Medical physics and imaging

Computer-aided detection of clustered microcalcifications on digital mammograms

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Abstract—*A computer-aided diagnosis scheme to assist radiologists in detecting clustered microcalcifications from mammograms is being developed. Starting with a digital mammogram, the scheme consists of three steps. First, the image is filtered so that the signal-to-noise ratio of microcalcifications is increased by suppression of the normal background structure of the breast. Secondly, potential microcalcifications are extracted from the filtered image with a series of three different techniques: a global thresholding based on the grey-level histogram of the full filtered image, an erosion operator for eliminating very small signals, and a local adaptive grey-level thresholding. Thirdly, some false-positive signals are eliminated by means of a texture analysis technique, and a non-linear clustering algorithm is then used for grouping the remaining signals. With this method, the scheme can detect approximately 85% of true clusters, with an average of two false clusters detected per image.*

Keywords—*Automated detection, Computer-aided diagnosis, Digital imaging, Mammography, Microcalcifications*

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1 Introduction

SEVERAL STUDIES have shown that screening of asymptomatic women by mammography can reduce mortality from breast cancer (SHAPIRO *et al.*, 1982; TABAR *et al.*, 1985; ANDERSSON *et al.*, 1988). However, approximately 20% of women with breast cancer have negative mammograms (BAINES *et al.*, 1986; BIRD, 1989). In certain series, for two-thirds of these false-negtaive mammograms, the cancer was identified on the mammogram retrospectively (SICKLES, 1986; HERMANN *et al.*, 1988). If the number of 'missed' cancers can be reduced, then the effectiveness of mammography can potentially be increased.

It is believed that double reading of mammograms can reduce the false-negative rate (BIRD, 1989). Currently, double reading is accomplished by having two radiologists interpret the films independently. In our laboratory, we are developing computer-aided diagnosis (CAD) schemes for detection and characterisation of breast masses and microcalcifications (CHAN *et al.*, 1987; 1988; 1990; GIGER *et al.*, 1990; NISHIKAWA *et al.*, 1990*a*; *b*; YIN *et al.*, 1991). These CAD schemes will be implemented on an 'intelligent' mammography workstation that will assist radiologists in diagnosing breast cancer (GIGER *et al.*, 1991). The workstation will produce a new kind of 'second opinion' for the radiologist's use.

We conducted a preliminary observer study to determine whether radiologists' accuracy in detecting clustered microcalcifications could be improved if they were assisted by a CAD scheme (CHAN *et al.*, 1990). 30 normal mammograms and 30 with clustered microcalcifications were viewed, in random order, by six radiologists and six radiology residents. At the time of the study, the computer scheme had a sensitivity of 87%, with four false-positive clusters per image. Using receiver operating characteristic (ROC) analysis (METZ, 1986), there was a statistically significant increase ($P < 0{\cdot}001$) in the observers' accuracy when they were shown the mammogram together with the computer results, compared with viewing the mammogram only. In addition, the results suggested that a reduction in the computer's false-positive rate would further improve radiologists' diagnostic accuracy.

This paper describes our CAD scheme for the automated detection of clustered microcalcifications. A flow chart of our approach is shown in Fig. 1. This scheme is an advanced version of one developed earlier in our laboratory (CHAN *et al.*, 1987; 1988; 1990). The new CAD scheme has a comparable sensitivity of 85%, but a reduced false-positive rate of two per image, compared with four previously.

2 CAD scheme for detection of clustered microcalcifications

2.1 *Film digitisation*

All mammograms in this study were digitised by a Fuji drum scanner, at a 0·1 mm sampling distance using a

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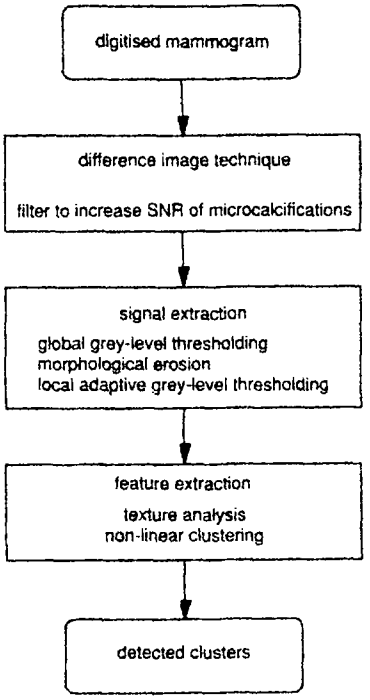

