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Masek, M., Chandrasekhar, R., de Silver, C.J.S. and Attikiouzel, Y. (2001) Spatially based application of the minimum cross-entropy thresholding algorithm to segment the pectoral muscle in mammograms. In: Seventh Australian and New Zealand Intelligent Information Systems Conference, 18 - 21 November 2001, Perth, Western Australia, pp. 101-106.

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Spatially Based Application of the Minimum Cross-Entropy Thresholding Algorithm to Segment the Pectoral Muscle in Mammograms

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A threshold-based algorithm is presented for the extraction of the pectoral muscle edge in mediolateral oblique view mammograms. The minimum cross-entropy thresholding algorithm is applied to local areas around the pectoral muscle to determine a series of thresholds as a function of area size. Using a model image it is shown that an inflection point in this function corresponds to a threshold that will separate the pectoral muscle from the rest of the breast. Post processing is performed on mammograms to eliminate false positive points of inflection and a straight line is fitted to the detected pectoral boundary in order to smooth jaggedness caused by the non-uniform intensity of the pectoral muscle edge.

1 Introduction

The pectoral muscle in a mediolateral oblique view mammogram appears as a bright triangular region in one corner of the image. Location of the pectoral muscle edge is a basic segmentation step in the process of isolating different regions of the mammogram. Knowledge of the pectoral muscle tissue and its boundary is a prerequisite for tasks ranging from the classification of breast type [1] to image registration [2]. A straight-line approximation to the muscle edge is typically used in these tasks.

2 Materials and Methods

Taking the mediolateral oblique view mammo-

gram, the image corner containing the pectoral muscle is found using an automated orientation algorithm [3]. To determine orientation, the breast tissue near the skin is extracted and its intensity gradients used to find the chest wall. Once the chest wall is located, the characteristic asymmetry of the mediolateral oblique view is used to find the top of the image. The pectoral muscle lies at the top of the image on the side of the chest wall. To simplify further processing, the image is re-oriented to place the pectoral muscle in the top left corner.

Figure 1(a) shows mammogram mdb007 from the Mammographic Image Analysis Society (MIAS) database [4]. The image can be divided into four regions based on tissue type, their outlines shown in Figure 1(b). The position of the regions is in-

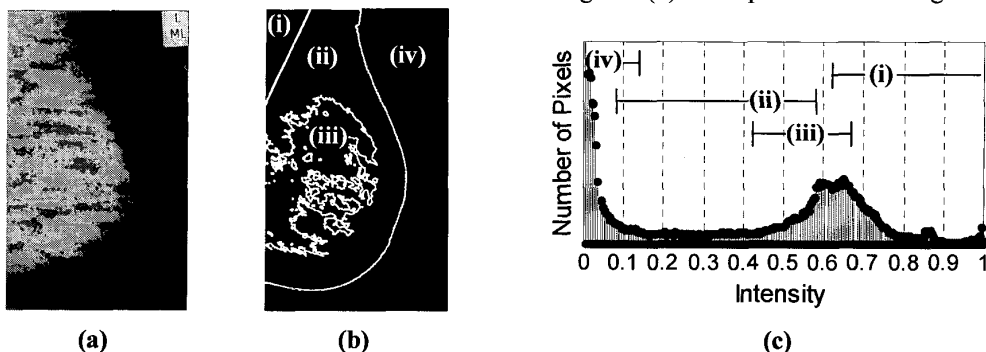


Figure 1: MIAS image mdb007 (a) has been decomposed into four tissue type regions (b). The image histogram is shown in (c) with approximate region position shown. The regions correspond to (i) pectoral muscle, (ii) fatty tissue, (iii) denser tissue and (iv) image background.

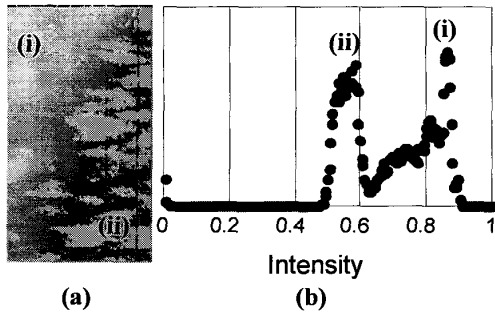


Figure 2: (a) A local area near the top-left image corner, the histogram (b) appears as a bimodal distribution with two peaks, corresponding to the pectoral muscle (i) and the fatty tissue (ii).

indicated on the image histogram in Fig. 1(c). The regions are separated in the image but overlap in the histogram; they correspond to (i) the pectoral muscle, (ii) fatty breast tissue, (iii) denser glandular tissue and (iv) the image background.

