Detection of Areas Containing Microcalcifications in Digital Mammograms

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***Abstract* - Microcalcifications are tiny calcium deposits present in the breast tissue. They are proved to be an important early sign of a process which started to happen and could be a development of a breast cancer. Because of that computer-aided detection systems (CADe) for detection of microcalcifications with low false positive rate can be very useful and helpful for breast cancer prediction. Accurate detection of microcalcifications is a very challenging task because of their visual property which is very similar to the noise in the image. To be able to perform accurate detection it is necessary to remove the background influence and at the same time preserve microcalcifications in the image. In this paper we propose a method for detection of presence of microcalcifications using the contrast enhancement of microcalcifications against the background tissue. For background suppression we use combination of wavelet filtering and grayscale morphology. The results of detection of suspicious areas which could contain microcalcifications are shown to be good in comparison to other methods which do not use manual selection of suspicious areas.**

***Keywords* - Microcalcifications; Digital Mammograms; Contrast Enhancement**

I. INTRODUCTION

Computer-aided detection (CADe) of microcalcifications is important in modern computerized mammography systems because it helps radiologists reach their diagnosis is shorter time. Since mammography is being established as a rather standard screening method for women of age 40 and above, there is a very large number of mammograms which need to be examined by each radiologist. That process is rather time consuming and since most of mammograms belong to healthy women there is a possibility of having some false negative readings. Microcalcifications which belong to suspicious categories are usually very small in size and often come in clusters. Those tiny clusters of microcalcifications are difficult to spot not only because of their size but also because of low brightness of objects which have similar physical dimension to the spatial resolution of a mammography imaging device. Typical size of a microcalcification is between 0.1 mm and 1 mm, and the average is about 0.3 mm [1]. Clustered microcalcifications are often smaller than the average size and that needs to be taken into account. Mammography is an x-ray method which produces 2-D images of different tissues in grayscale in a way that dense tissue provides more attenuation for x-rays and produces higher intensity in the output image. Mammograms are therefore projection images captured after performing a strong compression of the breast in order to produce uniform breast height. Because of the projection nature of mammograms there can be a lot high intensity areas and objects which should not really be bright because of their density but because of overlapping of blood vessels and fibrous tissue. Although there have been many approaches to develop an as good as possible detection algorithm, development of a method which will be completely accurate and with no false positive (FP) and false negative (FN) results still remains a challenge. For an accurate detection of microcalcifications radiologists need to have very well captured mammograms with very high spatial resolution and with low noise. Modern digital mammography devices offer spatial resolutions of 50 μm to 80 μm but the bit depth is still not completely standardized, although DICOM standard [2] prescribes usage of 12 bits per pixel in mammography modality. Therefore, each calcification will occupy an area of about 5×5 pixels in average. By knowing the approximate microcalcification size it becomes possible to filter smaller and larger bright objects from the image and to remove them as a part of the background. There have been many different approaches in detection of microcalcifications. Almost all of them are based on detection of bright objects with specific size and there is a lot of research which aims at detection of microcalcifications on manually selected areas. Enhancement of microcalcifications is an important preprocessing step which should produce good results for both manual and automatic detection process. One of the most popular methods is contrast enhancement by histogram equalization [3]. There are many contrast enhancement techniques, but one of the most widely used, named contrast-limited adaptive histogram equalization (CLAHE), was proposed by Pizer et al. [4] This histogram equalization method provides local contrast enhancement on arbitrary selected patches from the image. It aims at providing good contrast enhancement while preserving the values of histogram bins with high probability and distributing their probabilities equally above the certain clip limit. This technique was recently used in conjunction with the redundant discrete wavelet transform [5]. Another approach is image filtering using the unsharp mask filter which amplifies high-frequency details but is not sensitive solely to microcalcifications [6]. Besides the direct contrast enhancement and image filtering, it is possible to apply feature based contrast enhancement techniques which allow enhancement of objects with certain morphological characteristics. One of these methods is multiscale image analysis [7]. Multiscale image analysis provides possibility to filter out or suppress objects of dimensions which do not correspond well to the possible size of microcalcifications. Usage of the discrete wavelet transform for multiscale analysis in the detection of microcalcifications was presented by Strickland and Hahn in [8]. Salvado and Roque [9] proposed a method which uses both contrast enhancement and the wavelet-based analysis. Their method consists of histogram analysis, 2D DWT analysis, noise removal, low spatial frequency object removal, image enhancement and finally reconstruction. For the decomposition using DWT they proposed usage of Daubechies-6 wavelet with up to 10 levels of decomposition. Juarez et al. [10] proposed a method which also uses DWT and they tried to reconstruct the image based on the approximation coefficients which represent objects of high spatial frequency. Besides their work, many other authors also used wavelet analysis which proved to be one of the most widely used methods for detection of microcalcifications. Wavelet decomposition for image enhancement in mammography was also presented by Mencattini et al. [11] and shows the power of spatial filtering in image enhancement for different purposes, like the automatic detection and segmentation of objects. Rizzi et al. [12] also used DWT-based method and reported a sensitivity of about 98% at a rate of 0.65 FP/image and a specificity of 89% with 0.05 FN/image with manual selection of the threshold parameter to achieve more accurate results.