Fig. 1 *Flowchart of CAD scheme for automated detection of clustered microcalcifications from mammograms*

0·1 × 0·1 mm sampling aperture. The scanner had 10-bit grey-scale resolution. Although the whole breast area was digitised, only an 8 × 10 cm region was analysed because of the memory limitations of our present computer. With the proposed 'intelligent' workstation, the full mammogram can be analysed. An example of a digitised mammogram is shown in Fig. 2.

Fig. 2 *8 × 10 cm portion of a digitised mammogram; pixel size is 0·1 × 0·1 mm; arrow indicates location of cluster of microcalcifications*

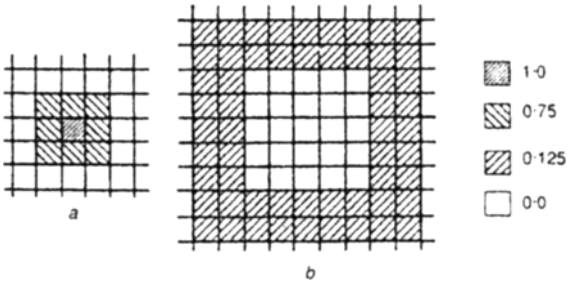

Fig. 3 *Kernels used for (a) enhancement filter and (b) suppression filter*

2.2 *Difference-image technique*

The difference-image technique is used for enhancing the signals from microcalcifications while the background structure of the breast is suppressed (CHAN *et al.*, 1987). This is achieved by use of two linear filters, whose kernels are shown schematically in Fig. 3. The kernel in Fig. 3*a* enhances the appearance of small structures, such as microcalcifications, whereas that in Fig. 3*b* suppresses these same structures. Therefore, by subtracting the suppressed image from the enhanced image, a difference image is obtained. In practice, the two linear filters are combined into a single linear filter, and an offset of 512 is added to each pixel to avoid negative pixel values. As a result, we designate a value of 512 as the background pixel value. It is apparent that in the difference (filtered) image, shown in Fig. 4, the normal background structure is greatly reduced.

2.3 *Signal-extraction technique*

The signal-extraction technique consists of two different thresholding methods (CHAN *et al.*, 1987) and a morphological operator (NISHIKAWA *et al.*, 1990*a*). After the difference image is obtained, a global thresholding is performed. The threshold level is based on the grey- level histogram of the whole image and is chosen such that 98% of all pixels in the difference image are set to the background pixel value (512). Next, morphological erosion is performed by means of the structuring elements shown in Fig. 5. This operation eliminates signals that are less than 3 pixels in area, because very small signals are likely to be caused by random noise in the image and not by the presence of true

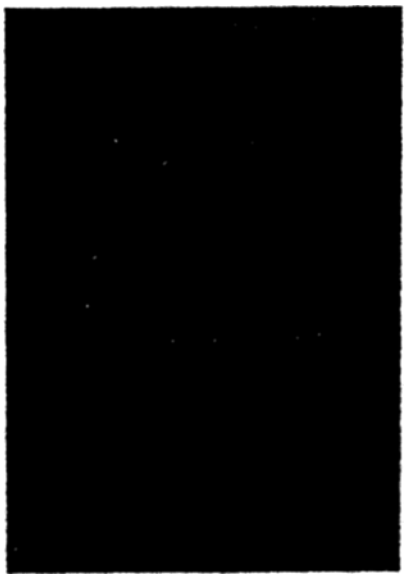

Fig. 4 *Example of difference-image technique; original mammogram, shown in Fig. 2, after filtering*

