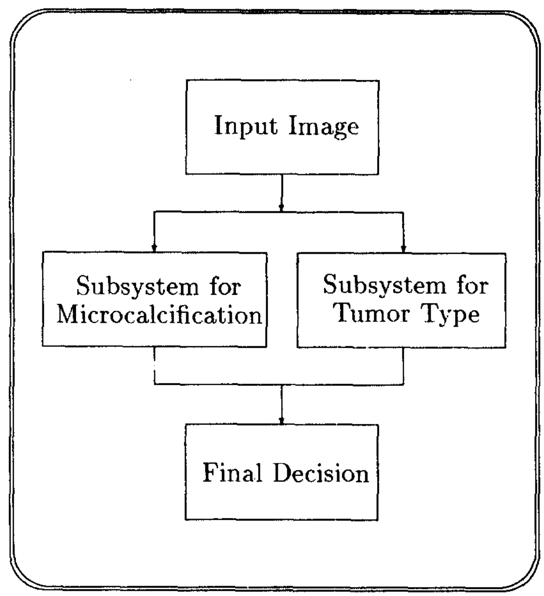

Figure 1: Diagnostic system of breast cancer

static spatial filters and gray-scale thresholding techniques are used[3].

The purpose of our research is to develop a reliable system for automatic diagnosis of breast cancer using CR(Computed Radiography) image. The proposed system basically consists of two subsystems which is shown in Figure 1. One of them is used to detect malignant tumors and the other is used for detecting the presence of microcalcifications on mammogram. By combining the results of these two subsystems, a final decision is made. We have previously reported a method for detecting malignant tumors by using the degree of convergence of gradient vector and ridge point direction[4]-[8]. This paper proposes a new method for detecting microcalcifications by using morphological filters.

In designing morphological filters, exact specification of the structuring element is required. In almost all applications of morphological filtering, only a single structuring element with a disk shape or square shape has been used. Such simple filters are not very effective for detecting microcalcifications on mammogram. In some researches, very simple morphological operations such as erosion have been adopted to detect microcalcifications[9]. We have developed a new effective filter, which is an extension of Top-hat transformation in morphological operations with multi-scale, multiple structuring elements and makes it possible to detect geometrical structures considered to be microcalcifications on the basis of their size, shape and density.

Experiments to test the performance of the proposed method are given, whose results show the effectiveness of this method. Quantitative analysis of the filter characteristics is given.

2 MATHEMATICAL MORPHOLOGY

Mathematical Morphology is useful to extract geometrical features in the image. It is basically a set theory and uses set transformations for image analysis. It is effective to extract a particular shape in image via the concept of Structuring Element. The structuring element encodes the primitive shape information.

There are four basic morphological operators. They are Erosion, Dilation, Opening, and Closing. These transformations use a structuring element to interact with the set and extract information. A structuring element is a set with simple size and shape and is chosen for its geometric properties. Morphological filters are thus transformations of signals based on the theory of mathematical morphology and utilizing its basic operations to perform the transformation.

Morphological operators when applied to binary images are conventionally known as binary morphological operators. The binary morphological transformations of a binary image X by structuring element B are defined as follows[10]-[11].

Erosion and Dilation are defined by

$$X \ominus \check{B} = \{z : B_z \subseteq X\} = \bigcap_{b \in B} X_{-b}, \tag{1}$$

and

$$X \oplus \check{B} = \{z : B_z \cap X \neq \emptyset\} = \bigcup_{b \in B} X_{-b}. \tag{2}$$

Opening and Closing are given by

$$X_B = (X \ominus \check{B}) \oplus B, \tag{3}$$

and

$$X^B = (X \oplus \check{B}) \ominus B, \tag{4}$$

respectively. $\check{B}$ is the symmetric set and it is expressed by

$$\check{B} = \{-b : b \in B\}.$$

Erosion operator can be regarded geometrically as a set transformation that shrinks a set. It is defined as the set of all points z such that the translation of B by z, B_z, is contained in the original set X.

Dilation operator can be considered geometrically as a set transformation that expands a set. It can be defined as the set of all points z such that translation of B by z intersects the original set.

