MICROCALCIFICATION SEGMENTATION AND MAMMOGRAM IMAGE ENHANCEMENT USING NONLINEAR FILTERING

Metin Nafi Gürcan, Yasemin Yardımcı, A. Enis Çetin

Bilkent University
Department of Electrical and Electronics Engineering
Bilkent, Ankara, Turkey
gurcan@ee.bilkent.edu.tr

ABSTRACT

Microcalcifications are tiny calcium deposits in breast tissues. They appear as small bright spots on mammograms. Since microcalcifications are small and subtle abnormalities, they may be overlooked by an examining radiologist. In this work, we propose microcalcification segmentation and mammogram enhancement methods based on nonlinear subband decomposition structures and outlier detection. The mammogram image is first processed by a nonlinear filter bank, then the locations of the outliers are determined by outlier labeling method. The proposed method can also be used in the three-dimensional reconstruction of microcalcification clusters. Simulation studies are presented.

1. INTRODUCTION

Breast cancer is one of the most deadly diseases for middle-aged women. One out of eight women is prone to this disease in her lifetime [1]. The success of treatment depends on early detection. Breast cancer detection on mammograms (X-ray images of breasts) is currently carried out by radiologists who examine mammograms with a magnifying glass to find out tumors such as microcalcifications, masses, and stellate lesions [2].

Clustered microcalcifications are observed between 30% and 50% of breast cancer cases [3]. Microcalcifications are tiny calcium deposits in breast parenchymal tissue structures, which appear as small bright spots on mammograms. Since microcalcifications are small and subtle abnormalities, they may be overlooked by an examining radiologist. For instance, retrospective studies indicate that between 10%-30% of the undetected breast cancers are actually visible on mammograms [4]. Therefore, computer-aided diagnosis is an important research area [5].

In microcalcification detection schemes, parts of mammogram image with microcalcifications are marked as suspicious regions. Within these marked regions, individual microcalcifications can be segmented through further processing. The shape and exact extent of segmented microcalcifications can provide valuable information to radiologists in their diagnosis and classification of the abnormalities as benign or malignant. They can also be used in three dimensional reconstruction of microcalcifications within the breast structure [6].

Individual microcalcifications can be segmented in a two-stage process. The first stage is removal of the breast structure corresponding to the healthy tissues. The second stage is statistical outlier detection. Bandpass filtering, nonlinear 'subband' decomposition, adaptive filtering, and adaptive filtering based subband decomposition can be used to remove the underlying breast structure from mammogram images [5]. After this step, the remaining detail image mainly contains microcalcifications as well as some additional noise. Because of their impulsive characteristics on mammograms, microcalcifications will produce outliers in this detail image. Therefore, an outlier detection method can single out these abnormalities. Finally, segmented microcalcifications can be combined with the original mammogram image to get visually enhanced mammogram images. Ffrench et al. observe that adaptive filtering enhances the mammogram images by predicting the breast tissue and leaving the small microcalcifications in the error image [7].

In Section 2, nonlinear filtering based microcalcification segmentation is introduced. Mammogram image enhancement is presented in Section 3.

2. MICROCALCIFICATION SEGMENTATION USING NONLINEAR FILTERING

Nonlinear filters such as median type filters have been previously used for the detection of microcalcifications by Chan et.al. [4]. In their work, the effects of lin-

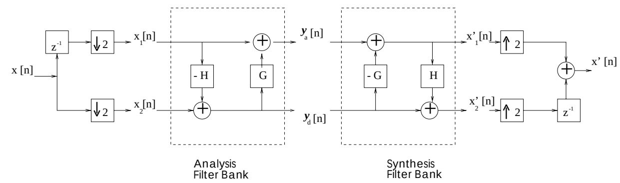

Figure 1: Nonlinear Subband Decomposition Structure.

ear and nonlinear filters and their Region of Support (ROS) on the detection and enhancement of microcalcifications are investigated. A median filter with a 9×9 support is found to be most effective on mammogram images with simulated microcalcifications in [4]. However, such a median filter cannot be effective in eliminating all of the microcalcifications on the mammogram images in every database [5].

2.1. Nonlinear Subband Decomposition

Recently, the 'subband' decomposition using nonlinear filters have been proposed and used in image coding [8]–[9]. We also investigate the use of nonlinear filters and filterbanks in the analysis of mammogram images, microcalcification segmentation and mammogram image enhancement.

