

Optimal Second-Order Texture Descriptors for Automatic Breast Tumor Segmentations in Ultrasound Images

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Abstract

Texture descriptors have been widely used in order to improve the results of automatic breast tumor segmentations in ultrasound images. In this work we present a comprehensive evaluation of the ability of different texture descriptors to enhance the contrast between breast tumors and the surrounding tissue in ultrasound images, and how they affect the outcome in automatic segmentations. We evaluated the main second-order descriptors extracted from the analysis of co-occurrence and run-length matrices. The contrast between the tumor region and the surrounding tissue was evaluated using contrast to noise ratio and histogram intersection between the tumor and surrounding tissue histograms. Also the ability to preserve borders was evaluated for each descriptor using the edge preserving index. We have implemented a probabilistic segmentation method in order to evaluate the changes in the accuracy, sensitivity and specificity of the method when using different texture descriptors. The results have shown that the Short Run Emphasis of the run-length matrix has better results in the automatic segmentation of breast tumors in ultrasound images with values of 91.96%, 88.58% and 95.99% respectively; this texture descriptor also showed higher values in the contrast indexes.

Introduction

Since breast cancer has become the number one cause of death among women around the world, it is very important to have fast, safe and accurate diagnostic methods to improve the prognosis of a patient¹. Although biopsy is the gold standard for cancer diagnosis, minimally invasive methods are preferred in order to reduce further complications. Mammography and ultrasound are the two main medical imaging modalities for breast tumor screening; while mammography has a high sensitivity in the detection of microcalcifications, ultrasound is able to detect tumors in dense breast tissue (usually found in young women) with higher sensitivity than mammography². Young women have low incidence rates of breast cancer, however, cancer incidence increases at a faster rate with increasing age in young women and their tumors tend to be larger and with a higher grade of malignancy and poorer prognostic characteristics,

making ultrasound necessary as a coadjuvant technique in breast screening³. Currently, ultrasound is responsible for about one in five of all image based diagnosis⁴. Several diagnostic methods using ultrasound images have been proposed for the diagnosis and classification of breast tumors. In breast ultrasound images, the malignity of a tumor is estimated by the expert ultrasonographer mainly from its shape, echogenicity (which is an indicator of tumor density) and the internal echo pattern (which describes the texture of the tumor), but the visualization of lesions in ultrasound breast images is a difficult task due to some intrinsic characteristics of the images like speckle, acoustic shadows, and blurry edges⁵. Accurate automatic segmentation methods of breast tumors can help the experts to achieve faster diagnoses, and it's a key stage of fully automatic systems for breast cancer diagnosis using ultrasound images⁶.

Texture analysis refers to the characterization of regions in an image according to their texture content, quantifying intuitive qualities described as roughness, smoothness, silkiness and bumpiness⁷. In ultrasound images echo patterns are generally referred as textures⁸. A good breast tumor segmentation method in ultrasound images should take into account texture features in order to differentiate tumors from other objects with similar gray intensities, like glandular tissue and acoustic shadows⁹; however, texture analysis in ultrasound images is not an easy task and many metrics have been used to describe the echo patterns in breast tumors. Several automatic and semi-automatic segmentation methods using pixel intensity along with texture information have been proposed⁹. Some of these methods use first-order texture descriptors obtained from histogram statistics^{9,10}, but these descriptors are not able to give a good texture description because they do not take into account the spatial relation between pixels and gray-levels¹¹; because of this, other proposed methods use second-order texture descriptors extracted from co-occurrence matrices statistics¹², but the computational cost for computing the co-occurrence matrix is very high and much more demanding while working in per-pixel computation¹³. Other texture descriptors extracted from run-length matrices statistics (which have lower computational cost than co-occurrence matrices) have been used for breast tumor classification in ultrasound images with good results¹⁴.

Texture is a rich source of visual information and there are a number of methods for texture representation, but it is difficult to define the properties than can be used to effectively distinguish textures found in a given image¹⁵. On the other hand, image enhancement is a key factor to improve the visual appearance of an image and make it more pleasant for human interpretation or more applicable in some special fields such as computer vision and image processing^{16,17}. Because of this, it is important to evaluate which texture descriptor is the one that enhances the contrast of the images the most, and how this improves the outcome of an automatic segmentation method. Except for the work done by Liao et al⁸, where they compare the ability of different texture descriptors extracted from co-occurrence matrices statistics to enhance the contrast between the tumor region and the surrounding tissue and how this affects the results of manual and automatic segmentations, there is no related work that evaluates different descriptors extracted from different second order statistics. In this work we present a comprehensive and extensive evaluation of the effects of texture descriptors (extracted from co-occurrence matrices statistics and run-length matrices statistics) on the contrast between the tumor region and the surrounding tissue in breast ultrasound images and how this improves the results for an automatic segmentation algorithm. To evaluate the ability of these descriptors to enhance the contrast we obtained different texture images, using per-pixel computation with each texture descriptor, and compare the contrast to noise ratio, histogram intersection between the tumor region and the

surrounding tissue histograms and the ability to preserve the edges of the tumor. We have also evaluated the ability of these descriptors to improve the segmentation results; we implemented an automatic probabilistic segmentation method based on the work of Madabhushi et al⁹ and compared the accuracy, sensitivity and specificity of the method when using different texture descriptors. We have found that the short run emphasis of the run-length matrices improves the contrast and the segmentation results previously reported by other authors^{8,9}.