Opening operator cuts the sharp point and edges and Closing operator fills in the holes and gaps in the object image.

The gray scale morphological transformations are expressed as algebraic operations instead of set operations. The forms of erosion, dilation, opening and closing on the gray scale can be defined as follows.

$$(f \ominus \check{B})(x) = \inf\{f(y); y \in B_x\}, \tag{5}$$

$$(f \oplus \check{B})(x) = \sup\{f(y); y \in B_x\}, \tag{6}$$

$$f_B = (f \ominus \check{B}) \oplus B, \tag{7}$$

$$f^B = (f \oplus \check{B}) \ominus B. \tag{8}$$

The erosion of an image f by a structuring element B reduces the peaks and enlarges the minima of the image. The dilation of f by B increases the valleys and enlarges the maxima of the image. The opening of f by B smoothes the function f from below by cutting down its peaks, and the closing smoothes the function f from above by filling up its valleys.

The shape and the size of B must be determined considering information which is expected to be extracted from the object image. Generally, morphological operations are expressed in the multiscale forms as follows:

$$f_{\lambda B} = (f \ominus \lambda \check{B}) \oplus \lambda B, \tag{9}$$

$$f^{\lambda B} = (f \oplus \lambda \check{B}) \ominus \lambda B, \tag{10}$$

where,

$$\lambda B = \overbrace{B \oplus B \oplus \ldots \oplus B}^{\lambda},$$

and λ is a scale parameter. If B is convex, then λB has a shape like B but has a size λ. The shape of λB is controlled by the shape of the primary pattern B, whereas λ controls the size. More detailed descriptions of both binary and gray scale transformations can be found in [10]and[11].

3 ALGORITHM FOR DETECTION OF MICROCALCIFICATIONS

We propose a new method of detecting microcalcifications on mammogram based on morphological operations. It is a multiscale nonlinear filtering that depends on a structuring element pattern and on a scale parameter.

For the detection of microcalcifications on mammogram, two problems have to be solved. The first problem is how to combine basic operators to realize efficient filter which can directly extract microcalcifications. The second one is how to select the structuring element. It should not only be effective to detect microcalcifications but also insensitive to background noises such as a mammary gland and mammary ducts. To solve the first problem, we evaluated the performance of the following five morphological filters:

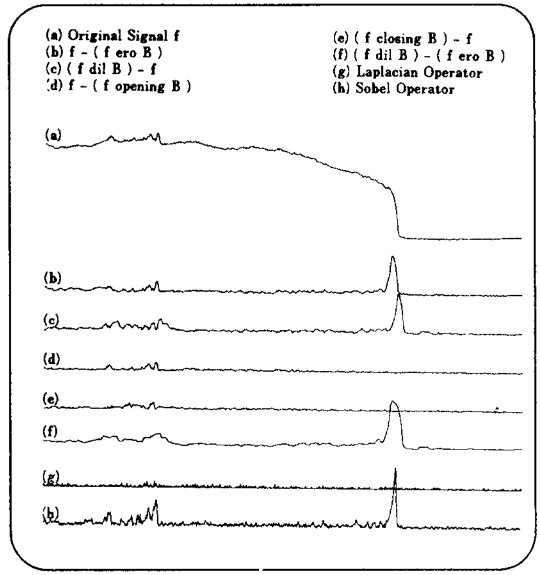

Figure 2: Comparison of different types of morphological filters

$$FilterA: \quad f - f \ominus \lambda B, \tag{11}$$

$$FilterB: \quad f \oplus \lambda B - f, \tag{12}$$

$$FilterC: \quad f - f_{\lambda B}, \tag{13}$$

$$FilterD: \quad f^{\lambda B} - f, \tag{14}$$

$$FilterE: \quad (f \oplus \lambda B) - (f \ominus \lambda B). \tag{15}$$

$FilterA$ is an edge/line enhancement filter and it enhances the edges of gray scale images. $FilterB$ is a similar edge-enhancing operator. By combining the two operators, another operator $FilterE$ is derived. $FilterC$ is Meyer's Top-hat transformation. By applying the filter, a signal is transformed into such one that contains only peaks. $FilterD$ works as a general valley generating process.