The pectoral edge represents a line between the pectoral region and the fatty breast tissue. A sub-image can be taken from the top-left corner that will contain only those two regions, excluding the denser glandular tissue and the image background. Such an image is shown in Figure 2(a). Its histogram in Figure 2(b) contains two peaks corresponding to the pectoral muscle and fatty tissue regions. This shows the segmentation of the pectoral muscle to be a two-class thresholding problem for a subset of spatially separable image pixels.

This problem is investigated using a two-class model image shown in Figure 3(a). A bright region representing the pectoral muscle Figure 3(a-

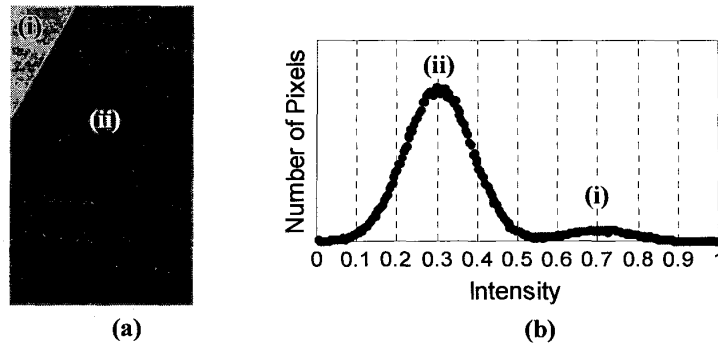


Figure 3: Two class mammogram model (a) and its histogram (b). The pectoral muscle is modelled by a bright triangle with a Gaussian intensity range (i). The model background, which has replaced other breast tissue and the mammogram background has a lower intensity Gaussian distribution (ii).

i) is set on a dark background Figure 3(a-ii) representing the fatty tissue. A Gaussian intensity distribution has been used for these two regions. The model image histogram is shown in Figure 3(b). The four parameters to define this model (and this specific model image) are: a) mean intensity of pectoral muscle, or mid-point of the pectoral histogram peak (0.7), b) mean intensity of the model background histogram peak (0.3), c) the standard deviation of both Gaussian distributions (0.007) and d) the aspect ratio of the rectangle enclosing the pectoral muscle (4:7), the aspect ratio being defined here as ratio of width to height. Knowing the aspect ratio, it is adequate to state the dimensions of only one side to specify a window size; the width will be used here.

Minimum cross-entropy thresholding is used to process the model and mammogram images. The concept of minimum cross-entropy, first proposed by Kullback [5], is used here in the form developed by Brink and Pendock [6] for the thresholding of greyscale images. The algorithm is given as Equation 1.

$$H_{CE}(T) = \sum_{g=a}^T f_g \mu_0(T) \log \frac{\mu_0(T)}{g} + \sum_{g=T+1}^b f_g \mu_1(T) \log \frac{\mu_1(T)}{g} \quad (1)$$

Each possible threshold T , in the range of image intensities (a to b) is associated with a cross-entropy $H_{CE}(T)$. The cross-entropy is determined by examining all intensities, g , in the image histogram. The algorithm makes use of the frequencies of grey level intensities (f_g) and the mean of intensities below ($\mu_0(T)$) and above ($\mu_1(T)$) the considered threshold T . These values are not dependent on the spatial distribution of pixels and

thus can be extracted from the image histogram making the algorithm speed independent of image size, (but dependent on image depth). The grey level corresponding to the lowest cross-entropy is used as the resultant threshold.

The minimum cross-entropy thresholding algorithm is applied to rectangular windows of fixed aspect ratio and varying width anchored to the top-left image corner. A wide range of window aspect ratios has been tried on the model with similar results. Due to the exclusion of mammogram regions (iii) and (iv) in Figure 3(b) from the model, the window aspect ratio for a mammogram must be set to exclude these regions from the window for as many window sizes as possible. A useful aspect ratio is that of the window containing the entire pectoral muscle, this however varies between mammograms. An aspect ratio of (1:2) has been chosen here to demonstrate results on images with a variety of pectoral aspect ratios, including the model image and actual mammograms.