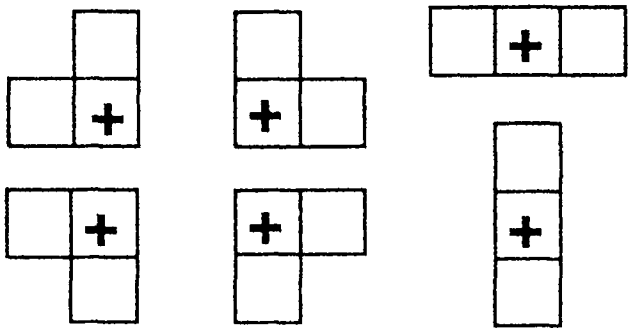

Fig. 5 *Six structuring elements used in morphological erosion operator; plus signs indicate position of pixel under consideration with respect to structuring element*

microcalcifications. Finally, a local adaptive grey-level thresholding is used. This thresholding is based on the local statistics (mean and standard deviation) of grey-level values within a 5·1 × 5·1 mm area of the processed image. Only pixels whose values are greater than a specified multiple of the standard deviation above the local mean pixel value are kept. By varying the local-threshold value, the sensitivity and specificity of the computer scheme can be changed. The processed images after global thresholding, morphological erosion and local thresholding (for a threshold value of 3·6 times the standard deviation) are shown in Fig. 6.

2.4 *Feature-extraction technique*

The feature-extraction technique consists of two steps; texture analysis and clustering of the signals. The texture analysis is based on the work of Katsuragawa *et al.* (KATSURAGAWA *et al.*, 1988). For each signal that remains in the image after signal extraction, a 6·4 × 6·4 mm region of interest centred on the signal is analysed. First, a low-frequency background-trend correction with a polynomial of degree 3 is applied. A two-dimensional Fourier power spectrum is then calculated. The power spectrum is averaged with the assumption of rotational symmetry, and then the first moment of the averaged power spectrum is calculated. If the first moment is greater than 3·0 cycles mm^{-1}, the signal is eliminated.

Finally, the remaining signals are grouped or clustered by passage of a 3·2 × 3·2 mm box over the image (NISHIKAWA *et al.*, 1990*b*). If there are three more signals in the box, these signals are passed to the output image. Fig. 7 shows the processed image after texture analysis and after clustering (the final step). In this case, one 'true' cluster was detected by the CAD scheme without a false- positive detection. In clinical implementation of our CAD scheme, the position of all computer-detected clusters would be indicated on a copy of the original mammogram, for example, with an arrow.

3 Results

Using the method outlined above, we analysed a database of 78 mammograms. 39 of the mammograms had no visible clusters, whereas the other half had at least one cluster. The 'truth' for the 78 cases (either the absence of microcalcifications or the *x-y* locations of clustered microcalcifications) was determined visually by an experienced mammographer. The 39 mammograms with a cluster were chosen by two experienced mammographers over a period of three years as being representative of subtle or difficult cases. The presence of a cluster in these mammograms was verified by biopsy, with the exception of two cases that were, in the opinion of the radiologist, clearly not malignant and therefore were not sent to biopsy. For this study, visual interpretation was used as the 'gold standard' for determining 'truth'. This approach was used in part because it is not possible to determine the *x-y* location of microcalcifications that are not visible in the mammogram.

The performance of the computer scheme is shown in Fig. 8. Different values in the graph are obtained by changing the local threshold value. As the performance of a CAD scheme depends on the difficulty of the cases used to test it (SWETS *et al.*, 1991), we determined the extremes in performance of our scheme. This was done by testing the scheme with two different databases, each consisting of 60 cases chosen from the 78 cases. The first subset consisted of the 60 cases for which the detection scheme had the 'best' performance. The second subset consisted of the 60 cases for which the scheme had the 'poorest' performance. The line in Fig. 8 is the average of the results for the two extreme databases, and the error bars indicate the actual results for the two databases. The CAD technique is capable of

