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4.4.1: Image Segmentation I - Model/Knowledge Based Methods

Gross Segmentation of Mammograms using a Polynomial Model

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Abstract

The breast and background on a mammogram form complementary, connected sets. Generally, the intensities comprising the background are spatially continuous, low in value and lie within a closed interval. The background may therefore be approximated by a polynomial in x and y on the basis of the Weierstrass approximation theorem. We include the whole background and a small portion of the breast in the region being modelled. The modelled background is subtracted from the original image, the resulting image thresholded, and the largest low intensity region taken to be the background. Connected regions are identified, labelled and merged. The background is flood-filled, and inclusions removed from the object, to yield a breast-background binary image. The method has been tested on 58 mammograms of two views from two digital mammogram databases. With one exception, it performs well and yields a skin-air interface with sufficient fidelity to preserve a nipple in profile.

Keywords—segmentation, mammograms, skin-air-interface, image-modelling

Introduction

The separation of object from background is the most fundamental step in image segmentation, which in turn is a primary step in processing an image. The mammogram is a particularly simple class of image in that the background and the object—the breast—are complementary sets that are both connected. Moreover, the physics of the imaging process results in an image in the analog domain, where, save for the film label and artifacts, the intensities comprising the background, $b(x,y)$, defined on some closed set $B \in \mathbb{R}^2$, are spatially continuous and usually occupy a band of low values on a closed interval $[0, b_m]$. Because there is a sudden and visually distinct change in intensity at the skin-air interface, it might be surmised that the background could therefore be segmented by global thresholding. However, the intensities constituting the breast and the background can and often do overlap as illustrated in Figure 1, and rule this out. Indeed, if the nipple is in profile, global thresholding will very likely segment it out of the object. Methods such as logarithmic transformation of intensities or increasing image gamma followed by thresholding will not work well, again because of this intensity overlap. Reports in the literature on segmenting breast from background range from manual segmentation using a computer mouse [1] to grey-level thresholding followed by morphological operations [2]. We note that the size and shape of the structuring element used in morphological operations could affect the fidelity of the extracted boundary when compared to the original. We adopt here an approach to segmentation based on a spatial model [3] of the image background that accords well with reality.

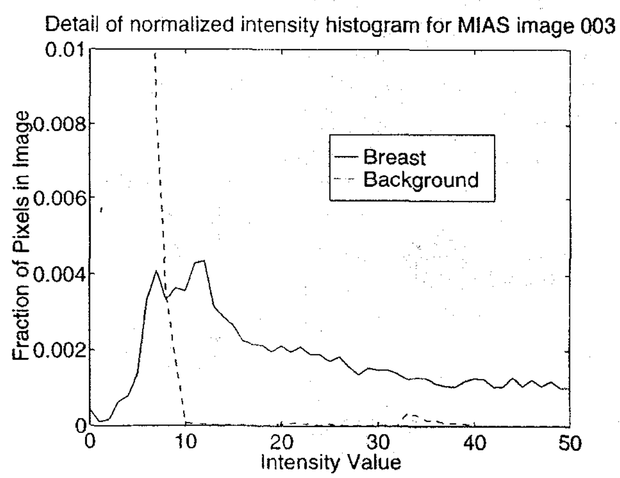

Figure 1: Overlap of background and breast intensities at values of 10 or less. The *same* intensities may therefore represent the breast in one region and the background in another region of the image. This precludes simple, spatially-invariant intensity thresholding to separate the breast from the background.

Because $b(x,y)$ is continuous over a closed domain B, we may approximate it to arbitrary accuracy by a polynomial in the spatial variables x and y, by virtue of the Weierstrass approximation theorem for ordinary polynomials [4, p 408]. By subtracting the background from the original image and processing it further, we obtain a binary image in which the boundary between the background and object is the skin-air interface. We believe that our method of modelling and subtracting out the background is particularly suited to mammograms and produces a skin-air interface with greater fidelity than methods relying on global thresholding or morphological operations.

Method

Analysis of the 8-bit greyscale mammograms in the MIAS database [5] has shown that $b_m \leqslant 10$; higher-valued background pixels being associated with artifacts (scratches, stripes, tapes) or film labels, both of which do not normally occur close to the breast. After orientating the *original image*, I_o, so that the nipple faces the right, we *threshold* it at an absolute intensity value of $t = 12$. The resulting region will contain the *entire* background and a small portion of the breast adjoining it. We then fit a polynomial of degree n in x and y, of the form, $c_{00}x^0y^0 + c_{10}x^1y^0 + c_{20}x^2y^0 + c_{11}x^1y^1 + c_{02}x^0y^2 + \cdots + c_{n0}x^ny^0 + \cdots + c_{0n}x^0y^n$, to all the thresholded pixels and determine the coefficients c_{ij} that minimize the square of the error. The *model image*, I_m, resulting from this polynomial, is then subtracted from I_o to yield the *subtracted image*, I_s (see Figure 2); the subtraction being clamped to prevent negative pixel values. The degree of the polynomial is chosen interactively so that the subtracted image yields a smooth, distinct *skin-air interface* that compares well with the original on visual inspection; the fidelity of the background elsewhere in I_s does not matter. We have found that values of n between zero and three are satisfactory in most cases to ensure that the background adjoining the breast is zero-valued in I_s.

The image I_s is then thresholded at a value k to give a binary image I_b where pixels of value less than or equal to k in I_s are black in I_b and others are white. We have found that although k could be chosen interactively, k may be set to zero automatically if the degree of the polynomial, n was chosen carefully. The background is taken to be the largest black region in I_b and is assigned a unique label on a congruent *label image*, I_l. The image I_b is then scanned from left to right and from top to bottom to identify all top- and left-connected *white* pixels to form regions. Contiguous regions of the same colour but with different labels are synonymous; synonym reduction is performed by hierarchically merging these regions. The largest white region is labelled the object. All white regions not connected to the object are merged into the background, which is then flood-filled. Inclusions of black in the object are also removed and the result is the final labelled image I_l shown in Figure 2(d) consisting purely of the breast and background as two *disjoint* regions.

