Nipple Detection in Craniocaudal Digital Mammograms

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Abstract – *Digital mammography brought many changes in the development of Computer Aided Detection (CAD) algorithms. Many preprocessing steps on mammograms are made automatically before the detection and diagnosis process begins. One of the very important steps is mammogram registration, which helps in finding asymmetrical regions in left and right breast. Mammogram registration is done by determining some key points of the breast. Key points are generally coordinates of the nipple and the pectoral muscle position. Nipple position can be detected using the algorithm presented in this paper. There are two possible nipple locations, outside and inside the skin-air interface. Each of these two cases has different intensity properties that should be taken into consideration when detecting the exact position.*

Keywords – *Nipple detection, Mammogram registration, Digital mammography*

1. INTRODUCTION

Today mammography can be roughly divided into analog Screen Film Mammography (SFM) and digital mammography. Analysis of the mammograms obtained from films requires digitalization as an additional preprocessing stage. After the digitalization process, mammograms have to be properly segmented from the background that can contain different objects, mostly orientation tags. Another drawback that occurs in the process of SFM image digitalization is inconsistency of the background intensity that occurs because of the film imperfection. In digital mammography, these problems are mostly avoided, thus digital mammograms are much easier to segment from the background. Mammogram registration is one of the most important steps in the preprocessing stage, before any detection is done. Correct registration can be helpful not only for the automatic detection methods but also to radiologists. There are different methods for mammogram registration. Some of the methods are registration by mutual information, alignment based on nipple location, alignment based on the center of mass and warping [1]. Chandrasekhar and Attikiouzel developed a method for the automatic nipple locating based on the detection of the sudden intensity change along the normal to the breast skin-air interface with the detection accuracy better than 1 mm for 23 of 24 tested images [2]. Another approach has been presented by Méndez et al. in [3]. This approach uses three algorithms to detect the nipple, the maximum height of the breast border, the maximum of the gradient across the median-top section of the breast and the maximum of the second derivative across the median-top section of the breast. 89% of tested images were successfully segmented and the mean error in detection of the nipple position was 14 pixels or 6 mm. Petroudi and Brady proposed a method for the nipple detection on mediolateral oblique (MLO) digitized mammograms [4]. They used a multi-scale approximation of the gradient along the inner and outer sides of the band near the skin-air interface, which they named the "fat-band". Because there are two possible cases (the nipple being outside or inside of the breast profile), they obtained two intensity diagrams from which the nipple position can be detected. Zhou et al. presented the nipple detection method that uses combination of searching the breast boundary and the identification using texture convergence analysis [5]. The proposed method has been evaluated on the set of 744 mammograms divided in groups with 377 and 367 mammograms used for training and testing, respectively, with the detection rate of 92.28% for the visible and 53.62% for the invisible nipples in the test set. The genetic algorithm approach for breast border and nipple position detection in order to register mammograms was presented by Karnan and Thangavel [6]. Kinoshita et al. presented the Radon-domain nipple detection approach [7]. The radon-domain transform is integration of the image along a straight line in the spatial domain with error<5 mm in 54.2%, 5 mm<error<10 mm in 25.1% and error>10 mm in 20.7% of tested images.

This paper presents a method for automatic nipple detection in digital mammograms. The proposed method is intensity based and uses certain morphological features of breast images. There are two possible cases when the nipple is visible on the mammogram and detection should be robust and invariant to both of those cases. For testing purposes a set of 144 digital mammograms in craniocaudal (CC) projection obtained from the same device is randomly selected. This paper is organized as follows. In Section 2 the nipple detection method is explained. Section 3 presents the data set used in experiments and results. Section 4 draws the conclusion.

2. NIPPLE DETECTION METHOD

There are two possible cases of visible nipple positions in mammogram, outside and inside of the breast profile. If the nipple is outside of the breast profile, it will have rather low overall intensity in comparison with the breast tissue. The reason for that is the physical dimension of the nipple. Mammogram is captured by squeezing the breast between two plates in order to achieve uniform intensity distribution. If one region of the captured breast is thicker than some other region, resulting mammogram will not be useful. The reason of its uselessness is the uneven intensity that is higher for the thicker area. For the same reason, nipples that are outside of the breast profile have very low intensity values and their detection generally depends on the sensitivity of the mammography system. If the nipples are inside of the breast profile, situation will be very different. This time the nipple position will have higher intensity than the surrounding, mostly fat, tissue. A case when the nipple is not visible in mammogram can also exist, but in that situation any detection is not possible, so those cases are not taken into consideration. Fig. 1 shows cases of the nipple being outside and inside of the breast profile with the belonging tissue masks.