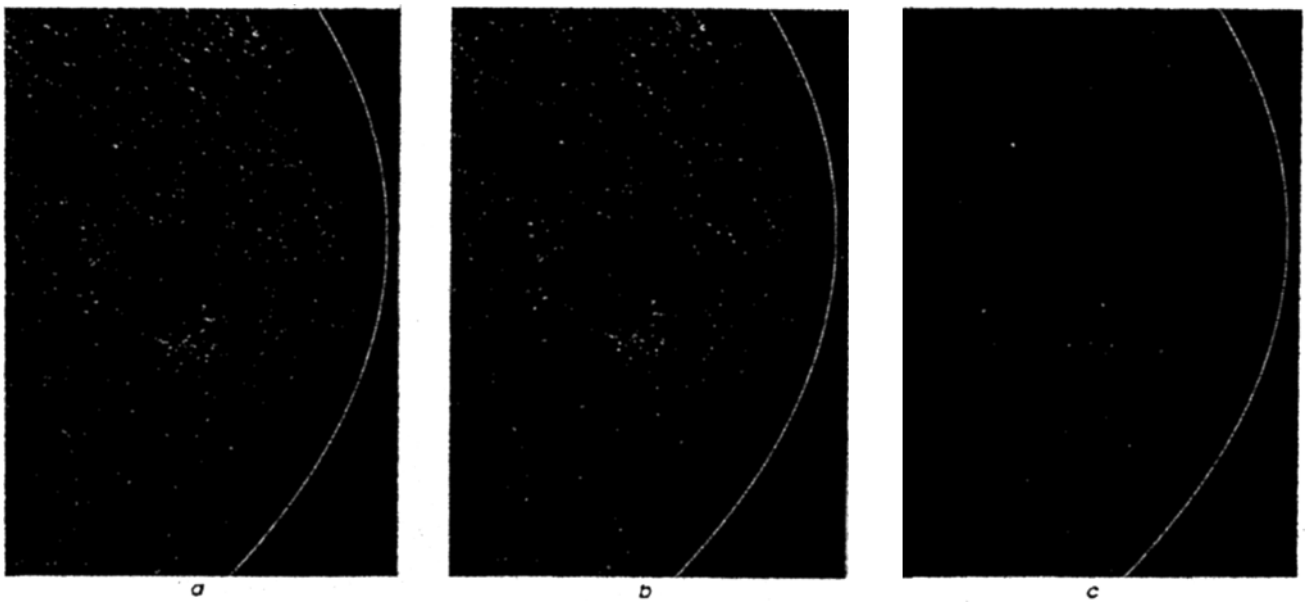

Fig. 6 *Example of signal-extraction technique: image shown in Fig. 4 after (a) global thresholding, (b) morphological erosion and (c) local adaptive grey-level thresholding*

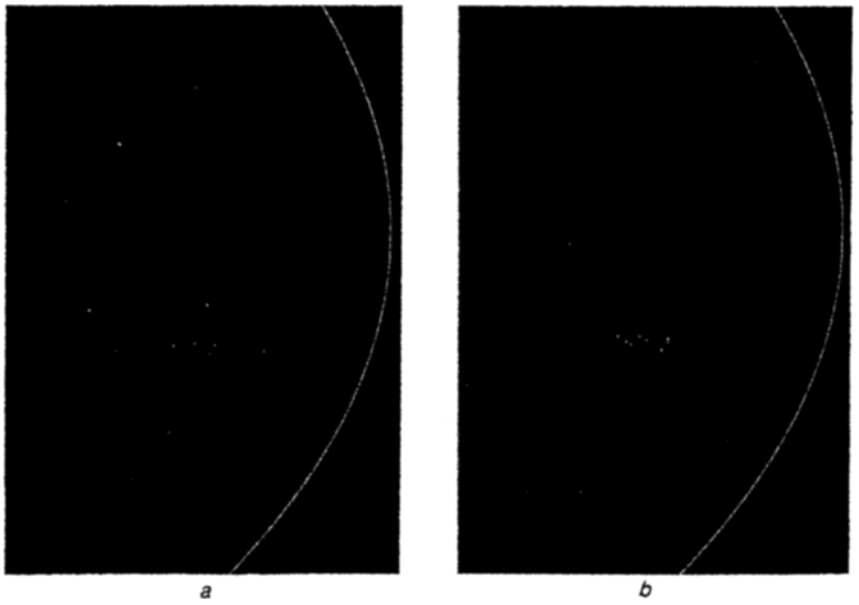

Fig. 7 *Example of feature-extraction technique: image shown in Fig. 6(c) after (a) texture analysis and (b) clustering: (b) shows final analysed image; one true cluster was detected; no false clusters were detected*

detecting approximately 85% of true clusters, with an average of two false-positive detections per image.