Materials and Methods

A data base of 30 breast ultrasound images with a lesion were acquired with a GE Healthcare Voluson 73 in the Changhua Christian Hospital, Taiwan. The images were processed in the open source software ITK-SNAP for image enhancement and semi-automatic segmentation supervised by an expert sonographer¹⁸.

Texture Analysis

Here we evaluate the main texture descriptors, extracted from histogram statistic, co-occurrence matrices statistics and run-length matrices statistics, in order to find the ability of each descriptor to enhance the contrast between the tumor and the surrounding tissue in breast ultrasound images and how does this reflects in the results of an automatic segmentation algorithm.

First-order texture descriptors are extracted from the original image gray-level values. The most frequently used first-order descriptors are central moments of the histogram²⁰. These descriptors have been widely used for the segmentation and classification of breast tumors in ultrasound images. Huang et al¹⁰ use the Mean and Entropy of the histogram to characterize the texture of breast tumors, also the Kurtosis and Skewness of the histogram have been used for tumor classification by Piliouras et al²¹. Another first-order descriptor extracted from the image original values of the image, is the difference of the pixel intensity with the mean of its neighborhood, it is called local variance ($V(i)$, eq. 5) and has been used in automatic segmentation of breast tumors in ultrasound images by Madabhushi et al⁹. But as noted before this descriptors do not take the spatial relation between the gray-level values and are not able to give a good texture characterization. Second-order descriptors take into account the spatial relationship between gray values; here we evaluate texture descriptors obtained from co-occurrence and run-length statistics.

The gray-level co-occurrence matrix (*GLCM*) describes how frequently two gray-levels (i and j) appear in a window separated by a given distance d and an angle θ ²⁰ (eq. 1).

$$GLCM(i, j|d, \theta) = n_{ij}; d = (d_x, d_y) \quad (1)$$

Second order descriptors computed from the analysis of the co-occurrence matrices have been proposed by Haralick²². Some of these descriptors have been used for the segmentation and classification of breast tumors in ultrasound images. Lui et al¹² use the Entropy (eq. 2) and Contrast (eq. 3) of the co-occurrence matrix for breast tumor segmentation. Liao et al⁸ evaluated the ability of the Contrast, Homogeneity (eq. 4), Energy (eq. 5) and Variance (eq. 6) of the co-occurrence matrix to enhance the contrast between the tumor and the adjacent tissue in breast ultrasound images, concluding that the Variance is the best

texture descriptor of the four to be used in breast tumor contrast enhancement and segmentation in ultrasound images.

$$Entropy_{CM} = \sum_{i,j} GLCM(i,j) \log GLCM(i,j|d,\theta) \quad (2)$$

$$Contrast = \sum_{i,j} |i - j|^k GLCM(i,j|d,\theta)^l \quad (3)$$

$$Homogeneity = \sum_{i,j} \frac{GLCM(i,j|d,\theta)}{1 + |i - j|} \quad (4)$$

$$Energy = \sum_{i,j} GLCM(i,j|d,\theta)^2 \quad (5)$$

$$Variance = \sum_{i,j} (i - e)^2 GLCM(i,j|d,\theta); \quad e = \sum_{i,j} i \cdot GLCM(i,j|d,\theta) \quad (6)$$

Although co-occurrence matrix based descriptors take into account the spatial relationship between pixels, the computational cost of computing the co-occurrence matrix is very high compared to first-order descriptors¹³. Another method to characterize texture that also takes into account the spatial relationship between pixels, but with lower computational cost than co-occurrence matrices, is based on run-lengths of image gray-levels, where the run-length matrix (*GLRL*, eq. 7) of an image is defined as the number of runs with pixels of equal gray-level i and a given run j inside a maximum distance d and a given angle θ .

$$GLRL(i,j|d,\theta) = n_{ij}; d = (d_x, d_y) \quad (7)$$

Run-length matrix based descriptors have not been widely used as an effective texture classification and analysis method, however it has been demonstrated by Tang et al²³ that there is rich texture information contained in this matrices. Galloway²⁴ proposed five texture descriptors based on the analysis of run-length matrices: short run emphasis (SRE, eq. 8), long run emphasis (LRE, eq. 9), gray-level nonuniformity (GLN, eq. 10), run-length nonuniformity (RLN, eq. 11) and run percentage (RP, eq. 12); these descriptors have been used successfully for the classification of malignancy of breast tumors in ultrasound images^{21,25,26}.

$$SRE = \frac{1}{n_r} \sum_{i,j} \frac{GLRL(i,j|d,\theta)}{j^2} \quad (8)$$

$$LRE = \frac{1}{n_r} \sum_{i,j} GLRL(i,j|d,\theta) \cdot j^2 \quad (9)$$

$$GLN = \frac{1}{n_r} \sum_i \left(\sum_j GLRL(i,j|d,\theta) \right)^2 \quad (10)$$

$$RLN = \frac{1}{n_r} \sum_j \left(\sum_i GLRL(i,j|d,\theta) \right)^2 \quad (11)$$

$$RP = \frac{n_r}{n_p} \quad (12)$$

where n_r is the number of total runs and n_p is the number of pixels in the image.

