Detection of Microcalcifications by Means of Multiscale Methods and Statistical Techniques

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The detection of clustered microcalcifications can help the radiologist to detect early breast cancer. Microcalcifications exhibit some important characteristics, such as small size and high luminosity. Use of a computer-aided diagnosis (CAD) method can prevent them being overlooked. In this report, a multiresolution analysis is performed based on a multilevel wavelet transformation. Decomposition produces sub-band images which become visible only as details of the different scales. Thereafter, all the images will be combined in a final image, in order to obtain an image that contains all the interest details at the scale where microcalcifications tend to appear. Once the image, called detail image, is obtained, it is necessary to determine which details correspond with microcalcifications. Statistical analysis of the histogram permits classification of the zones likely to contain microcalcifications. Applying this statistical techniques over the whole image and representing the results in a two-dimensional map, clustered microcalcification regions are clearly distinguishable.

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THE DETECTION of clustered microcalcifications can help radiologists to detect early breast cancer. However, determining their location is difficult due to their small size: 0.05 to 1 mm diameter.¹ If we add the convenience of detecting these anomalies when microcalcifications present a small size, a computer-aided diagnosis (CAD) method can be useful to avoid them being overlooked. Microcalcifications exhibit some important characteristics, such as small size and high luminosity, which have resulted several recognition techniques that attempt to find small high-luminosity details. Nevertheless, problems are encountered due to the similarity with background. Furthermore, individual microcalcifications are of no clinical interest for the radiologist, unless there are several of them close to each other or clustered. We adopted the detection criteria proposed by Karssemeijer,² namely, that a cluster is considered detected if two or more microcalcifications are found in the region identified by the radiologist. The objective is to find regions where microcalcifications of different sizes appear.

In fact, clustered microcalcifications may appear in bright zones of the mammogram, where the difference of luminosity between microcalcifications and its neighbors is negligible. Furthermore,

the size and shape of microcalcifications are variable; therefore, elements that must be encountered have different sizes.

Several techniques have been developed for detection of clusters based on textures analysis,³ spatial filtering of the mammography,^{4,5} and wavelet transform,⁶ all of which have the objective of showing detailed information from the mammography, that is, sharply and located variations in luminosity.

In this report, a multiscale analysis is proposed to decompose the image through a multilevel wavelet transform, so that in each sub-band image become visible only the details at the given scale. Images obtained will be combined in a final one in order to obtain an image that contains all the details of interest at the scale where microcalcifications tend to appear. Once the image is obtained, it is necessary to determine which details correspond to microcalcifications. Statistical analysis of the histogram⁷ permits classification of the zones likely to contain microcalcifications.

PREPROCESSING AND ENHANCING OF THE IMAGE

Clustered microcalcifications appear as small, white, highly-luminous groups of spots that generally appear to have irregular forms on a variable luminosity and fibrous texture background. Microcalcifications that appear on dark backgrounds are easier to detect because of the notable difference in luminosity between the sought object and the background. When clusters appear on a clear background, detection is more difficult; therefore, it is convenient to enhance the mammogram before decomposition. This preprocessing of the image is accomplished in two phases: (1) linear expansion of the luminosity ranges of the mammogram, so that a contrast-enhanced image is obtained; and (2)

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nonlinear modification of the luminosity, so that high-luminosity zones are expanded in contrast (differences between clear background and clusters will be emphasized), in detriment of the dark zones (where differences were clearly visible).

Modifications in mammograms can be observed in Fig 1, where initial enhancement has been applied to the image.

WAVELET DECOMPOSITION

To achieve the detection of clusters, the different microcalcifications that compose it, must be located. Because they exhibit several sizes, searching at a given scale implies that microcalcifications of different sizes will be disregarded.

Other components that appear in the mammogram are elongated forms (due to breast tissue characteristics), which appear as high-luminosity linear structures. These elements can be mistaken for clustered microcalcifications with linear appearance.

Multilevel Wavelet Decomposition

The reader is assumed to be familiar with two-dimensional sub-band decomposition and

wavelet transform. For an introduction and image application, refer to Mallat⁸ and Prasad and Iyengar.⁹ The original image is processed in a filter bank, so four subbands images are provided: one approximation image (low-low, [LL]) and three of details (Horizontal high-low [HL], vertical low-high [LH], and diagonal high-high [HH]). This process can be repeated for the approximation sub-band (or detail sub-bands), so that new approximation and detail bands will appear. A biorthogonal wavelet (Biorthogonal 3.7) is used due to the linearity phase, and a three-level decomposition depth is performed.

Inverse wavelet transformation is performed to obtain images where only details appear, in a similar way to the undecimated wavelet transformation.⁶ In this way, LH, HL, and HH subbands at full size are obtained at each level of decomposition, which correspond with horizontal, vertical, and diagonal details. Preserving the size of the images is an important feature for combination of the images obtained.