Figure 2 shows an example of the experimental results to test the performance of the five filters. From the results we have found $FilterC$ very useful to extract microcalcifications from the original image. The shape of calcification obtained by $FilterC$ is controlled by the shape of B, whereas the scale of calcification is controlled by the size of B. We have used a circle pattern as a structuring element in the above experiments, and it is useful to extract microcalcifications from the image. Mammary glands, however, have been transformed into peaks as large as calcifications. In order to reduce those needless peaks, we have introduced multiple structuring elements. And at the same time, several primitive elements have been adopted instead of the circle pattern. Finally, we used multi-scale and multiple structuring elements and defined a new filter for detecting microcalcifications. The new filter is defined as follows:

$$P_\lambda = f - \max_{i\in(1,..M)}\{(f \ominus \lambda\check{B}_i) \oplus \lambda B_i\} = f - \max_{i\in(1,..M)}\{f_{\lambda B_i}\}. \quad (16)$$

Where, f is an image including microcalcifications. B_i's and λ are multiple structuring elements as shown in Figure 3, and a scale parameter, respectively. Both true calcifications and false ones are detected by the processing P_λ.

Figure 4 shows the results of applying a new filter for detection of microcalcification. (a) is a one dimensional slice signal of the original two dimensional image data. (b) is the results of the openings of f by λB_i, and (c) is the subtraction of (b) and (a). (d) is an enhanced signal of (c). The peaks in (d) correspond to microcalcifications. It is clear that the proposed filter is very effective to detect microcalcifications.

To improve the detection sensitivity, we introduced a morphological gradient. True microcalcifications have usually edges much clearer than those of false calcifications such as mammary glands. It means that they can be discriminated by the value of gradient. Morphological gradient is given by

$$M_{grad} = \frac{f \oplus \lambda B - f \ominus \lambda B}{2\lambda}. \quad (17)$$

Let $P_\lambda(i,j)$ and $M_{grad}(i,j)$ be values of P_λ and morphological gradient of f at (i,j), respectively. Intermediate result, $C_s(i,j)$, is generated according to the following rules:

If $P_\lambda(i,j) \geq T_1$ and $M_{grad}(i,j) \geq T_2$
Then $C_s(i,j) = P_\lambda$ else $C_s(i,j) = 0$

If the value of $C_s(i,j)$ is larger then zero, it means that suspicious microcalcification is extracted.

In order to detect clusters of calcifications, grayscale multi-scale closing and opening operators are used. Let C_c be an image of clustered calcifications. It is obtained from the following morphological operations.

$$C_s^{\lambda_1 B} = C_s \oplus \lambda_1 B \ominus \lambda_1 B, \quad (18)$$

$$C_c = C_s^{\lambda_1 B} \ominus \lambda_2 B \oplus \lambda_2 B. \quad (19)$$

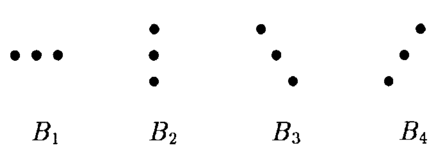

Figure 3: Structuring Elements Patterns of B_i

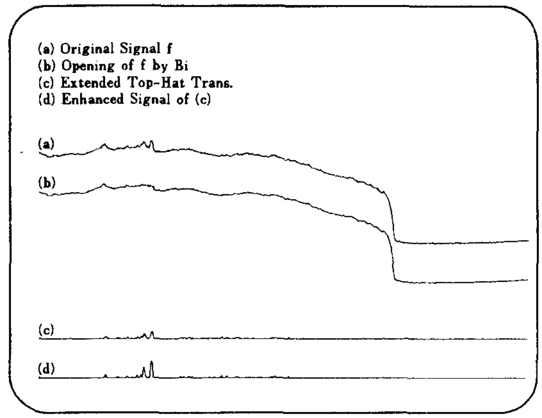

Figure 4: An example of detected microcalcifications

4 EXPERIMENTAL RESULTS

We used 12 CR images of mammograms in which clustered microcalcifications are observed. The image size was 2510×2000 and its spatial resolution was 0.1mm/pixel. Figure 5 shows the processing flow of the subsystem for microcalcifications. The first step is the preprocessing. The second step is the detection of breast boundary. The next processing step is the calculation of P_λ by the proposed filter. In the next step, morphological gradient M_{grad} is calculated, and C_s is obtained. In the last processing step, multiscale closing and opening are applied to detect clusters of microcalcifications.