In this paper we propose a method which should provide contrast enhancement only for microcalcifications and also detection of presence of microcalcifications inside the observed patches in the mammogram. The proposed method uses wavelet decomposition and subband suppression in order to filter out the background and objects which size is larger than the expected size of microcalcifications. On filtered images we are using grayscale morphology to emphasize objects of dimension similar to the expected dimension of microcalcifications. Our aim is to suppress all the surrounding breast tissue and to boost the intensity of each individual microcalcification which can be identified in the patch. This procedure should provide good results for standalone microcalcifications as well as for clusters of microcalcifications, even though size of clustered microcalcification is often smaller. Standalone microcalcifications are usually brighter with higher contrast in comparison to the surrounding tissue while clusters of microcalcifications are often consisted of physically smaller and scattered calcium deposits with much lower contrast to the background. Detection of standalone microcalcifications is therefore easier but clinically less important because it is less expected that a standalone microcalcification is missed and because clustered microcalcifications are often an early sign of developing process inside a breast.

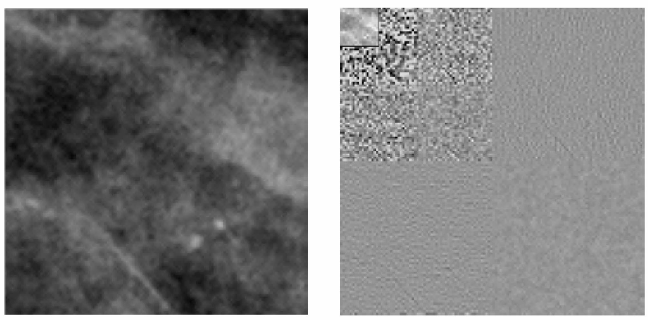
This paper is organized as follows. In Section II the contrast enhancement procedure is explained and contrast enhancement results are shown. Section III presents a method for detection of areas which contain microcalcifications. Section IV draws the conclusion.

II. CONTRAST ENHANCEMENT OF MICROCALCIFICATIONS

The image contrast enhancement method which we have chosen consists of the discrete wavelet transform (DWT), subband filtering and grayscale morphology. To be able to extract objects of an expected dimension it is necessary to know the spatial resolution of the observed image. Therefore it is important to adapt the algorithm to different image sources. Mammograms are currently being captured with spatial resolutions of 50 μm/pixel to 80 μm/pixel. By knowing the spatial resolution it is possible to determine the expected size of each individual microcalcification which proves to be around 5×5 pixels from (1):