Detailed Image Generation

The final objective of the wavelet decomposition process is an image containing details at a given scale, by combining the vertical, horizontal, and diagonal detail bands (or images). As described by Strickland,⁶ the sum of all the detail bands gives an image containing small elements detected in each direction. However, this assembly has the problem of locating small details (ie, microcalcifications) or objects that have a small size in only one direction, which would be treated as linear structures. Microcalcifications are objects with small size in all directions. So, the image we are interested in would be an image in which detail elements appear in at least in two directions. In this way, the detail image obtained is likely to contain clustered microcalcifications. Figure 2 shows images of details in the three directions and the result of their combination.

Obtaining a Multiscale Details Image

Individual images containing details at a specific scale must be combined in order to obtain a new all-sizes details image.

Since clusters used to present a set of microcalcifications with different sizes, only sections in mammograms containing small detail elements at different scales simultaneously should be considered as real clustered microcalcifications. Isolated

Fig 1. Original mammogram and enhanced images with linear and no linear procedures. Preprocessing phase.

Fig 2. Sub-bands LH (low-high), HL (high-low), and HH (high-high) decomposition at one specific scale. A cluster of microcalcification is clearly visible in the final combination of the 3 details images. Decomposition phase.

microcalcifications are not of clinical interest and provide no information for the detection of breast cancer.

Before combining the images, a nonlinear contrast modification is performed at each scale with a double objective:

- (1) A weight equalization of the details at different levels or scales, because the small size details appear with lower amplitude than the greater size elements. In this way, different level details will have the same quantitative contribution in the final image.
- (2) Microcalcifications poorly distinguishable from background (which will appear with a low amplitude in its detail image) would be hidden by a bright and differentiated one. So, an inverse process achieved in the preprocessing phase will be performed: the amplitude increase of the lower weighted areas, thus emphasizing the low-luminosity details that could have been masked.

Once detail images of comparable magnitude are obtained at the different scales, a linear combination between them is accomplished, so that the resulting image contains not only the contribution of all the details elements at different scales, but also zones with similar size detail objects.

CLUSTERED MICROCALCIFICATIONS DETECTION USING STATISTICAL ANALYSIS

Studies by Gürçan et al.⁷ on histogram characterization of images with or without microcalcifications led to the conclusion that there is an asymmetry in zones with clusters, while no asymmetry can be detected when no microcalcifications are present. Moreover, regions within microcalcifications could be approximated by a gaussian distribution, so that a gaussian test indicates regions of the mammogram likely to contain clusters. The gaussianity test used¹⁰ estimates the first three moments, so that values close to zero indicate a gaussian-distributed sequence. The gaussian test is performed as follows:

$$\left. \begin{aligned} I_1 &= \frac{1}{N \times M} \sum_{i=1}^M \sum_{j=1}^N e[i, j] \\ I_2 &= \frac{1}{N \times M} \sum_{i=1}^M \sum_{j=1}^N e^2[i, j] \\ I_3 &= \frac{1}{N \times M} \sum_{i=1}^M \sum_{j=1}^N e^3[i, j] \end{aligned} \right\}$$

$$\Rightarrow h(I_1, I_2, I_3) = I_3 - 3I_1(I_2 - I_1^2) - I_1^3$$

Fig 3. Two regions of the global detail image and the result of the gaussian test. No microcalcification region exhibits lower values than microcalcification region. Analysis phase.

where $e[i, j]$ are values at locations (i, j) in detail images of the total of $N \times M$ pixels, and h is the value that indicates how much nearby the sequence from a gaussian distribution is.

In Fig 3, two regions of the global detail image (for regions with and without microcalcifications) and the gaussian test obtained for each one are presented. It can be observed how the region with no microcalcifications exhibits a much lower value than the region containing microcalcifications. Ap-

plying this gaussian test over the whole image and representing the results in a two-dimensional map, regions of clustered microcalcifications are clearly distinguishable.

RESULTS

In Fig 4, the graphical summary of the results obtained in the work is presented. Taking a mammogram represented in the Fig 4A, it is submitted to

Fig 4. Graphical summary of the results. The original mammogram (A) and global details image, containing microcalcifications at all the scales considered (B). A new image (the original and detail images superposed) is shown in (C). Finally, a gaussian map shows clusters detected (D).

the multiscale analysis processes, and a final image is obtained as result (Fig 4B) that contains all of the details at different scales, which probably correspond to a clustered microcalcification. In Fig 4C, the original image is combined with the details

image, to emphasize susceptible clustered region, which are superimposed. Finally, applying the gaussian test, the microcalcification detection process is automated, and the zones with microcalcifications are apparent in Fig 4D.

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