A list of the descriptors evaluated in this work, extracted from co-occurrence and run-length statistics is show in table 1, along with the works that have used them in order to segment or classify breast tumors in ultrasound images.

Table 1. List of evaluated texture descriptors.

Co-occurrence	Entropy	Liu et al ¹²
	Contrast	Liu et al ¹²
	Homogeneity	Liao et al ⁸
	Energy	Liao et al ⁸
	Variance	Liao et al ⁸
Run-length	Short Run Emphasis	Lefebvre et al ²⁶
	Long Run Emphasis	Lefebvre et al ²⁶
	Gray-Level Nonuniformity	Murmis et al ²⁵
	Run-length Nonuniformity	Murmis et al ²⁵
	Run Percentage	Murmis et al ²⁵

Segmentation Method

Because of inherent artifacts in breast ultrasound images such as speckle and blurry edges, the segmentation of tumors in this image modality is not an easy task⁵. Several works have been done in order to create semi-automatic and automatic segmentation methods. Based on the literature, these methods can be divided in two groups; thresholding based methods and classifier based methods. The thresholding based methods have low computational cost and usually use only gray-level intensities for segmentation, leading to poor segmentation results since other objects in the image may have similar gray-level intensities^{5,10,27}. The classifier based methods are more robust since they use more than one feature for classification, but the implementation and the computational cost increases considerably compared with thresholding based methods^{1,9,12,28}; the image features used in a classifier based method should be appropriately selected according to the application, texture information seems highly suitable for ultrasound images⁵.

We have implemented an automatic segmentation method based on the work of Madabhushi et al⁹. This method is based on a region-growing algorithm applied to a probability image instead of an intensity image. A probability image refers to the visual representation of the probability of a pixel of being part of a tumor, and it is calculated based on some predefined features; the echogenicity and the internal echo pattern are used as features in this method to compute the pixel probability. Two probability density functions (*pdf*) are obtained from previously segmented images, one for intensity and one for texture.

The intensity *pdf* is obtained from the extraction of the normalized histogram of the tumor region of pre-processed images. Most of the proposed methods for tumor segmentation in breast ultrasound images use a pre-processing step to obtain more homogenous regions and enhance the contrast of the image. For contrast enhancement some works used the sticks method^{5,27,28}, but Madabhushi et al⁹ proposed the use of histogram equalization because it is a fast method with good results in tumor enhancement. To obtain more homogenous regions a Gaussian filter was used by Chen et al⁵ and a Butterworth filter was

used by Madabhushi et al⁹, however Abd et al²⁹ showed that the Gaussian Anisotropic Filter has better results in ultrasound images since it preserves boundaries. Based on this, we implemented a pre-processing step to obtain a contrast enhanced image using histogram equalization and a Gaussian Anisotropic Filter to obtain more homogenous regions while preserving borders.

To obtain the texture *pdf*, the normalized histogram of the tumor region is extracted from a texture image, obtained by per-pixel computation of the original image using a texture descriptor. Because texture parameters in ultrasound images characterize the acoustic properties of the tissue²⁶, the texture image was computed from the original image without any pre-processing step to avoid elimination of any texture related information.

After computing the probability image, using the intensity and texture joint probability, extracted from the intensity and texture *pdfs*, as shown in figure 1, the method uses a region growing algorithm on the probability image in order to obtain the region that belongs to the tumor. The seed point of the region is automatically determined by the method using the probability of each pixel, along with spatial information about the potential seed. Usually the ultrasound probe is placed above the region of interest, trying to locate the lesion in the center of the image, while the subcutaneous fat, glands and skin are located in the upper part of the image, and acoustic shadows usually are located in the lower part of the image; for this reason, the pixels that are near the central area of the image have a higher probability of belonging to the tumor according to spatial location. To quantify the probability of each pixel of being the seed of the region growing method $S(x)$, Madabhushi et al⁹ proposed a mathematical approach based on eq. 18.