The relationship between minimum cross-entropy threshold and window width for the model is examined in Figure 4 and 5. Rectangular windows of various widths from Figure 4 correspond to histograms and cross-entropy values for grey levels shown in Figure 5, with corresponding lettering (a-c). Intensities indicated in the plots are the mean of the model pectoral muscle, mean of the model background and the mid-intensity between those means, which can be considered as a good threshold to separate the two distributions. A

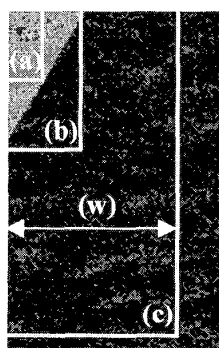


Figure 4: Rectangular windows (a-c) of various width and constant aspect ratio are extracted from the model image for analysis of histogram and cross-entropy in Figure 5. Width (w) is shown for window size (c) to demonstrate.

stem is used to mark the minimum cross-entropy.

For windows containing a majority of pectoral pixels a narrow minimum in the cross-entropy graph results in a region corresponding to the model pectoral intensities. The location of the minimum moves towards the mean intensity of the model pectoral Gaussian as the window width decreases (Figure 5a).

When the number of model background pixels is greater than the number of pectoral pixels a narrow minimum occurs in the cross-entropy function at the background pixel intensities. The location of the minimum converges towards the mean of the background Gaussian as the number of background pixels increases (Figure 5c).

The middle ground between the two narrow minimums is a broad minimum occurring when an equal number of pixels from the two classes are present in the window. The minimum corresponds to a threshold to separate the two classes (Figure 5b).

The characteristics of the cross-entropy minimum for varying window sizes are summarised by the graph of minimum cross-entropy threshold versus window width shown in Figure 6(a). The two regions converging to mean pectoral and mean background intensities are divided by a point of inflection, shown in the figure; this point corresponds to the broad minimum occurring in Figure 5(b). The location of the inflection point has been determined by examining the first and second derivatives of the function, graphs of which are omitted to conserve space. The inflection point is of interest since this threshold divides the model pectoral muscle from the background. The border of objects extracted from the model using this threshold is shown superimposed over the model image in Figure 6(b).

Comparing this model to an actual mammogram, Figure 7(a) shows the threshold versus window width graph for the MIAS image from Figure 1(a). The shape of this function is a close approximation to the shape of the model function for small window sizes. The inflection point, found from the first and second derivative, is shown in the figure. The border of regions extracted using the inflection point threshold is shown in Figure 7(b), showing an outline near the pectoral boundary.

To demonstrate an inflection point exists, the first and second derivatives were examined by manual inspection. In order to determine thresholds with-