The CAD scheme takes approximately 13 min to analyse an 8 × 10 cm region of a mammogram on a DEC VAX 3500 computer. Preliminary results indicate that a full mammogram can be analysed in less than 40 s on an IBM (RISC 6000) Powerstation 560.

4 Discussion

The CAD technique presented here is an improvement on the technique previously developed in our laboratory. While maintaining a sensitivity of approximately 85%, the false-positive detection rate has been reduced by half, to an average of two false clusters per image. The improvements are the results of two changes. First, in an effort to reduce the false-positive rate, the previous scheme eliminated small signals (less than 3 pixels in area) after local thresholding. As the size of a signal is very sensitive to the threshold level, some true microcalcifications were eliminated, and as a result some true clusters were lost. In the new approach, morphological erosion is applied before local thresholding, and as a result no true clusters are eliminated at this stage. Secondly, the method for the clustering of signals in the new technique is more accurate than the 'region-growing' technique used previously.

Furthermore, the new clustering technique can eliminate some false clusters based on the spatial distribution of individual microcalcifications within the cluster. Microcalcifications in true clusters tend to be tightly distributed, whereas in some false clusters their distribution is more diffuse. If there are not at least three signals within a 3·2 mm^2 area, the signals are not clustered, and thus some false clusters are eliminated with the new technique that would not have been removed by the previous method.

Our approach to the detection of clustered microcalcifications is one of several currently being developed (ASTLEY *et al.*, 1990; FAM *et al.*, 1988; MAGNIN *et al.*, 1989; DAVIES and DANCE, 1990; GRIMAUD *et al.*, 1990; KARSSEMEIJER and VAN EARNING, 1991). As each investigator uses a different database, it is not possible to compare results directly. It should be noted, however, that, if the purpose of the computer detection scheme is to improve radiologists' accuracy, (as opposed to its being used as a prescreen for radiologists or actually replacing radiologists), then another measure of performance can be applied that may be useful for comparing different schemes. An observer study can be carried out that examines whether radiologists' accuracy increases when they interpret mammograms with the aid of the results of the CAD scheme. To date, the scheme developed in our laboratory (although it was an earlier version of the scheme described in this paper) has been the only one tested in such a manner and shown to improve radiologists' accuracy ($P < 0.001$) over reading film alone (CHAN *et al.*, 1990).

5 Summary

This paper describes a computer technique for the automated detection of clustered microcalcifications. Our CAD technique is capable of detecting approximately 85% of true clusters, with an average of two false-positive

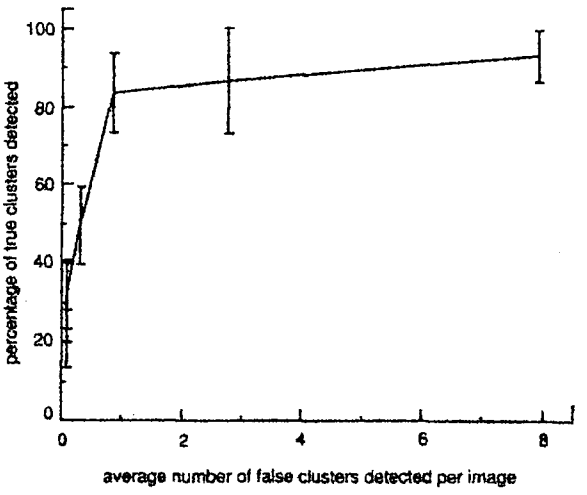

Fig. 8 *Performance of CAD scheme; error bars represent extremes in performance obtained by choosing different subsets of 60 mammograms from database of 78 cases; line joins average of two extremes at each point*

detections per image. This computer scheme will soon be implemented on an 'intelligent' mammography workstation and will undergo clinical evaluation in the near future.

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