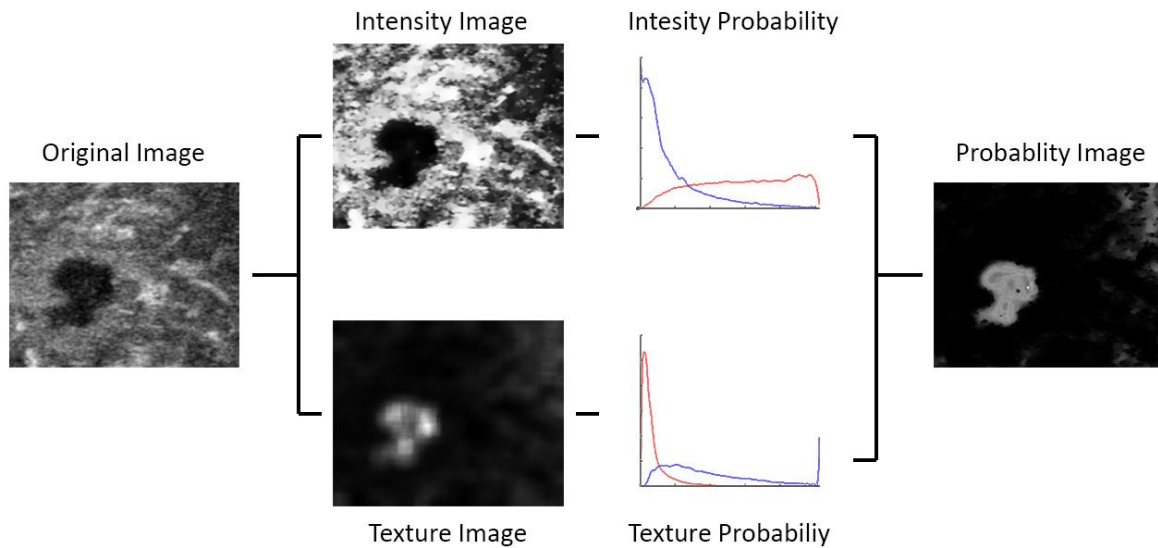


Figure 1. Steps for the computation of a probability image using intensity and texture information.

$$S(x) = \frac{I_P(x)N_xY_x}{d_x} \quad (18)$$

where $I_P(x)$ is the joint probability of belonging to the tumor according to texture and intensity features; N_x is the mean of the joint probability in a neighborhood around the pixel; Y_x is the vertical position of the pixel and d_x is the Euclidean distance from the center of the image to the pixel. $S(x)$ is computed for every pixel in the image and the pixel with the highest value is used as the region growing algorithm seed.

To include one pixel t inside the tumor region T it should satisfy two conditions: First, the probability of the pixel $I_P(t)$ should be inside a range of values between the mean of the tumor region probability J_{C_0} by an upper and a lower threshold β_1 and β_2 ; second, at least one pixel in the immediate neighborhood $N_t(t)$ of the pixel should had been included already in the tumor region; these conditions are shown in eq. 19.

$$t \in T \text{ if } \beta_1 J_{C_0} \leq I_P(t) \leq \beta_2 J_{C_0} \text{ and } T \cap N_t(t) \neq \emptyset \quad (19)$$

After applying the region growing algorithm, the borders of the final region are used as the initialization of a Snake in order to find the final segmentation of the tumor. A complete description of the method can be found in the original work by Madabhushi et al⁹.

Experiments and Results

Contrast enhancement using texture descriptors

Evaluation of contrast enhancement can be done with different indices, but there is no standardized approach; therefore, it is important to compute several indices for this purpose in order to have a good contrast enhancement evaluation³⁰. To evaluate the ability of the texture descriptors listed in table 1 to enhance the contrast between the tumor region and the surrounding tissue we use the contrast to noise ratio (CNR, eq. 20) used by Liao et al⁸.

$$CNR = \frac{|\mu_{ROI} - \mu_{Background}|}{\sigma_{ROI} + \sigma_{Background}} \quad (20)$$

where μ_{ROI} and $\mu_{Background}$ are the mean brightness values of the tumor region (ROI) and the surrounding tissue (Background) respectively, and σ_{ROI} and $\sigma_{Background}$ are the standard deviations.

In addition to CNR we computed the histogram intersection (INT, eq. 21) between the ROI and the background regions as a similarity measurement between histograms. The intersection of the histograms is a useful similarity measurement when the number of pixels is different between images or regions, and also is well suited to deal with scale changes; a small histogram intersection value corresponds to larger dissimilarities between histograms³¹.

$$INT(H_{ROI}, H_{Background}) = 1 - \frac{\sum_i \min(H_{ROI}(i), H_{Background}(i))}{\sum_i H_{Background}(i)} \quad (21)$$

where H_{ROI} and $H_{Background}$ are the normalized histograms of the regions.

Along with contrast enhancement, another important aspect to take into account when using texture analysis for image segmentation is the ability of the descriptor to preserve the edges of the structures we want to segment⁸. To evaluate this, we used the edge preservation index (EPI, eq. 22).

$$EPI = \frac{\sum |p_T(i, j) - p_T(i - 1, j + 1)|}{\sum |p_o(i, j) - p_o(i - 1, j + 1)|} \quad (22)$$

where $p_T(i, j)$ is the value of the texture image pixel and $p_o(i, j)$ is the value of the original image; the pixel (i, j) is in the edge area, previously segmented in the original image³².