Figure 1 shows the block diagram of the nonlinear subband decomposition structure used by Hampson and Pesquet [9]. This structure is based on the lifting scheme of Sweldens [10]. It is obtained by replacing linear filters of the lifting filter bank by nonlinear operators H and G. The approximate signal y_a, and the detail signal y_d are obtained from the input signal $x[n]$ as follows [9]:

$$\begin{aligned} y_a[n] &= x_1[n] + G(y_d)[n] \\ y_d[n] &= x_2[n] - H(x_1)[n] \end{aligned} \tag{1}$$

where $x_1[n] = x[2n-1]$, $x_2[n] = x[2n]$ which are the odd and even samples of the input $x[n]$, respectively.

The corresponding synthesis equations are:

$$\begin{aligned} x'_1[n] &= y_a[n] - G(y_d)[n] \\ x'_2[n] &= y_d[n] + H(x'_1)[n] \end{aligned} \tag{2}$$

In this structure, perfect reconstruction is achieved as $x'_1[n] = x_1[n] + G(y_d)[n] - G(y_d)[n]$ and $x'_2[n]$ turn out to be odd and even samples of the original signal, $x[n]$, respectively.

In the mammogram image analysis, H is chosen as a median filter. A median filter eliminates impulsive

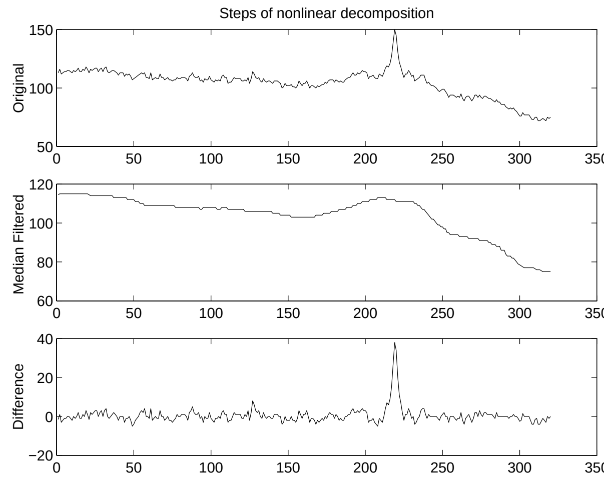

Figure 2: Median filter based nonlinear processing (a) A line extracted from the mammogram image (b) the median filter output (c) the difference between the signals in (a) and (b).

type structures in an image. As microcalcifications exhibit impulsive character, a median filter with suitable ROS can eliminate these abnormalities from the mammogram image. The detail signal, $y_d[n]$ in Equation 1 is obtained by subtracting the median filtered image from the original image. Therefore, we expect that mainly microcalcifications are observed in $y_d[n]$. The nonlinear operator G will be chosen as the outlier detection scheme, which is discussed in Section 2.2.

Figure 2 shows the outputs at different stages of the nonlinear processing. Figure 2 (a) illustrates an original line of mammogram image which contains a microcalcification. Figure 2 (b) shows the same line of image after median type nonlinear filtering. Most of the noise as well as microcalcifications are not present in the output. As can be observed in this figure, the output of the median filter mainly represents the relatively smooth part of the mammogram image corresponding to the normal breast tissue. Figure 2 (c) displays the difference between the original line of image and the median filter output. In the difference image mainly the microcalcification is observed.

There are different approaches to remove the underlying breast structure from mammogram images [5]. Figure 3 (a) shows the a line of mammogram image. All the other images are the detail images which are obtained by bandpass filtering in Figure 3 (b), adaptive filtering in Figure 3 (c), nonlinear subband decomposition in Figure 3 (d) and adaptive filtering based subband decomposition in Figure 3 (e). It can be observed from these figures that the detail images are similar and they produce high values at the locations

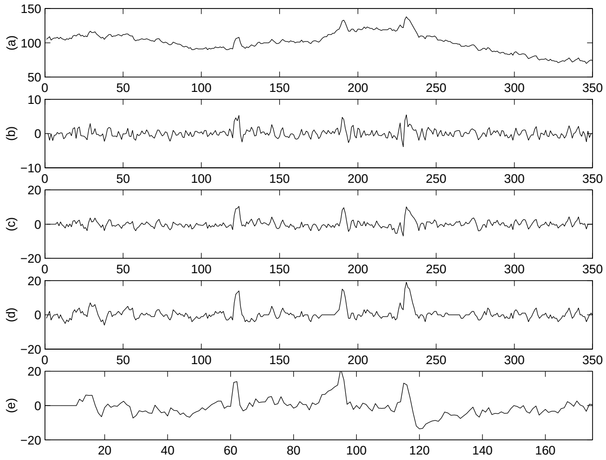

Figure 3: Comparison of detail images produced by different breast structure removal operations. (a) Original line of mammogram image, (b) bandpass filtering, (c) adaptive filtering, (d) nonlinear subband decomposition (e) adaptive filtering based subband decomposition.