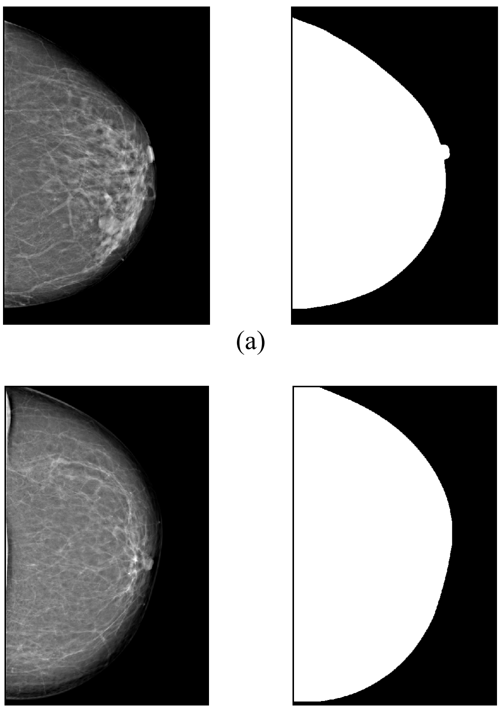


Fig. 1. (a) Case of the nipple outside of the breast profile with belonging binary mask. (b) Case of the nipple inside of the breast profile with the belonging binary mask.

Fig. 1 shows that the part of the nipple inside of the breast profile is brighter than the surrounding tissue. The first task is therefore to determine whether the nipple is outside or inside of the breast profile. For that purpose the opening method applied to segmentation mask is used. The first step is to erode the binary mask with a structuring element and then to dilate the obtained mask with the same structuring element. As a structuring element, a 13×13 pixel square has been chosen. If there are differences between the original and the mask after opening, the presumption is that the nipple is outside of the breast profile. If there are no differences, the nipple is inside of the breast profile. The nipple is always located somewhere close to the skin-air interface near the central point of vertical image coordinate. The geometry used to extract the data for the analysis is obtained as follows (as illustrated in Fig. 2). First the segmentation mask is reduced for the side length of the square which area equals 1/3 of total area covered by the segmentation mask,

$$a = \frac{\sqrt{M}}{3}, \qquad (1)$$

where a is one side of the square and M is the total area of the binary segmentation mask. From the newly obtained mask, the center pixel for semicircle approximation is calculated as the center from two detected borders of the mask. From that center point, the Euclidean distances to the mask edge are calculated for angles between -45° and +45° as shown in Fig. 2,

$$d_R = \sqrt{(x_C - x_E)^2 + (y_C - y_E)^2}, \qquad (2)$$

where d_R is the Euclidean distance between the center and edge points, (x_C, y_C) is coordinate of the center and (x_E, y_E) is coordinate of one of the edge points. Fig. 2 shows the geometry used to extract the area where the nipple will be detected.

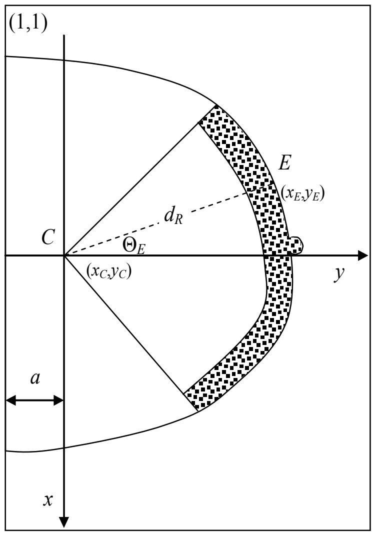


Fig. 2. Geometry used to extract the area for nipple detection.

The starting presumption is that the nipple should be located inside the 90° angle in the dotted band shown in Fig. 2. The extracted band has the same height of 40 pixels for each angle. The angle resolution being used is 0.5°, what gives the total number of 181 calculated angles. For each angle a set of 40 pixels is extracted from the image with coordinates calculated from the parametric line equations

$$\begin{aligned} x_{i,E} &= x_C + (d_R - i)\cdot\sin(\Theta_E) \\ y_{i,E} &= a + (d_R - i)\cdot\cos(\Theta_E) \end{aligned}, \qquad (3)$$

where i is the distance from the edge of the segmentation mask [0, 39] pixels and Θ_k is the corresponding angle [+45°, -45°], while other variables are explained in Fig. 2. This approach, of course, highly depends on accurate image segmentation, but that is not a big problem with digital mammograms because they are usually well preprocessed.