We compare the CNR, INT and EPI of the original images with the corresponding values of the texture images obtained using per pixel computation with the descriptors listed in table 1. Table 2 shows the results for the original image. Our results showed that second-order descriptors based on the co-occurrence matrices are not useful for image enhancement, since none of the descriptors proposed by Haralick²² are able to enhance the contrast of the image, having lower values in CNR and EPI, and a higher INT value compared with the original image; although none of these texture descriptors improve the contrast, the co-occurrence matrix based texture descriptor that obtained the best values in all indexes was the Homogeneity (as shown in table 2). Of all the run-length based texture descriptors the SRE had better results, improving the INT and CNR values significantly; this texture descriptor is also the one that reduces the INT the most of all the descriptors listed in table 1, making easier the differentiation between regions using their probabilities, since the normalized histogram can be used as the probability density function of belonging to a region³³. None of the texture descriptors listed in table 1 was able to preserve the borders, reducing the EPI value. The values of the contrast indices for the Homogeneity of the co-occurrence matrices and the SRE of the run-length matrices are summarized in table 2; figure 2 shows the corresponding images for each descriptor and figure 3 shows the normalized histogram of the tumor region (blue) and background (red) in each image of figure 2. The results of contrast enhancement for all the texture descriptors is shown in table A of the appendix.

Table 2. Contrast indices.

Image	CNR	INT	EPI
Original	1.0784 ±0.3316	0.2932 ±0.1632	1 ±0
Homogeneity	0.5256 ±0.4724	0.5829 ±0.2233	0.5491 ±0.2257
SRE	1.2124 ±0.3924	0.1892 ±0.1472	0.3925 ±0.2319

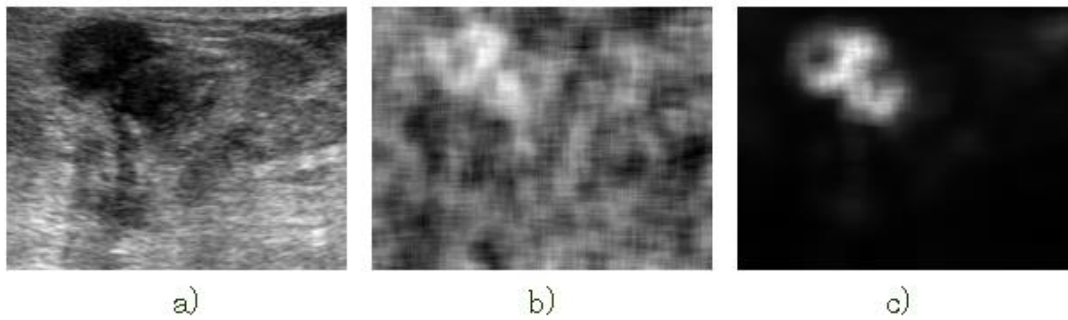


Figure 2. Textural analysis of breast ultrasound images; a) original ultrasound image, b) Homogeneity of the co-occurrence matrix texture image, and c) SRE of the run-length matrix texture image.