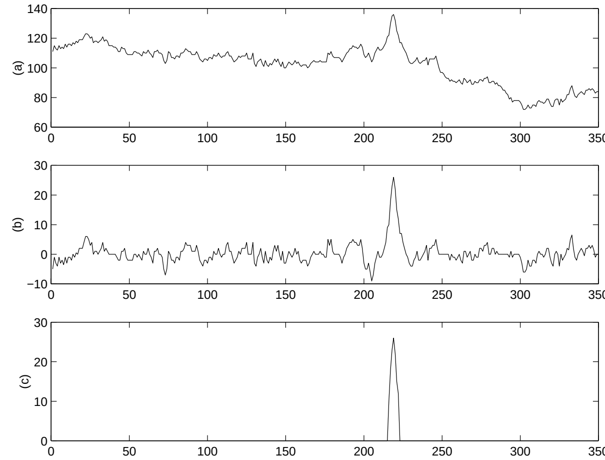

Figure 4: Microcalcification segmentation using outlier detection: (a) A horizontal line of the mammogram image which is known to contain a microcalcification, (b) high-band sub-signal x_h, (c) output of the outlier detection method.

of microcalcifications. The number of samples in the detail image Figure 3 (e) is half of those of the other detail images because of downsampling operation in the decomposition structure. However, downsampling operation can eliminate some of small microcalcifications if the resolution of the scanner is not high enough.

The nonlinear subband decomposition structure illustrated in Figure 1 can be extended to two dimensions in a straightforward manner [8, 11]. In two dimensions, the detail image, $y_d[m,n]$ is obtained by simply subtracting the median filtered image from the original image. In this detail image higher order statistical based microcalcification detection can be carried out [12].

The detail image is further processed by the nonlinear operator G to segment individual microcalcifications. We chose G as a statistical outlier detection scheme because individual microcalcifications appear as outliers in the detail image. Section 2.2 discusses the use of boxplot outlier labeling method in microcalcification segmentation.

2.2. Boxplot Outlier Labeling Method

An outlier is "an observation (or subset of observations) which appears to be inconsistent with the remainder of that set of data [13]." Therefore, the microcalcification segmentation problem is equivalent to outlier detection in the detail subimage. Generally, due to the random nature of data, identifying and handling individual outliers is not an easy task. Nevertheless, there are numerous techniques available to detect and handle outlier locations [14]. In this work, we used the boxplot outlier labeling method [14] which is available in most of the statistical software packages.

Figure 4 (a) shows a horizontal line of mammogram image which is known to contain a microcalcification. Figure 4 (b) depicts the difference between the original signal and its median filtered version. This difference plot corresponds to the detail signal of the nonlinear decomposition structure. The boxplot outlier labeling method is applied to this detail signal. Figure 4 (c) illustrates the output of the outlier detection scheme. Similar results are also obtained in two dimensions [5].

The output of the boxplot outlier detection method produce the segmented microcalcifications. The output can either be used in the three–dimensional reconstruction or in mammogram image enhancement which is discussed in the next section.

3. MAMMOGRAM IMAGE ENHANCEMENT

It is desired that segmented microcalcifications be readily noticeable in an enhanced version of the original mammogram image. Therefore, the output of the microcalcification segmentation is combined with the original mammogram image to get an enhanced version of the mammogram. We propose three different approaches: superposition, amplification and nonlinear subband decomposition based enhancement. In this section superposition and amplification based enhancement schemes are considered. The use of nonlinear subband decomposition structures in mammogram image

