Contrast enhancement of microcalcifications in mammograms using morphological enhancement and non-flat structuring elements

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Abstract

This paper presents an approach to enhancing the contrast of microcalcifications in mammograms using a contrast enhancement algorithm based on a combination of morphological enhancement and non-flat structuring elements. Given that microcalcifications appear as small domes on a 3D relief of a mammogram, enhancement is achieved by using structuring elements which have a 3D form.

1. Introduction

Mammography plays a central role in the process of detecting abnormalities in breast cancer screening. A mammogram is a x-ray projection of the 3D structures of the breast obtained by compressing the breast between two plates. Mammograms have an innate "fuzzy" or diffuse appearance due in part to the superimposition of densities from differing breast tissues, and the differential x-ray attenuation (absorption) characteristics associated with these various tissues. A high contrast is always required to differentiate very fine structures with slight differences in density, such as microcalcifications. A microcalcification is a tiny granule-like calcium deposit that has accumulated in the breast tissue, appearing as a small bright spot on a mammogram. There is a distinct correlation between the presence of microcalcifications and the incidence of breast cancer which indicates that precise detection of microcalcifications will improve the ability to detect malignant masses. Enhancement is the first stage in the process of microcalcification detection and classification.

In this paper we propose an enhancement algorithm based on morphological analysis. First we isolate the breast region and use morphological pre-processing to suppress the background artifacts, then morphological enhancement (ME) is used to improve the contrast of the microcalcifications. Previous approaches using ME to improve the perspicacity of microcalcifications have focused on the use of small square [1] or disk shaped flat structuring elements (SE), which may be inappropriate for the natural shape of microcalcifications. We investigate a new approach to ME, one based on non-flat (grayscale) structuring elements, and compare our results against ME using flat SE and traditional enhancement techniques using images from various databases.

2. Complexities of microcalcification enhancement

Many factors contribute to difficulties in detecting microcalcifications. Foremost microcalcifications are small, and exhibit a broad range of variability with respect to their morphology (Figure 1), size, and distribution pattern. Secondly, microcalcifications are often situated in a non-homogeneous background, and due to their low contrast with the background, their intensity may be similar to noise or other structures (e.g. film artifacts, radiopaque markers). If the background region is composed of fatty tissue the process of identifying microcalcifications is easier than if they are embedded in dense

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fibroglandular tissue. Enhancement of microcalcifications is a delicate process which involves improving contrast while preserving visual acuity. Too little enhancement may preclude the detection of minor microcalcification peaks, while too much enhancement may significantly increase the amplitude of background noise leading to a large number of false detections.

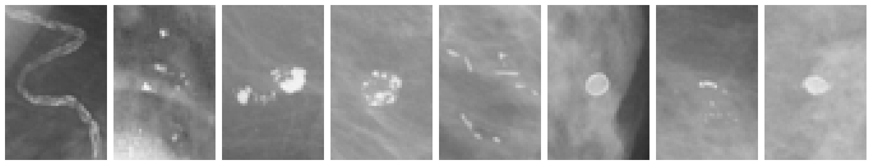


Figure 1. Some types of microcalcification (left-to-right): vascular, round, popcorn, rim, rod, spherical, punctuate, dystrophic

3. Morphological Enhancement

The notion of contrast can be approximately defined as the relative difference in intensity between an image structure and its background. The principal objective of contrast enhancement or sharpening is to emphasize fine detail in a mammogram, or to enhance detail that is blurred. The principle of morphological contrast enhancement was introduced by Soille [2], as an extension to toggle contrasts. Morphological contrast enhancement is based on the notion of morphological top-hats which were first proposed by Meyer [3]. A *top-hat* is a residual filter which preserves those features in an image that can fit inside the *structuring element* (SE) and removes those that cannot. Morphological contrast enhancement is derived by calculating the dual area top-hats in parallel. Performing a structural opening removes from an image the high-intensity regions, i.e. features that cannot accommodate the structuring element. The *top-hat by opening*, γ_{TH}, is defined as the difference between the original image, I_o, and its grayscale opening, γ_B, using the structuring element *B*:

$$\gamma_{TH} = I_o - \gamma_B \tag{1}$$

Similarly the dual *top-hat by closing*, ϕ_{TH}, is the difference between the grayscale closing, ϕ_B, using the structuring element *B* and the original image, I_o:

$$\phi_{TH} = \phi_B - I_o \tag{2}$$

The top-hat by opening, yields an image that contains all the residual features (i.e. peaks and ridges) removed by the opening. Adding these residual features to the original image has the effect of accentuating high-intensity (light) structures. The dual residual (i.e., valleys and troughs) obtained by using the top-hat by closing, is then subtracted from the resulting image to accentuate low-intensity (dark) structures:

$$\kappa = I_o + \gamma_{TH} - \phi_{TH} \tag{3}$$

4. Non-flat Structuring Elements

A *structuring element* is a small set used to probe an image. Morphological analysis has traditionally been performed using *flat* structuring elements, which have two dimensions in the case of two-dimensional images. Conversely *non-flat* structuring elements (also known as grayscale or volumic SE) are 3D structuring elements, used to probe the intensity "shape" of features in the image, in addition to simply shape. Sternberg [4] introduced the concept of such non-flat SE, however there is very little application of such SE in the literature. Di Ruberto et al. [5] use a hemisphere shaped SE to enhance the roundness and compactness of red blood cells in images of stained blood slides. A non-flat SE has more of a 3D appearance. For example, consider a non-flat "ball-shaped" structuring element whose radius in the X-Y plane is 8 and whose height is 50. hemisphere, as shown in Fig.2.

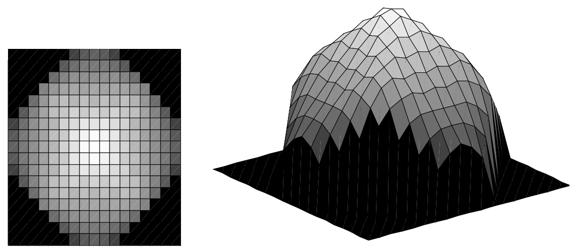


Figure 2. A “ball-shaped” non-flat structuring element

5. Results

5.1 Performance evaluation

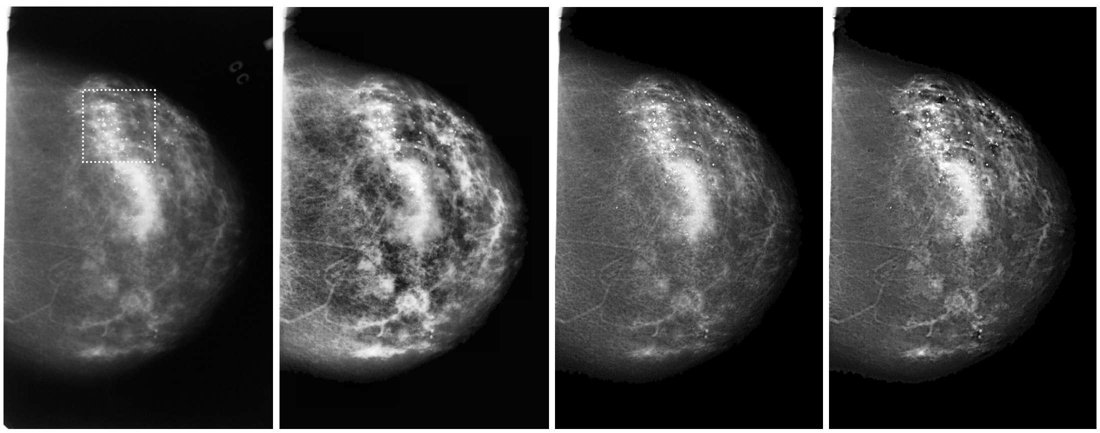
The performance of the enhancement schema is characterized through a process of direct visual inspection, quantitative measures such as those based on background and detail region variance, and comparative measures such as image profiles. An experimental comparison is made between morphological enhancement using non-flat structuring elements and techniques such as classical morphological enhancement and the Contrast-Limited Adaptive Histogram Equalization (CLAHE) algorithm [6]. The measure used here is formed by two figures of merit representing an estimate of the local variance of an image [7]. The estimate is performed separately in detail regions (detail variance, DV) and in relatively uniform regions (background variance, BV) of an image. Here we expect reasonably high values of DV in the enhanced images, while the BV value should remain low in order to indicate limited noise amplification.