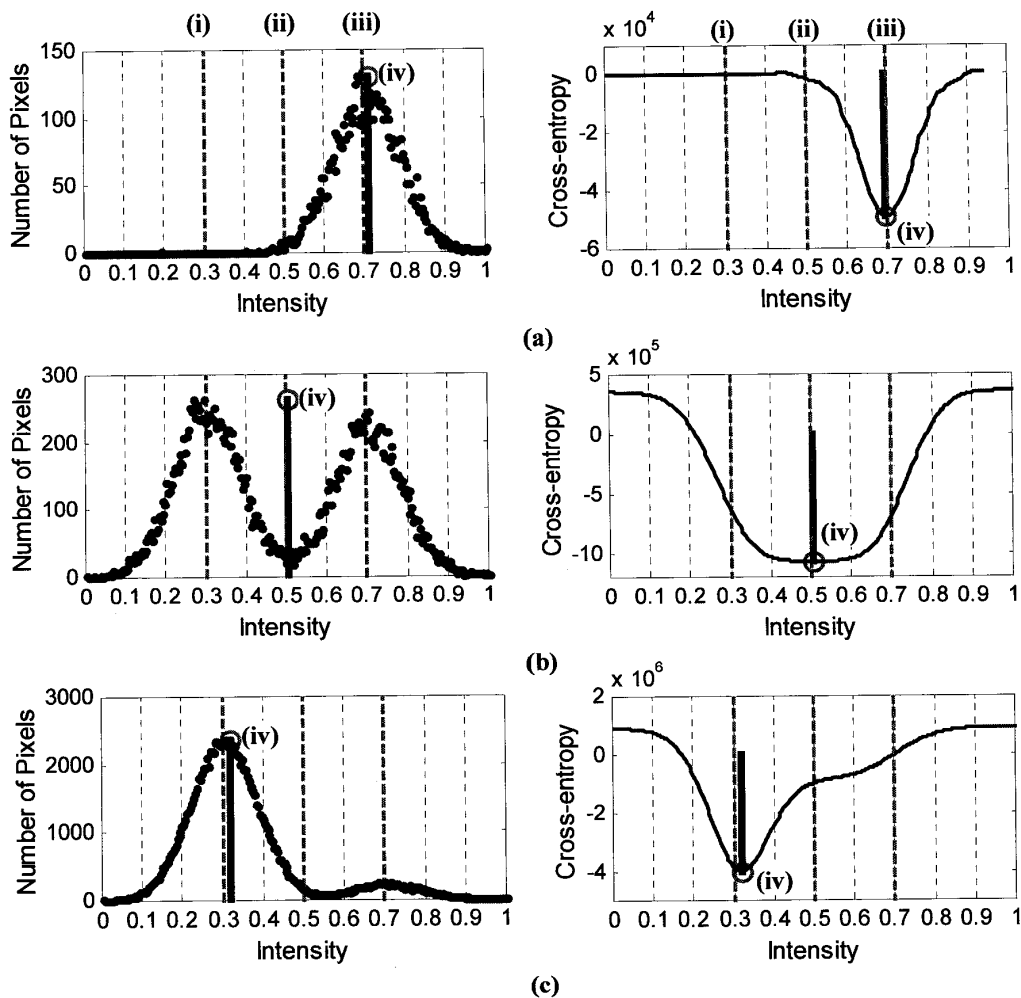


Figure 5: Histogram and cross-entropy function for rectangular windows from the model in Figure 4(a-c) shown with corresponding lettering. Mean model pectoral intensity (i), optimal segmentation intensity (ii) and mean model background intensity (iii) are marked. The threshold corresponding to minimum cross-entropy (iv) is marked with a stem.

without user intervention, the inflection points must be found by an automatic procedure. This is accomplished by fitting a series of quadratic functions to a sliding neighbourhood on the threshold versus window width function. First of all this smooths the function. Second, points of inflection are found where the x^2 term of the quadratic changes sign. If the quadratics on either side of a point are taken as parts of a piecewise quadratic function the change in sign between them corresponds to a change in the direction of concavity, corresponding to zero second derivative.

2.1 Deviation from the Model

Several issues arise from fitting the model to a mammogram. First of all, the model is only valid for a limited range of window sizes as the model does not take into account regions (iii) and (iv) of Figure 1(b). Because other intensity regions exist in the mammogram, there may be multiple points of inflection in the threshold function, only one corresponding to the pectoral boundary intensities. The second issue stems from the fact that the regions of a mammogram are not homogeneous in intensity like the Gaussian based model image. The pectoral boundary can vary in intensity along its length and defining a single intensity to extract it leads to jaggedness in some parts

of the border. Also, due to the glandular tissue having similar grey levels to the pectoral muscle, parts of it will also be outlined when using the correct threshold, as is shown in Figure 7(b). These are overcome by the post processing described below.

2.2 Post Processing

To locate the outline most likely to correspond to the pectoral muscle and to eliminate the jagged boundaries, a set of straight lines is fitted to the image. Each line is fitted to the border pixels of objects extracted using one of the inflection point thresholds. To fit the line, a simple gradient operator is applied to the binary border. The horizontal edges of a window around each pixel in the border are examined. Due to its angle, the pectoral boundary is expected to run from one corner of the window to a point near the opposite corner. As the location of the pectoral muscle is known, these corners are known also. The horizontal dis-

tance between pixels nearest each opposite corner is then taken as the gradient. A tally of gradients and the number of pixels of each gradient is kept. Since the pectoral muscle is the most distinct and straightest boundary in the image, the most common pixel gradient can be assumed to belong to it, thus the straight line that is fitted to the binary border image must correspond to that gradient.

Once a series of straight lines is fitted to correspond to each threshold, it remains to differentiate between the actual pectoral boundary and the boundaries resulting from non-pectoral points of inflection. The pectoral boundary represents a division between two regions of the mammogram. One side of the boundary has relatively high intensities due to the presence of the pectoral muscle, the other side is relatively dark. A line fitted accurately will display the properties of this boundary. To determine which fitted line is most representative of the pectoral outline, a pixel neighbourhood is taken from each side of a line