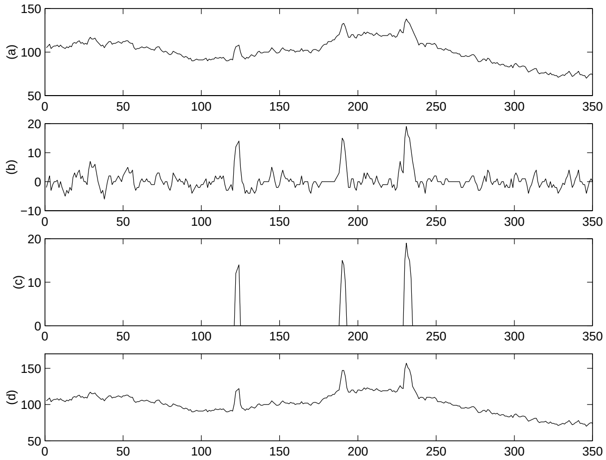

Figure 5: Superposition based mammogram image enhancement: (a) A horizontal line of the mammogram image, (b) the detail signal, $y_d[n]$ obtained by nonlinear subband decomposition, (c) output of the outlier detection method, (d) microcalcifications are enhanced by superposition.

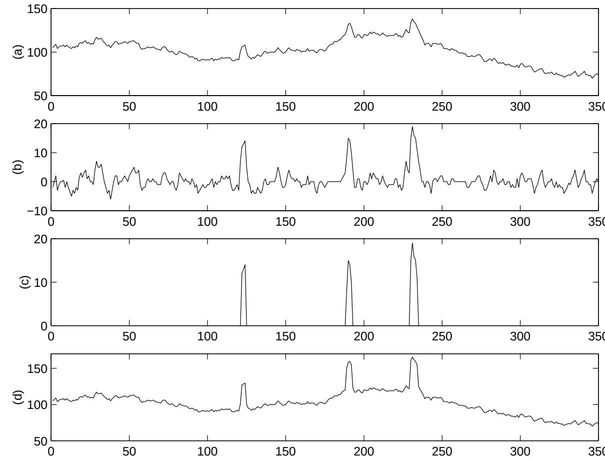

Figure 6: Amplification based mammogram image enhancement: (a) A horizontal line of the mammogram image, (b) the detail signal, $y_d[n]$ obtained by nonlinear subband decomposition, (c) output of the outlier detection method, (d) microcalcifications are enhanced by amplification.

enhancement is discussed in [12].

In the superposition approach, segmented microcalcifications are superimposed to the original mammogram image at the locations of microcalcifications. In the amplification based approach, the original mammogram image pixel values are weighted by a fixed weight, again at the locations of microcalcifications.

Figure 5 illustrates the steps of superposition based mammogram image enhancement on a horizontal line of a mammogram image. In particular, Figure 5 (a) depicts the original line of a mammogram image which is known to contain three microcalcifications. The difference between the original signal and its median filtered version is shown in Figure 5 (b). This difference plot corresponds to the detail–signal, $y_d[n]$, of the nonlinear decomposition structure. Figure 5 (c) illustrates the output of the outlier detection scheme. Three microcalcifications are successfully segmented. The microcalcifications are more visible in Figure 5 (d). Similarly, the mammogram image enhancement by amplification is shown in Figure 6. The amplification weight it 20%.

In case enhancement of the tissue around the microcalcification regions is also desired, the final image can be displayed after scaling so that the full dynamic range of the display device is employed. This operation is called contrast stretching [5].

Figure 7 illustrates the effects of the two different enhancement operations on a part of a mammogram image shown in Figure 7 (a). In Figure 7 (b) the contrast stretching operation is applied to the original image. In this picture both the microcalcifications and the background structure is enhanced. Therefore, the visibility of the microcalcifications is slightly better. In Figures 7 (c) and (d) superposition and magnification based enhancement operation results are shown, respectively. In both figures the visibility of microcalcifications is significantly improved.

4. CONCLUSION

In this paper, we present nonlinear subband decomposition based microcalcification segmentation and mammogram image enhancement methods. Experimental studies on mammogram images indicate that these methods can be used as diagnostic tools in breast cancer detection.

In the segmentation and enhancement processes nonlinear operations with relatively high computational costs can be used while keeping the overall computational complexity of the system low. Because, only suspicious regions are considered rather than processing the entire image for segmentation and enhancement. Future work will concentrate on developing similar segmentation and mammogram image enhancement methods for other breast cancer indicators, mass lesions and stellate lesions.