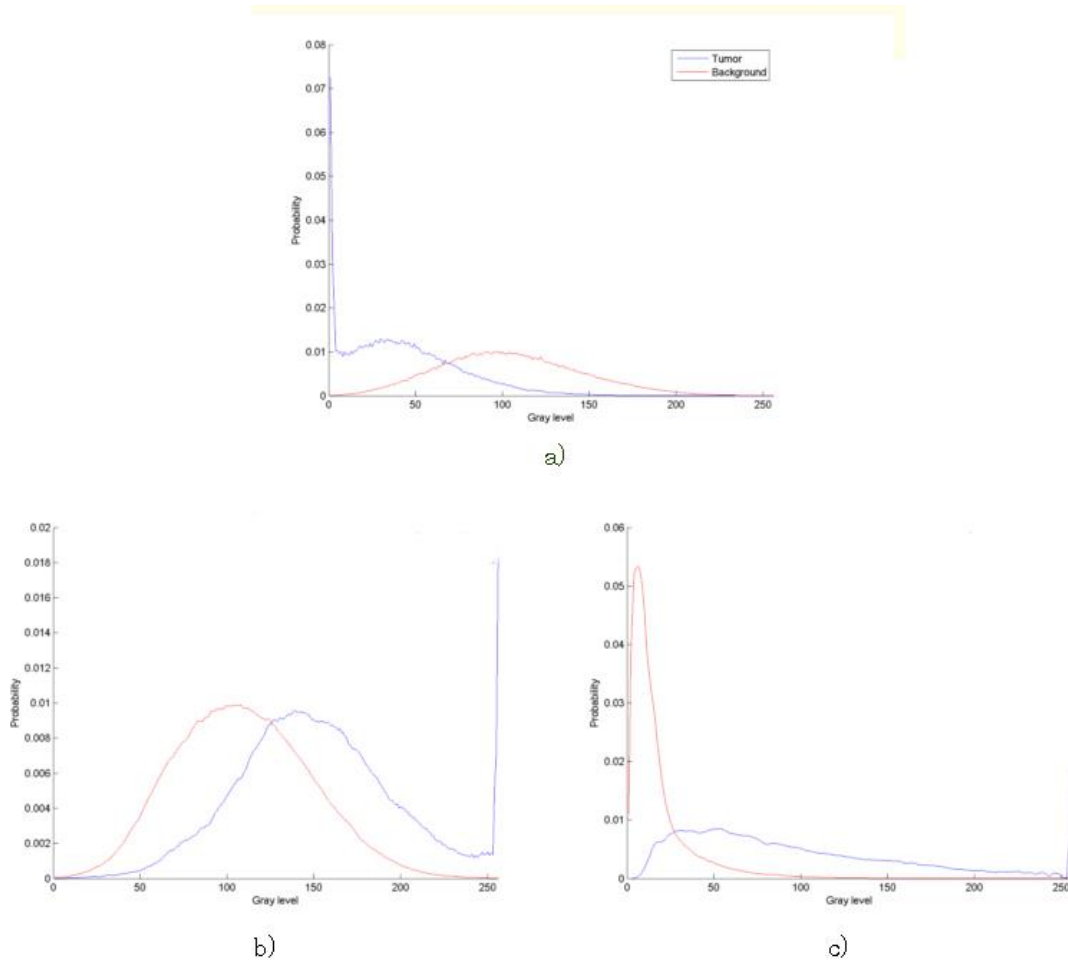


Figure 3. Normalized histograms of textural analysis; a) original ultrasound image, b) Homogeneity of the co-occurrence matrix texture image, and c) SRE of the run-length matrix texture image.

Another important aspect to take into account when dealing with different descriptors and automatic segmentations is the processing time. In table 3 we show the time that takes to process an image with per-pixel computation, with a window of 11x11 pixels, in order to obtain a texture image with the homogeneity and the SRE. It can be seen in table that run-length texture features have lower computational costs than co-occurrence based descriptors, since the difference of the processing time is more than one minute.

Table 3. Processing times for different texture descriptors

Category	Descriptor	Time
Co-occurrence	Homogeneity	00:05:39
Run-length	SRE	00:04:28

Segmentation evaluation

We implemented an automatic segmentation method based on the work of by Madabhushi et al⁹, which includes a pre-processing step to obtain an intensity image and a texture image in order to build a probability image to segment the tumor with a region growing algorithm and a Snake. to obtain the texture images we used per-pixel computation in an 11x11 window, since it is the smallest window which leads to better contrast enhancement results, and for co-occurrence and run-length matrices we obtained 4 matrices with $d = 1$ and $\theta = 0^\circ, 45^\circ, 90^\circ, 135^\circ$; The region growing and snake user define variables where extracted from the original work.

In order to assess the contribution of texture features to the segmentation, we evaluate the results of the segmentation method when using only the original image, only the pre-processed intensity image and using the pre-processed intensity image along with a texture image obtained with one of the descriptors listed in table 1. To evaluate the segmentation results we used the accuracy (eq. 23), sensitivity (eq. 24) and specificity (eq. 25)³⁴.

$$Accuracy = \frac{TP + TN}{TP + TN + FP + FN} \quad (23)$$

$$Sensitivity = \frac{TP}{TP + FN} \quad (24)$$

$$Specificity = \frac{TN}{TN + FP} \quad (25)$$

where TP , TN , FP and FN are the true positives, true negatives, false positives and false negatives pixels found in the segmentation process. These indices were evaluated for our 30 images using leave-one-out cross-validation.

The accuracy is the ratio of correctly classified pixels (TP and TN) in the entire area of the image³⁵. The sensitivity and specificity are often used to complement the evaluation of segmentation algorithms; sensitivity is used to measure how many pixels in the region of interest are correctly segmented, it does not tell anything about how many pixels in the background are going to be segmented as tumor³⁶; the

specificity measures how many pixels in the background are correctly excluded and does not tell if a tumor pixel is going to be correctly segmented³⁶.

Table 4 shows the segmentation results using only the original image without any pre-processing. This table also shows the results of the segmentation using only the intensity image obtained by the pre-processing step; it can be observed that a more homogeneous image with higher contrast increases the accuracy, and specificity values of the method, but decreases the sensitivity value by 1.24%. We evaluated the ability of all the texture descriptors previously shown in table 1, to find out which one provides better segmentation results, the table of all the segmentation results is shown in the appendix of this work in table B. The homogeneity of the co-occurrence matrix was the best descriptor of this type, showing higher percentages of accuracy, sensitivity and specificity than using only intensity information. The best segmentation results using gray-level intensities and texture information were obtained using the SRE of the run-length matrix, showing the highest percentages in accuracy, sensitivity and specificity. The results of the segmentation using the best descriptors of each class are also shown in table 4.