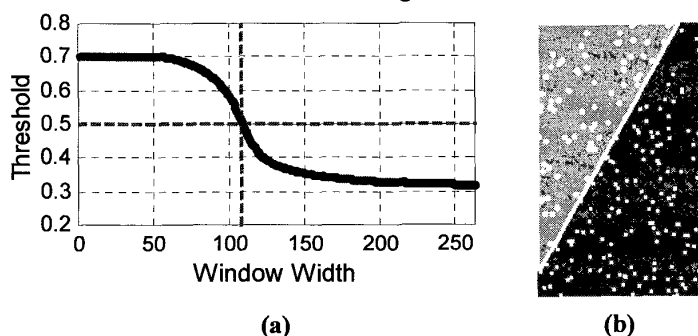


Figure 6: Model Image - Graph of minimum cross-entropy threshold for varying window widths (window aspect ratio 1:2) (a). The inflection point, determined from the zero of the second derivative, corresponds to a threshold of 0.5. The result of applying this threshold to the model image is shown in (b) as an outline of the regions extracted in the left-hand corner of the image.

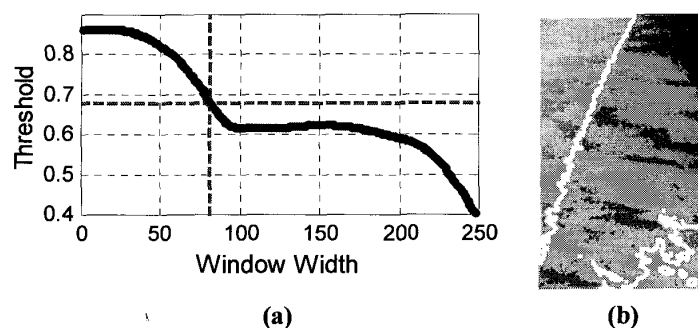


Figure 7: Mammogram - Graph of minimum cross-entropy threshold for varying window widths (aspect ratio 1:2) (a) comparable to that in Figure 6. The inflection point is found at intensity of 0.667. Applying this threshold to the mammogram results in a segmentation for which the outline of regions is shown in (b) for an image portion near the pectoral muscle.

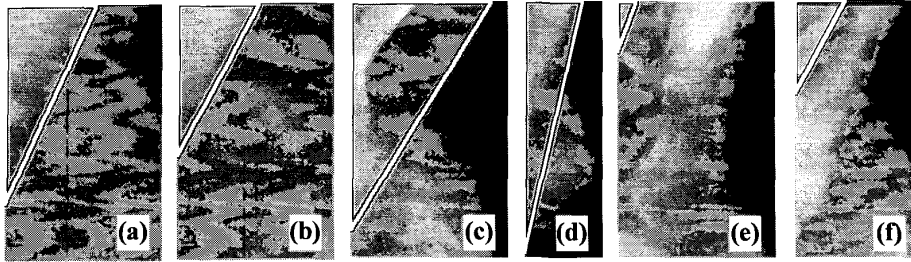


Figure 8: Final results of straight line fit (only pectoral area shown). Success in MIAS images mdb007, mdb015 and mdb039 (a-c) and failures in MIAS images mdb035, mdb062 and mdb123 (d-f).

and the mean pixel intensity difference from one neighbourhood to the other is determined. The line that maximises the difference is chosen as the best estimate of the pectoral boundary.

3 Results and Discussion

The algorithm produces visually acceptable results for a wide range of images in the MIAS database as shown in Figure 8(a-c). Inaccurate results arise for a number of reasons. In images where the pectoral muscle boundary lies at various angles (e.g. MIAS image mdb035 in Figure 8d), an inaccurate straight line fit results. Various inflection points exist in the functions of images where the pectoral muscle is broken up into diverse regions. These may result in the line being fitted to points inside the actual pectoral muscle, depending on their properties. In image mdb062 (Figure 8e), there is no strong outline for the pectoral muscle so an internal region is extracted. In image mdb123 (Figure 8f), an obvious pectoral outline can be seen, however an internal region also displays the properties of a straight-line boundary between two intensity regions and is extracted instead.

Further use of the expanding window is being investigated for extraction of the pectoral muscle edge as well as a general segmentation algorithm.

4 Conclusion

An algorithm for segmenting the pectoral muscle from mediolateral oblique view mammograms has been presented. A series of intensity thresholds is found for the pectoral edge by applying the minimum cross-entropy thresholding algorithm to variable sized areas around the pectoral muscle. Each threshold is graphed as a point in a function against the window size it came from. Properties of this function determine a threshold

to segment the pectoral muscle and straight line fitting is used to generate a cleaner pectoral line.

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