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Combining Data from Different Algorithms to Segment the Skin-Air Interface in Mammograms

M Masek[1], Y Attikiouzel[1], C J S deSilva[1]

Abstract – **This paper presents a method for combining several different estimates of the mammographic skin-air interface in order to eliminate noise inherent to each individual segmentation algorithm. Given that each algorithm provides a binary mask of the breast, the first step is to isolate pixels adjacent to the skin-air interface. A final estimate of the skin-air interface for each point results from the combination of skin-air interface location data from each procedure. Data for each point is grouped as a set, upon which statistical operators, such as the elimination of outliers, are applied. Since the skin-air interface is a continuous line, data from prior points is also used as an estimate of points that follow. Results are evaluated in terms of success with the combination of two skin-air interface segmentation algorithms. The resulting 'hybrid' technique overcomes several problems that beset each individual algorithm.**

Key words – **mammogram, skin-air interface**

I. INTRODUCTION

There are a number of reasons for determining the skin-air interface in mammograms. The skin-air interface marks the outer edge of the breast, making it possible to eliminate the background from further processing. The skin-air interface is also important for diagnosis, since signs of malignancy can present themselves as changes in the skin, thickening it or pulling it inward [1]. Finally, automated techniques that compare mammograms of both breasts need reference points, these can be determined from the skin-air interface in several ways, such as finding the point of maximum curvature [2] or the nipple [3].

Typically, an algorithm for segmenting the skin-air interface has its individual strengths and weaknesses. If the results of a number of segmentation algorithms can be combined, a more robust 'hybrid' technique results. Two of our automatic skin-air interface algorithms will be used in this paper to illustrate how this can be implemented. The first segmentation technique applies a single threshold to the grayscale image. This threshold is determined by the minimum cross-entropy thresholding algorithm [4] resulting in one estimate of the skin-air interface. The second technique uses the minimum cross-entropy thresholding algorithm individually on small areas localized around the skin-air interface [5]. Since the individual thresholds are optimized for each local area, there is greater tolerance to the changing intensity of the skin-air interface when compared with the single threshold algorithm. There is however less tolerance to local noise. The technique is preceded by automatic label removal [6] to filter out some of the locally specific noise but is still outperformed in this respect by the single threshold algorithm. Several estimates for each point result from the multiple threshold algorithm due to the overlapping of local areas for which a threshold is found.

The hybridisation approach combines data from different algorithms and also considers data from prior points to judge the validity of succeeding skin-air interface point estimates.

II. METHOD

In selecting the algorithms to combine, their strengths and weaknesses must be examined. For best results, the algorithms must complement each other. In places where one algorithm fails, the others should be successful so that the result of the failed algorithm stands out as being different.

The estimate from each skin-air interface segmentation algorithm is presented as a binary mask of the breast. The first step that must be performed is to extract only the breast pixels adjacent to the skin-air interface. In performing this, rules concerning the shape of the breast are applied to eliminate noise. Removing as much noise as possible from the individual estimates prior to their combination results in greater accuracy in the final skin-air interface.

Inaccuracies in the skin-air interface caused by noise overhangs, such as that shown in figure 1a) are eliminated through the application of these rules. Starting on the left side of the image, once the start of the breast is found at each row, the next black pixel signifies the end of the breast for that row. Performing this for all rows results in an overhang free skin-air interface (figure 1b) as far as the rows are concerned. A similar procedure can be applied to each column starting at the top of the breast and finding its bottom boundary. This results in the outline shown in figure 1c). Since each outline encompasses a region of the breast, applying the AND operator to those regions results in a complete skin-air interface as shown in figure 1d). The start of the breast for each row or column is taken as the first white pixel that is followed by a minimum number of white pixels. This requirement is needed as noise can exist near the edge of the

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image presenting itself as white pixels outside the breast boundary.

Once the skin-air interface for each approximation has been determined, they can be combined. Skin-air interface location data for each row is grouped together as a set of candidates. In the ideal situation, each estimate results from an independent algorithm but if several estimates are obtained from the same algorithm, or have similar problems, less weighting should be put on each of these estimates than on the result of a skin-air interface algorithm that produces only one estimate.