Figure 6 shows an example of the abnormal mammogram. Figure 7 shows $f_{\lambda B}$, which

Original Image
⇓
Preprocessing
⇓
Detecting Breast Boundary
⇓
Detecting Microcalcifications with Morphological Filter
⇓
Morphological Gradient
⇓
Suspicious Calcifications map
⇓
Grayscale Closing
⇓
Grayscale Opening
⇓
Cluster of Calcifications

Figure 5: Flow chart of processing

is an opening of f by single structuring element B. Figure 8 shows the result of f - $f_{\lambda B}$, which is a normal Top-hat transformation. It is clear that calcifications were extracted effectively, but mammary glands were also extracted. Figure 9 shows $max\{f_{\lambda B_i}\}$: maxima of Openings of f by multiple structuring elements B_i. Figure 10 shows the result of f - $max\{f_{\lambda B_i}\}$. It is a new filter proposed in this paper and it can be considered to be an extension of Top-hat transformation. From the comparison of Figure 8 and Figure 10, it is clear that the new filter is not only effective to extract calcifications, but also insensitive to background noises such as mammary glands. Figure 11 shows intermediate results C_s. Morphological gradient is useful to exclude false calcifications. Figure 12 shows Grayscale closing of C_s by $\lambda_1 B$. By applying this procedure, fusions between clustered calcifications were made, and the global clusters were obtained. Figure 13 shows Grayscale opening of $C_s^{\lambda_1 B}$ by $\lambda_2 B$. The isolated peaks were removed by using this operator and, whereas the global cluster regions can be preserved.

Experiments to test the performance of the proposed methods were performed for all 12 images. All their regions of clustered microcalcifications were detected successfully.