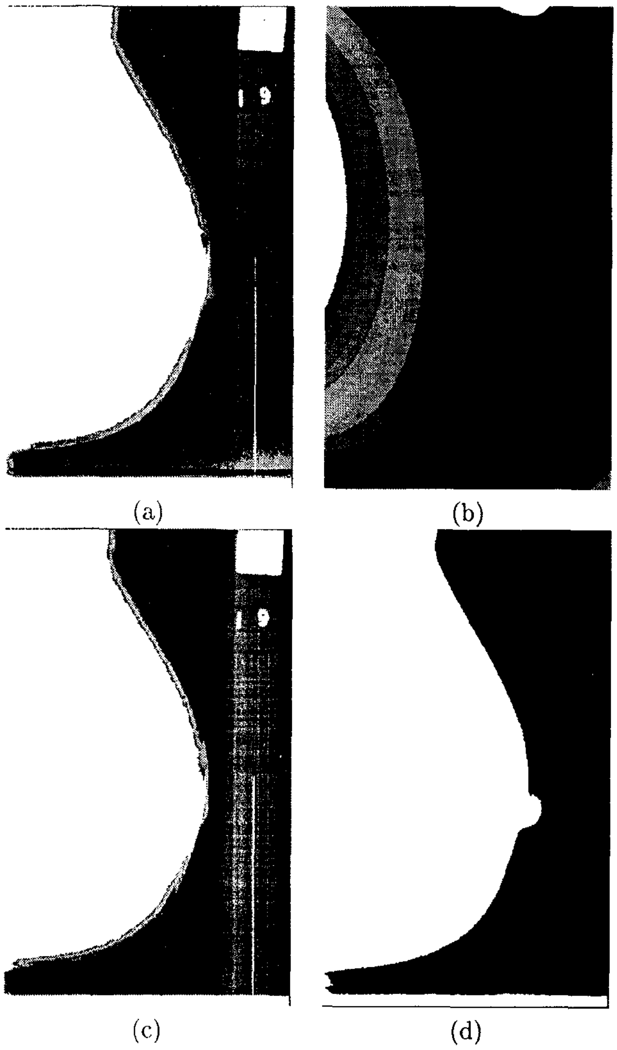

Figure 2: Background Subtraction: (a) original image I_o with sixteen lowest intensities shown as grey and all higher intensities as white; (b) image I_m of background modelled as a polynomial of degree 3; (c) subtracted image I_s; and (d) final segmented binary image I_l.

Results and Discussion

The method has been tested on a total of 58 images including both craniocaudal and mediolateral-oblique views from two databases: 28 from MIAS and 30 from UCSF/LLNL [6]. Except for one image (aslcc of UCSF/LLNL) where the film label and breast were contiguous, the results of the segmentation were in agreement with visual inspection of the original image using pseudo-colour. We are cautiously optimistic that the parameters n and k—which are at present chosen interactively, or semi-automatically—could be set to $n = 2$ and $k = 0$ to work on most images and thus automate the segmentation. Although our results vindicate the choice of $t = 12$, that value could be selected adaptively by analyzing the intensity histogram (or cumulative histogram) of I_o and estimating the value at which the rate of growth of (background) pixels decreases drastically. One qualitative comment is also in order: the background flare at the top and bottom edges of the image, is in some cases indistinguishable from the breast, e.g., in MIAS image 066. In such cases, our method gives rise to spurious "peninsulas" extending from breast to background. However, because segmentation of such images by eye, i.e., visual discrimination, is itself difficult, we do not consider this a serious drawback. Moreover, even in such images, the affected region is only the top or bottom 10 percent or so and the rest of the label image I_l gives a usable skin-air interface. The method has been used successfully as the pre-processing step in a nipple location algorithm in which 24 of the 58 test images were used.

There is a step-discontinuity in intensities at the skin-air interface where background ends and breast begins. All along this interface, therefore, the continuity assumption underlying the Weierstrass approximation theorem breaks down. We would therefore expect the approximation not to hold too well there. Moreover, there is a much larger number of background pixels compared to breast pixels in the thresholded portion of image I_o (see grey levels in Figure 2 (a)) . *This biased pixel ratio and the step discontinuity together ensure that the polynomial approximates the large continuous background better than the small region of the breast adjoining it.* This is one further reason why this segmentation preserves the nipple when other methods do not.

Taking logarithms or increasing image gamma tends to accentuate the separation between the lower intensities at the expense of the higher ones. Applying our method to an image so transformed would be one useful future line of investigation. Another would be to combine this method with edge-detection techniques and curve smoothing to improve the overall fidelity of the extracted boundary.

Conclusions

We have demonstrated that the background on a mammogram may be modelled as a polynomial in x and y on the basis of the Weierstrass approximation theorem. The pixel-by-pixel difference between the original image and the modelled background gives the subtracted image. If the degree of the polynomial is chosen so as to give a clean cleavage at the boundary of breast and background, the subtracted image may be thresholded and further processed to give a binary labelled image with a smooth skin-air interface that is faithful to the original image on visual comparison. This boundary has been used successfully in a nipple detection algorithm and is a prerequisite for bilateral comparison of the two breasts. It is our opinion that the results from this method are superior to those from simple global thresholding or morphological operations. The method is at present semi-automatic, but we are cautiously optimistic that it can be made fully automatic.

Acknowledgements

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