Once the set of skin-air interface candidates for a row is obtained, its standard deviation is determined. If the standard deviation of the candidates exceeds a fixed, experimentally determined threshold, information on the skin-air interface in the prior rows is used to eliminate outliers. Every time our algorithm combines data from different estimates, the resulting location of the skin-air interface point is saved. If we need to determine the most likely location of a point based on prior points, an estimate location for the point immediately prior to the one we seek is determined as a weighted average of a set number of prior points. The gradient of the skin-air interface for the prior point is also determined. From the gradient and previous point we determine the location of the next point. Points that fall outside a region around the estimated point are eliminated from the set of candidates. If no points remain, the estimated point is used as the location of the skin-air interface.

The elimination of points using previous data is only performed for candidate lists with a high standard deviation. This is because an approximation using the gradient of the previous points is valid only for relatively small areas close to the points for which the gradient is determined. Letting it guide the algorithm for too many successive points will result in errors. As there are usually some discrepancies between candidate points, a threshold must be set such that only when the standard deviation of a set of points is greater then the threshold, previous data is considered.

From the remaining candidates, any that are more then two standard deviations from the mean are eliminated as noise. This outlier removal occurs regardless of whether data have already been removed through the use of prior skin-air interface points. The mean of the remaining candidates is plotted as the skin-air interface for that row. A new binary mask is obtained for the breast from this skin-air interface.

The procedure is repeated in the same way for each column to obtain a more accurate outline of the bottom of the breast. This results in a second binary mask. The two masks are combined with the AND operator to obtain a complete mask for the breast. The skin-air interface is then the outer edge of this mask.

III. RESULTS

The method has been tested on 161 pairs of images from the Mammographic Images Analysis Society (MIAS) mammogram database [7]. The resulting location of the skin-air interface improved in accuracy when compared to its location resulting from each algorithm separately. The accuracy improvement was determined by observing regions of obvious degradation, like the ones circled in figures 2a) and 2b). Accuracy of the interface resulting from the combination algorithm was judged to be greater if it followed the skin-air interface line more accurately then the corresponding degraded image.

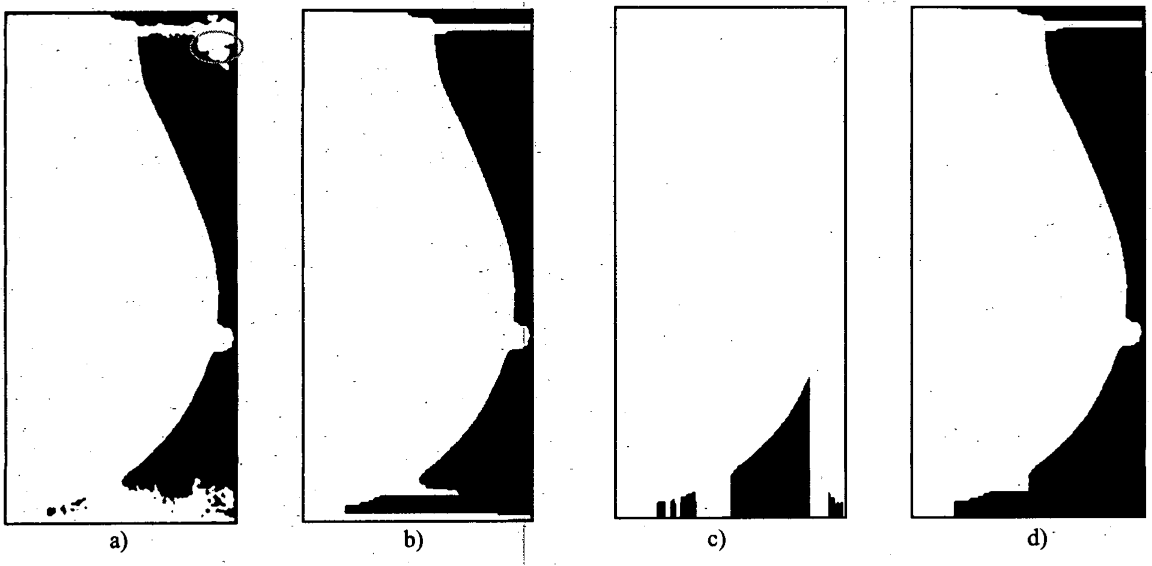
a) b) c) d)

FIGURE 1. a) Original breast mask with overhang caused by label circled, b) mask after finding the breast for each row, c) mask after finding the breast for each column, d) combination of the row and column images using the AND operator.