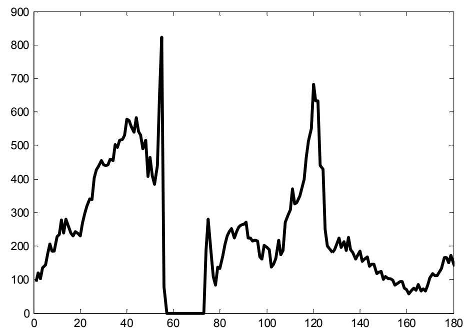
3. EXPERIMENTS AND RESULTS

The data set used in testing of the proposed method consists of 144 CC mammograms from 72 patients. All mammograms were captured using the same mammography device, Siemens Mammomat Novation DR [8] and therefore all have the same resolution and characteristics. Resolution of each image is 4084×3328 pixels with 12 bits allocated per pixel and 70 μm/pixel resolution. Images are stored in conformance with the DICOM standard [9], [10]. All images have defined displaying parameters that were used to convert amplitude range into 8 bits. Before determining the mask of each image, all images were downsampled 4 times to achieve better computational efficiency. After that, mask of the breast tissue is created without using windowing parameters, because in this way all the recorded pixels are taken into account. The range of amplitudes that represent tissue, recorded in the image header, is then transformed into 8 bits. Resulting data set images have resolution of 1021×832 pixels with 8 bits per pixel and 280 μm/pixel resolution. From each tested image the band of 181×40 pixels is extracted, as can be seen on Fig. 2. The opening is used to decide whether the nipple is outside or inside of the breast profile. If the nipple is outside of the breast profile then the detection algorithm is optimized to find the cumulative minimum. Reason for this approach is that the nipple outside of the breast profile is consisted of pixels that have amplitudes under or around lower window border. Those pixels will therefore exist as part of the image in the mask but their value in the transformed 8 bit image will be equal to zero. On the other hand, in a case that the nipple is inside of the breast profile, the detection algorithm should find the cumulative maximum. The two possible situations of different bands are shown in Fig. 3.

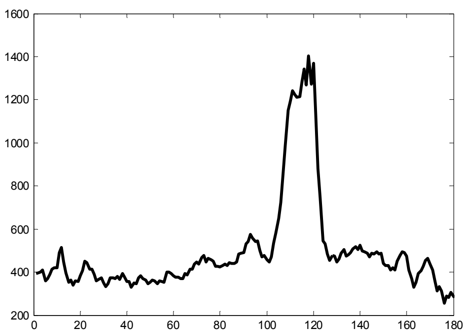
(a) (b)

Fig. 3. (a) The band in the case when the nipple is outside of the breast profile. (b) The band in the case when the nipple is inside of the breast profile.

From the Fig. 3 the idea of position detection is clearly visible. In the first case cumulative intensities are computed for first 10 columns and in the second case for the columns 21 to 30. Coordinates of the actual nipple position are calculated using the inverse of (3) with the data from cumulative intensity diagrams shown for these two cases in Fig. 4.



(a)



(b)

Fig. 4. (a) Cumulative intensity diagram for the nipple outside of the breast profile. (b) Cumulative intensity diagram for the nipple inside of the breast profile.

The reason why these starting and ending numbers of columns are chosen is the size of the nipple in the resized image, which is around 20×20 pixels. The cumulative intensity diagram is finally smoothed to remove sudden amplitude changes caused by non-uniform tissue intensities. The reason why image has not been filtered with averaging filter instead is that it would result in unsharp minimums and maximums which is the unwanted situation. Smoothing is done at each coordinate using

$$I_n = \frac{1}{5}\sum_{k=n-2}^{k=n+2} I_k \ , \tag{4}$$

where I_n is the n-th cumulative value in the diagram. After the smoothing, the additional simple thresholding is made in the way that maximum level detection threshold is lowered and minimum level detection threshold is raised for the value of 10. This is only being done for the cases where it does not affect the overall detection accuracy with the detection of unwanted components.

Results obtained using the method proposed in this paper are the following. In 141 of total 144 images nipples were detected (97.92%). The average detection inaccuracy is 4.82 pixels (1.35 mm). In 79 or 56.03% of images with the detected nipple, inaccuracy is less than 1 mm.

4. CONCLUSION

The accurate nipple position can be a very important parameter in the process of mammogram registration. This paper presents a method for automatic nipple detection in digital CC mammograms. The method is fully automatic and provides good results for the cases when the nipple is outside or inside of the breast profile. Opening of the breast binary mask has been used to determine which detection method should be used. The nipple detection has been done on the extracted band of pixels near skin-air interface with the angle resolution of 0.5°. Detected nipple position from the extracted band is than transformed to match the exact position in the original image. Overall detection rate is 97.92% with the accuracy better than 1 mm for 56.03% of images.

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