$$D_{\mathrm{p}} = \frac{D_{\mathrm{s}}}{R_{\mathrm{M}}}, \tag{1}$$

where D_{p} is the diameter of the microcalcification in pixels, D_{s} is the actual diameter of the microcalcification in μm and R_{M} is the spatial resolution of the mammogram. Usage of the DWT provides decomposition of an image into frequency subbands while maintaining knowledge of the spatial position of objects in the image, in this particular case of microcalcifications. By using the DWT it is possible to suppress certain objects which correspond to a group of frequencies in a subband. This property gives us the possibility to remove background objects that usually have lower spatial frequencies. The method which we propose uses a wavelet decomposition of the third or fourth level using Coiflet wavelet designed by Ingrid Daubechies which allows decomposition of up to 7th level on a patch with dimensions of 128×128 pixels. This dimension of a patch gives a good compromise between the number of computations needed and preservation of details on which size of the patch influences while maintaining patch size of 2^n. By decomposing images up to third level, the approximation or low frequency subband contains only 1/8 of the original frequency band, meaning that all objects smaller than 16 pixels are not contained in the approximation band if the image size is 128×128 pixels. Example of the third level decomposing with the corresponding subbands for a patch containing microcalcifications is shown in fig. 1.



(a) (b)

Figure 1. (a) Original patch containing calcifications; (b) Third level wavelet decomposition of the same patch.

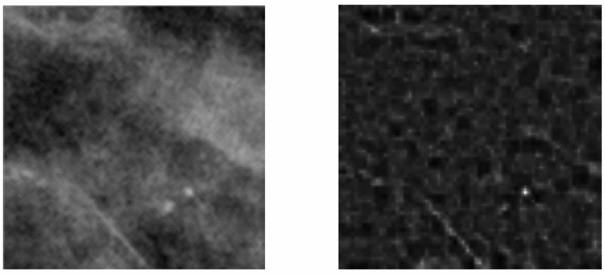
From fig. 1 it is visible that different decomposition subbands contain different details regarding to their spatial frequencies and therefore it is possible to remove subbands which contain objects that are of different dimension than the expected dimension of microcalcifications. Since we want to keep only objects with size of around 5×5 pixels it is necessary to choose the frequency band sensitive to objects having corresponding spatial frequencies. To achieve that we have chosen to remove the first level detail as well as the approximation subband. Removing the approximation image will result in suppression of uneven background caused by intensity variations due to different tissue type in the projection. Fig. 2 shows the reconstructed patch with removed approximation coefficients and first level details.

Figure 2. Reconstructed patch with removed approximation and first level details.

After filtering by removing frequency subbands containing information about objects which are not suitable candidates to be microcalcifications we used grayscale morphology operator. A structuring element needs to be similar in size to microcalcification which we want to emphasize. Therefore we have chosen our structuring element to be a square with dimensions of 5×5 pixels. The morphological closing allows further background suppression and gives a possibility to increase the contrast of microcalcifications in combination with the original image. To achieve higher contrast of bright pixels against the dark background, we used simple multiplication operation:

$$X = A * (A \bullet B), \tag{2}$$

where X represents output image of element by element multiplication of input image A with the same image A closed by the structuring element B.



(a) (b)

Figure 3. (a) Original patch containing calcifications; (b) Same patch after element by element multiplication of reconstructed patch and morphologically closed patch.

The result of this multiplication is contrast enhancement of the original patch which is shown in fig. 3. The gain in contrast between the original and the enhanced image is thoroughly described in [13].

III. Detection of Microcalcifications

In order to detect areas which contain microcalcifications we used a scheme of partially overlapped patches in order to create a system which gives less FN results of detection. The overlapping scheme provided by 50% overlapping of neighboring patches results in different number of overlaps, as shown in fig. 4, where numbers in boxes represent the number of region overlaps while each individual patch has size of four squares in the overlapping scheme shown in fig. 4.

The detection process relies on a proper choice of the decomposition level and a choice of subbands for the reconstruction. Different scenarios can occur in the detection process and the proper choice of the decomposition level also needs to be chosen based on some criterion from the binary images after applying a threshold. For the threshold we have empirically chosen the value which corresponds to 75% of the maximal intensity in the reconstructed image. This value is not always optimal but there is a need for a fixed threshold to be able to perform decision making based on the number of segmented pixels which are potential microcalcification candidates. In fig. 5 we can see results of thresholding at 75% two images which are obtained by three or four levels of wavelet decomposition, subband removal and reconstruction.