Table 4. Segmentation results without and with texture information

Category	Descriptor	Accuracy	Sensitivity	Specificity
Intensity	Original	83.89% \pm 11.42%	86.51% \pm 15.63%	87.63% \pm 14.01%
Intensity	Pre-processed	87.13% \pm 10.53%	85.28% \pm 16.75%	89.52% \pm 11.64%
Co-occurrence	Homogeneity	90.60% \pm 09.48%	88.66% \pm 10.43%	93.84% \pm 08.98%
Run-length	SRE	91.96% \pm 06.96%	88.58% \pm 09.83%	95.99% \pm 06.51%

Figure 4 shows the segmentation results of a breast tumor in an ultrasound image using different texture descriptors along with the pre-processed intensity image, it also shows the segmentation results obtained using only the original image and only the preprocessed intensity image without any texture information. Table 5 shows the accuracy, sensitivity and specificity of the segmented images in figure 4. It can be seen in table 5 that using texture descriptors along with a pre-processed intensity image for breast tumor segmentation can upgrade the results considerably. Although in this image the sensitivity was diminished using texture descriptors, the difference is very small (1%) compared with the increase in accuracy and specificity values (16% and 24% respectively) using the SRE of the run-length matrix as texture descriptor. Figure 5 shows the manual and automatic segmentations of three different ultrasound images using the pre-processed intensity image and the SRE of the run-length matrix as texture descriptor.

Table 5. Segmentation results for the segmented images shown in figure 4.

Descriptor	Accuracy	Sensitivity	Specificity
Original	82.41%	99.75%	74.03%
Intensity	91.10%	99.49%	85.14%
Homogeneity	95.97%	98.92%	93.96%
SRE	98.28%	98.74%	98.84%

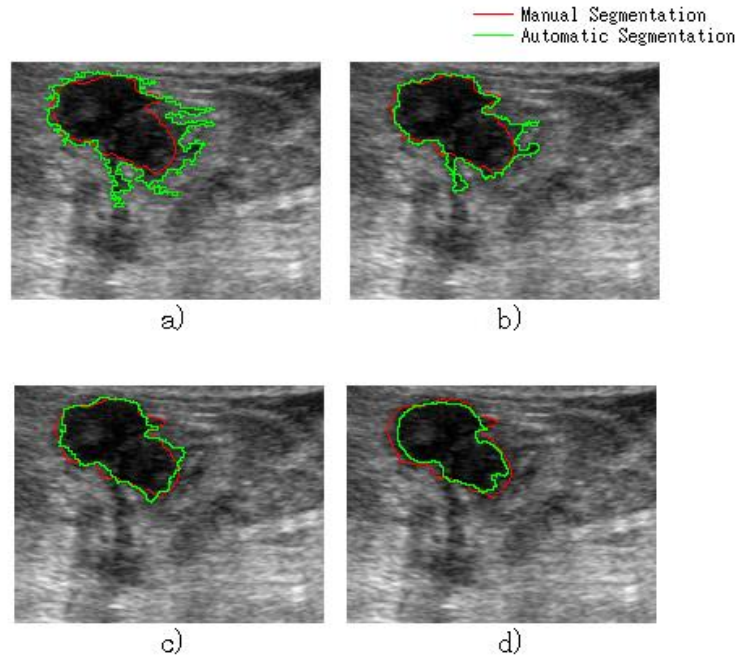


Figure 4. Segmentation of a breast tumor using; a) original image, b) pre-processed intensity image c) pre-processed intensity image and homogeneity of the co-occurrence matrix and d) pre-processed intensity image and SRE of the run-length matrix.

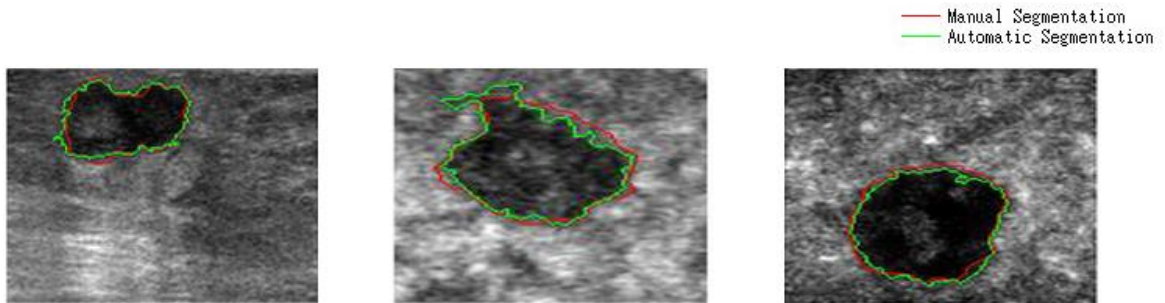


Figure 5. Segmentation of three breast tumor using pre-processed intensity image and SRE of the run-length matrix.

Discussion and Conclusion

Texture descriptors have been widely used in breast ultrasound images for tumor segmentation and classification since they help to differentiate structures with similar gray-level intensities from tumors, such as acoustic shadows. In this work we reported a quantitative evaluation of the main texture descriptors used in breast tumors ultrasound images, in order to find out which one is the most effective to enhance the contrast between the tumor and the adjacent tissue and how this affects the outcome of

a probabilistic segmentation algorithm like the one proposed by Madabhushi et al⁹. Image quality is a key aspect to consider in ultrasound images since they are affected by many types of artifacts, making hard to an observer to interpret the images and obtain quantitative and qualitative information from them³⁷.