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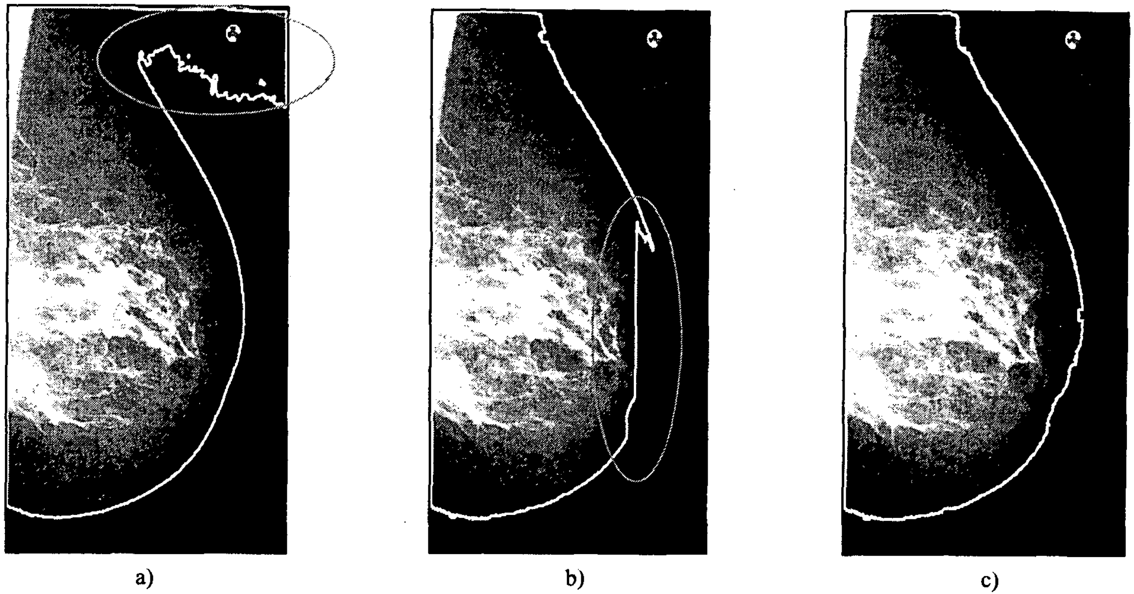

FIGURE 2. a) Histogram equalised original with skin-air interface outlined by single-threshold algorithm, noise at the top of the image (circled) is classified as part of the breast. The outer extremes of all estimates from the multiple threshold procedure are shown in b). Here there is an error in the skin-air interface where part of the breast (circled) is classified as background. Applying the combinatorial algorithm results in c), where the errors from the individual procedures have been removed.

The single threshold algorithm has problems with noise at the image edges due to the varying intensity of the skin-air interface. An example of this can be seen in figure 2a). The multiple threshold algorithm does not have such a severe problem at the edge, its output is shown in figure 2b). The result of combining these data is shown in figure 2c). The result does not contain the noise present in figure 2a) as the combination algorithm treats those points as outliers.

A fault of the multiple threshold algorithm is classification of locally specific noise as part of the breast in some local regions. This noise can be removed, as the single threshold algorithm is not as sensitive to local noise.

In some cases, the multiple threshold algorithm produces a skin-air interface for a portion of the image with the line being placed internal to the breast. This can be seen in figure 2b). In this case, the standard deviation between a point in this region and the corresponding point determined by the single threshold algorithm in figure 2a) will be large enough to force the algorithm to consider the prior data. This leads to the elimination of the erroneous points due to their distance from predictions based on prior data. Only points from the single threshold technique are considered, resulting in the smooth interface shown in figure 2c).

Problems are encountered when most of the estimates being considered contain an error. If this is the same error, the combinatorial algorithm sees no large discrepancy between the estimates and thus assumes them to be correct. If a number of different errors are supplied by each estimate for the same piece of the skin-air interface, the algorithm will use prior data to estimate the points within this piece. These estimates decrease in accuracy with the distance from the point used to determine the first such estimate.

IV. CONCLUSION

The method for combining different estimates of the mammographic skin-air interface is successful in eliminating noise characteristic to the individual methods. In cases where the estimates being combined are all inaccurate, the combinatorial algorithm can use the smooth continuity of the skin-air interface to predict where a point should be.

For best results, the different estimates must be complementary, in that a majority of the estimates should be accurate at any given point. Weights should be assigned to each estimate depending on similarity to the other estimates in terms of deficiencies.

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[1] Centre for Intelligent Information Processing Systems
Department of Electrical and Electronic Engineering
The University of Western Australia
Perth, Western Australia, 6907
masek-m@ee.uwa.edu.au