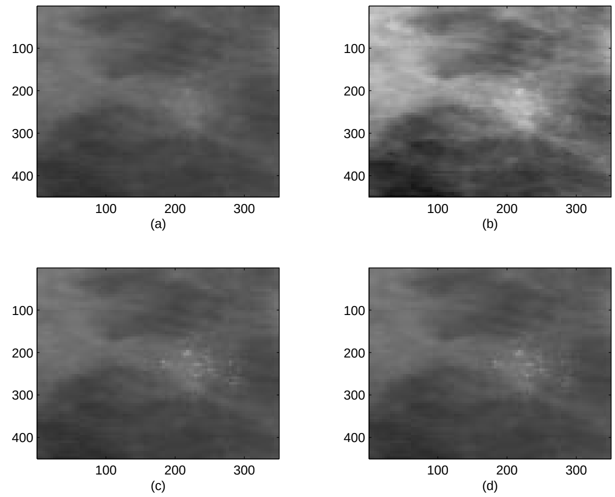

Figure 7: Results of mammogram image enhancement: (a) Part of a mammogram image to be enhanced (b) Output of the contrast stretching operation (c) Superposition based enhancement (d) Magnification based enhancement.

5. REFERENCES

[1] H. Chan, S. B. Lo, B. Sahiner, K. L. Lam, and M. A. Helvie, "Computer-aided detection of mammographic microcalcifications: Pattern Recognition with artificial neural network," Med. Phys., vol. 22, no. 10, October 1995.

[2] T. O. Gulsrud and S. Kjode, "Optimal filter for detection of stellate lesions and circumscribed masses in mammograms," SPIE Visual Communications and Image Processing'96, Orlando, Florida, vol. I, pp. 430-440, 17-20 March, 1996.

[3] R. N. Strickland and H. I. Hahn, "Wavelet Transforms for Detecting Microcalcifications in Mammograms," IEEE Trans. on Medical Imaging, vol. 15, no. 2, pp. 218-229, April 1996.

[4] H. Chan, K. Doi, S. Galhotra, C. J. Vyborny, H. MacMahon, and P. Jokich, "Image feature analysis and computer-aided diagnosis in digital radiography, I. Automated detection of microcalcifications in mammography," Medical Physics, pp. 538-547, vol. 14, no. 4, Jul/Aug 1987.

[5] M. N. Gürcan, Computer-Aided Diagnosis in Radiology, PhD. Thesis, Department of Electrical and Electronics Engineering, Bilkent University, Ankara, Turkey, 1999.

[6] T. Müller, R. Stotzka, W. Eppler, and H. Gemmeke, "Three-dimensional reconstruction of clustered microcalcifications," Proceedings of Computer Assisted Radiology (CAR) 98, 1998, Tokyo, Japan.

[7] P. A. Ffrench, J. R. Zeidler, and W. H. Ku, "Enhanced Detectability of Small Objects in Correlated Clutter Using and Improved 2-D Adaptive Lattice Algorithm," IEEE Transactions on Image Processing, vol. 6, no. 3, pp. 383-397, March 1997.

[8] O. Egger and M. Kunt, "Embedded Zerotree Based Lossless Image Coding," IEEE ICIP'95, vol. II pp. 616-619., June 1995.

[9] F. J. Hampson and J. C. Pesquet, "A Nonlinear Subband Decomposition with Perfect Reconstruction," in Proc. of IEEE Int. Conf. on Acoust., Speech, Signal Proc., 1996.

[10] W. Sweldens, "Wavelets and the lifting scheme: A 5 minute tour," Zeitschrift für Angewandte Mathematik und Mechanik, vol. 76 (Suppl. 2), pp. 41-44, 1996.

[11] D. E. F. Florencio, and R. Schafer "Perfect Reconstructing Nonlinear Filter Banks," in Proc. of IEEE Int. Conf. on Acoust., Speech, Signal Proc., 1996.

[12] M. N. Gürcan, Y. Yardımcı, and A. E. Çetin and R. Ansari, "Detection of microcalcifications in mammograms using nonlinear subband decomposition and outlier labeling," in Proceedings of SPIE Visual Communications and Image Processing Conference, pp. 909-918, 8-14 February, 1997, San Jose, CA.

[13] Y. Barnett and T. Lewis, Outliers in Statistical Data, 3rd Ed. New York: John Wiley & Sons, 1994.

[14] B. Iglewicz and D. C. Hoaglin, How to Detect and Handle Outliers, ASQC basic references in quality control; v.16, 1993.

[15] I. Pitas and A. N. Venetsanopoulos, Nonlinear Digital Filters - Principles and Applications, Massachusetts: Kluwer Academic Publishers, 1990.

[16] E. R. Dougherty and J. Astola, An Introduction to Nonlinear Image Processing, SPIE Optical Engineering Presss, vol. TT 16, Washington, 1994.