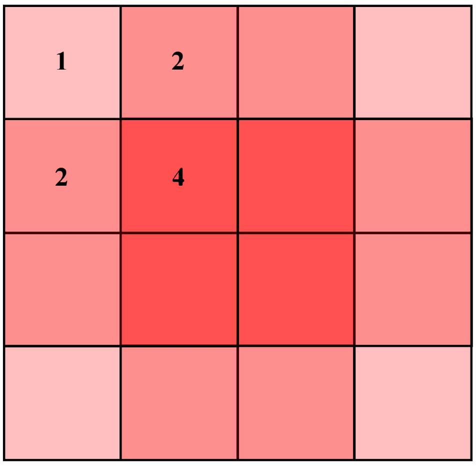
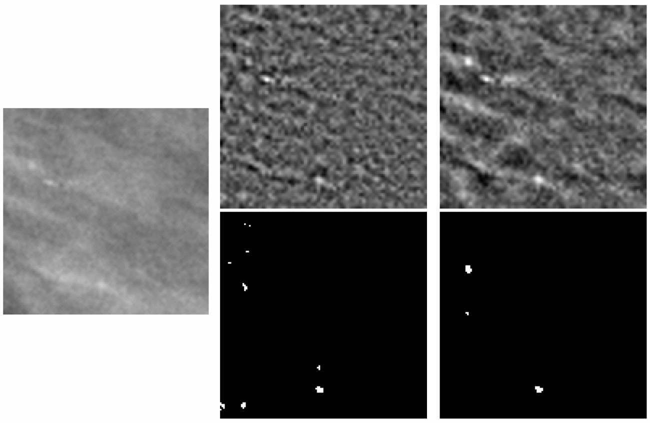


Figure 4. Overlapping of patches which results in four region overlaps for the patches which are not around the image border and eliminates FN results.

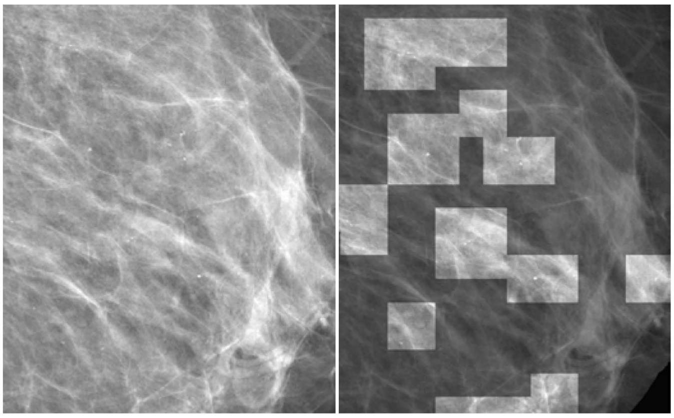
From fig. 5 it is visible that for the low contrast microcalcifications four-level decomposition provides better results after thresholding. In order to test the efficiency of the proposed method we have chosen a database which consists of digital mammograms all of the same size and captured using the same capturing device.



(a) (b) (c)

Figure 5. (a) Patch containing low contrast microcalcifications; (b) Result of third level decomposition and reconstruction after subband removal; (c) Result of fourth level decomposition and reconstruction after subband removal.

Mammograms used in the testing process have dimensions of 4084×3328 pixels with effective 10 bits per pixel and are part of the KBD-FER database. Patch size which we are using for these mammograms is 128×128 pixels and proves to be a good compromise between the number of computations needed and preservation of details on which size of the patch influences. Fig. 6 (a) shows example of a fibroglandular disc containing many regions which contain microcalcification and (b) shows automatically detected areas using the proposed method.



(a) (b)

Figure 6. (a) Fibroglandular disc containing microcalcifications; (b) Automatically detected regions which contain microcalcifications.

The proposed method was tested on the KBD-FER database containing, 144 mammograms and resulted in 84% of successfully detected areas which contain microcalcifications with the average of two FP areas per image, which mostly originated from small but x-ray dense blood vessels.

IV. Conclusion

In this paper we have presented a method for contrast enhancement of microcalcifications and detection of areas which contain microcalcifications in mammograms. The proposed method uses a combination of subband filtering using wavelet decomposition of the third and fourth level, thresholding and binary morphological filtering. The proposed method was tested on a set of 144 digital mammograms captured using the same device and resulted in 84% of correctly detected areas per image with the average of two FP detected areas.

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