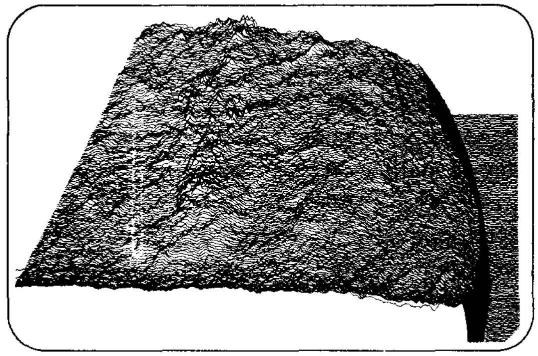

Figure 6: Original image f

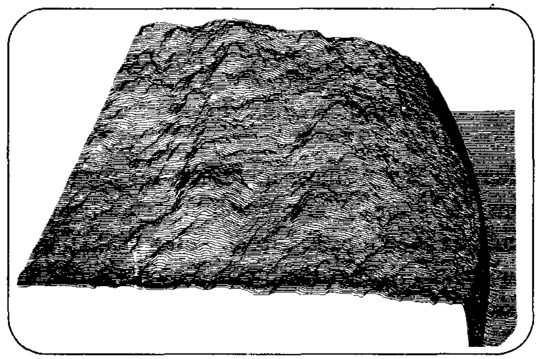

Figure 7: $f_{\lambda B}$: Opening of f by single structuring element B

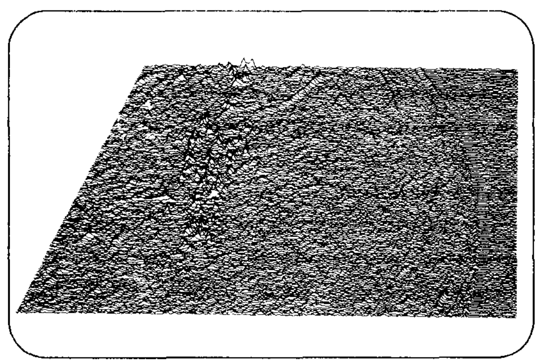

Figure 8: Subtraction of f - $f_{\lambda B}$

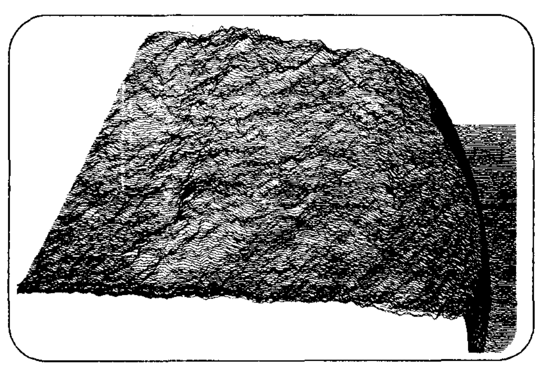

Figure 9: $max\{f_{\lambda B_i}\}$: maxima of Opening of f by multiple structuring element B_i

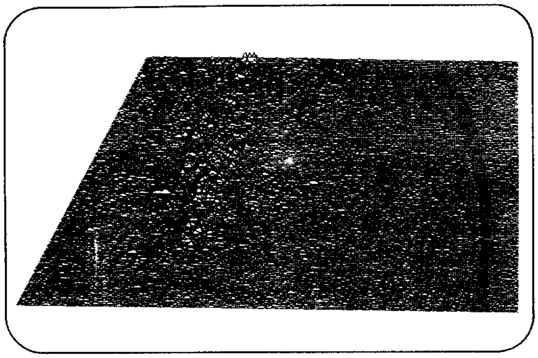

Figure 10: Subtraction of f and $max f_{\lambda B}$,

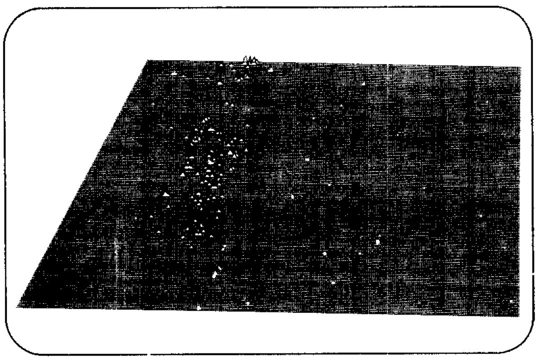

Figure 11: The image C_s

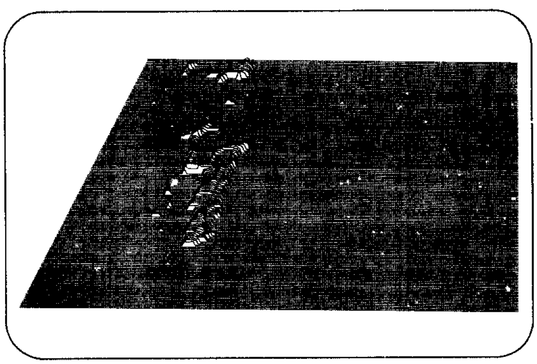

Figure 12: $C_s^{\lambda_1 B}$:Grayscale closing of C_s by $\lambda_1 B$

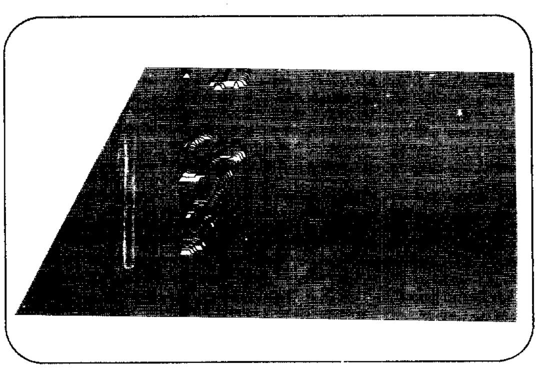

Figure 13: Grayscale opening of $C_s^{\lambda_1 B}$ by $\lambda_2 B$

5 CONCLUSION

We have proposed a new approach based on morphological filter for detecting microcalcifications on mammogram. The experimental results show the effectiveness of the proposed method.

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