The ability of different texture descriptors (listed in table 1) to enhance the contrast in the image was evaluated with tree indices (CNR, INT and EPI). It was shown in the results that some of these texture descriptors were able to improve one or more of the used contrast indices. The best results of contrast enhancement were obtained using the SRE of the run-length matrices, as shown in table 2, having the highest values in all indices, except for the EPI which was not increased by any of the texture descriptors listed in table 1.

We also evaluated the outcome of a segmentation method when using different texture descriptors; we evaluated the segmentation using tree indices (accuracy, sensitivity and specificity), and using a semi-automatic segmentation supervised by a physician as the ground of truth. Table 4 shows that the SRE of the run-length matrices is the texture descriptor, of all listed in table 1, that improves the segmentation results the most, having a significant improvement in all indices; it is important to notice that this texture descriptor was also the one that showed the best contrast enhancement results, decreasing the Intersection between histograms significantly, making easier to differentiate between regions when using the normalized histogram as a probability function. The results of the segmentation using the SRE of the run-length matrix were significantly better compared with the results reported in the work by Madabhushi et al⁹, where they reported 76.07% of TP and 76.06 of TN against 96.34% of TP and 87.58% of TN; also the results were better than the ones reported by Liao et al⁸, where they reported 95% of TP and 85% of TN when using the variance of the co-occurrence matrix as texture information for their automatic segmentation method. Although, run-length based descriptors have been used in the classification of malignancy in breast tumors, it is not of our knowledge that they have been successfully used in the segmentation of breast tumors in ultrasound images. The SRE of the run-length matrix is an indicative of fineness or higher frequency content in an image region; since a fine texture should contain primarily short runs, the improvement of the segmentation results when using this descriptor is most likely due to its ability to detect high spatial frequencies, of the speckle patterns of the tumor and the surrounding tissue²³.

Declaration of conflicting interests

The author(s) declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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APENDIX

Table A. Contrast enhancement results

Type	Descriptor	Intersection	CNR	EPI
Original	Normal	0.2932 \pm 0.1632	1.0784 \pm 0.3316	1 \pm 0
Co-occurrence	Contrast	0.5865 \pm 0.2105	0.4511 \pm 0.3694	0.4715 \pm 0.1303
	Correlation	0.7231 \pm 0.1146	0.1859 \pm 0.1466	0.4510 \pm 0.1838
	Energy	0.6319 \pm 0.2031	0.3793 \pm 0.3820	0.3255 \pm 0.3079
	Homogeneity	0.5829 \pm 0.2233	0.5256 \pm 0.4724	0.5491 \pm 0.2257
	Variance	0.6315 \pm 0.2021	0.3822 \pm 0.3827	0.3360 \pm 0.3093
Run-Length	GLN	0.5993 \pm 0.2262	0.5129 \pm 0.4886	0.6566 \pm 0.1873
	RLN	0.7220 \pm 0.1183	0.1843 \pm 0.1511	0.5598 \pm 0.2805
	LRE	0.2594 \pm 0.1559 x	1.0552 \pm 0.3067	0.3054 \pm 0.1188
	SRE	0.1892 \pm 0.1472 xxx	1.2144 \pm 0.3924 xx	0.3925 \pm 0.2319
	RP	0.6257 \pm 0.2489	0.5095 \pm 0.4851	0.6697 \pm 0.2521

Table B. Segmentation results.

Type	Descriptor	Accuracy	Sensitivity	Specificity
Original	Normal	0.8389 \pm 0.1142	0.8651 \pm 0.1563	0.8763 \pm 0.1401
Pre-Processing	Eq+Filt	0.8713 \pm 0.1053 x	0.8528 \pm 0.1675	0.8952 \pm 0.1164 x
Co-occurrence	Contrast	0.9057 \pm 0.0418 x	0.8788 \pm 0.0643 x	0.9671 \pm 0.0379 xxx
	Correlation	0.8678 \pm 0.1026	0.8253 \pm 0.1643	0.9181 \pm 0.1152 x
	Energy	0.8846 \pm 0.0727 x	0.8837 \pm 0.0714 x	0.9339 \pm 0.0904 x
	Homogeneity	0.9060 \pm 0.0948 xx	0.8866 \pm 0.1043 xxx	0.9384 \pm 0.0898 x
	Variance	0.8826 \pm 0.0991 x	0.8813 \pm 0.0713 x	0.9327 \pm 0.0875 x
Run-Length	GLN	0.9084 \pm 0.0748 x	0.8773 \pm 0.0963 x	0.9465 \pm 0.0767 x
	RLN	0.8725 \pm 0.1053 x	0.8747 \pm 0.1425 x	0.9398 \pm 0.1133 x
	LRE	0.8465 \pm 0.0969	0.8734 \pm 0.1640 x	0.8516 \pm 0.1114 x
	SRE	0.9196 \pm 0.0696 xxx	0.8858 \pm 0.0983 xx	0.9599 \pm 0.0651 xx
	RP	0.8916 \pm 0.0811	0.8588 \pm 0.0974	0.9468 \pm 0.0756

		x	x
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x improves the segmentation index.
xx best improvement of its category.
xxx best improvement of all descriptors.