5.2 Assessment of the non-flat SE

To illustrate the process, consider the example shown in Figure 3 showing various enhancement algorithms applied to a mammogram containing a series of round microcalcifications (Figure 3a). Figure 3b-d show the results obtained using the CLAHE algorithm, traditional morphological enhancement with a flat, disk-shaped structuring element ($\varnothing$=5) and our algorithm using a non-flat “ball”-shaped structuring element (height=50, $\varnothing$=17) respectively. The data in Table 1 summarizes the quantitative measures obtained for the mammograms shown in Figure 3. The SE-based morphological enhancement algorithm shows a moderate improvement in the DV over the CLAHE algorithm, due to the shape of the SE and localized behavior of the algorithm, however there is noticeable amplification of background noise. Enhancement using the non-flat SE offers an improvement of the DV over the flat SE while demonstrating a moderate increase in the contrast of background structures (and noise). CLAHE maintains the highest noise amplification, indicative of underlying dense breast tissue being enhanced.

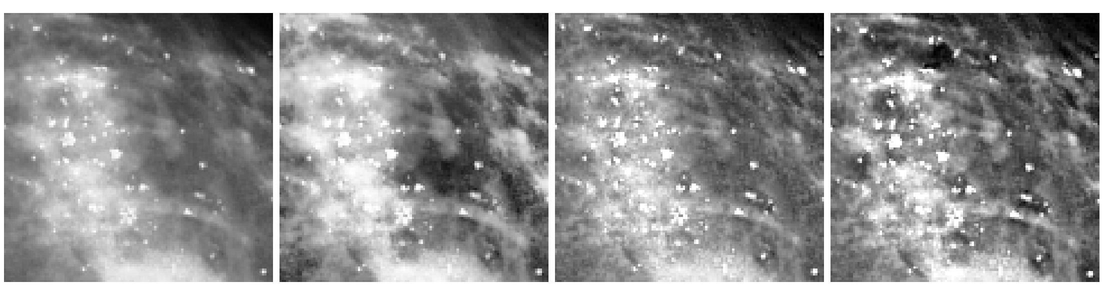
Table 1: Performance measures for enhancement of microcalcifications

Enhancement Algorithm	DV	BV
Original (no enhancement)	16887	8.2530
CLAHE (enhanced)	59155	823.7258
Non-Flat SE (morphology)	196060	447.7684
Flat SE (morphology)	92701	422.3583



(a) (b) (c) (d)

Figure 3. Contrast enhancement of a mammogram. (a) Original mammogram; (b) Enhancement using CLAHE algorithm; (c) Morphological enhancement using a flat SE; (d) Enhancement using morphological enhancement with a non-flat structuring element



(a) (b) (c) (d)

Figure 4. Magnified mass ROI from Fig.1. (a) Original mammogram; (b) Enhancement using CLAHE algorithm; (c) Morphological enhancement using a flat SE; (d) Enhancement using morphological enhancement with a non-flat structuring element

The quantitative results of Table 1 are substantiated by reviewing the region of interest (ROI), containing microcalcifications which were extracted from each of the mammograms in Figure 3, and magnified to show detail (Figure 4). Enhancement using the CLAHE algorithm (Figure 4b) reveals that whilst the microcalcifications have been enhanced, so too has the surrounding dense tissue, effectively obscuring many of the overlying microcalcifications. Both morphological enhancement techniques have improved the acuity of the microcalcifications, with the non-flat SE-based algorithm (Figure 4d) showing greater accentuation of the microcalcifications than the flat-SE (Figure 4c).

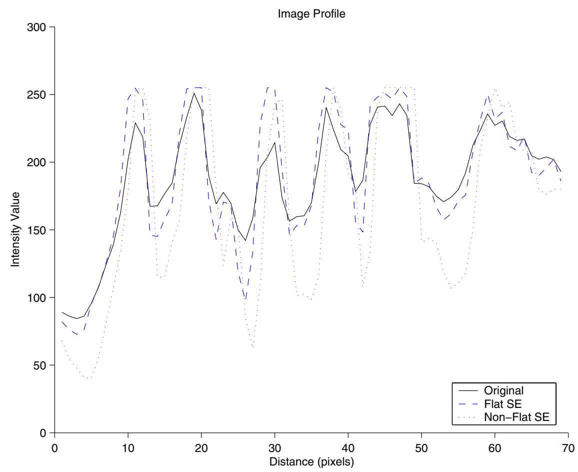
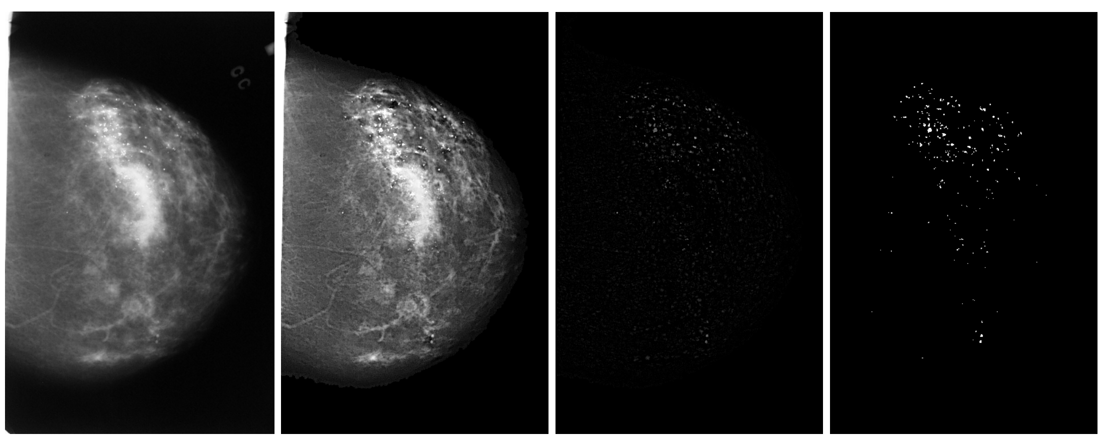


Figure 5. Profiles of flat versus non-flat structuring elements

The effect of the non-flat structuring element can be visualized using a series of profiles taken across a series of microcalcifications from the ROI in Figure 4. The resulting profiles for the original, flat and non-flat SE are shown in Figure 5. Notice that the non-flat SE exhibits deep valleys, separating the peaks of the microcalcifications more effectively than the disk-shaped flat SE.



(a) (b) (c) (d)

Figure 6. Extraction of microcalcifications. (a) Original mammogram; (b) After enhancement using 3D morphological enhancement; (c) After background subtraction; (d) Thresholding of (c) to extract potential microcalcifications.

Figure 6 illustrates the use of enhancement as a precursor to the microcalcification detection process. The original mammogram (Figure 6a) is enhanced using the proposed algorithm (Figure 6b) and the effect of suppressing the linear structures and fibroglandular tissue (Figure 6c). The resulting image (Figure 6d) shows the prospective microcalcifications extracted by thresholding [8].

Figure 7. Types of microcalcification after enhancement using the non-flat SE (left-to-right): vascular, round, popcorn, rim, rod, spherical, punctuate, dystrophic

The ability of the algorithm to adapt to changes in the size and shape of microcalcifications is illustrated through the enhancement of the microcalcifications in Figure 1. The results shown in Figure 7 demonstrate improved acuity in all the microcalcifications.

6. Discussion and Conclusion

The diffuse appearance of mammograms is caused in part by the lack of high-frequency components. One of the caveats encountered when using traditional enhancement techniques is that they invariably enhance noise while improving contrast, eliminating fine detail and edge sharpness. One of the benefits of morphological contrast enhancement is that it allows fine details to be preserved. The other benefit of this approach over existing enhancement algorithms is its ability to be tailored towards specific purposes. This paper has proposed a new algorithm for image enhancement of structures in mammograms based on the use of non-flat SE. We have demonstrated that the proposed method is able to enhance microcalcifications without noise emphasis or the over-accentuation of background tissue.

7. References

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