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Article

The Role of Acquisition Angle in Digital Breast Tomosynthesis: A Texture Analysis Study

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1. Short tutorial about relevant features calculations and descriptions

To keep consistency with the formulas used in the standard references (Haralick 1973, Haralick 1979) on texture analysis, it is assumed in MaZda that the intensity of image under analysis changes from 1 to Ng, where Ng = 2k, and k is the number of bits per pixel. Thus, if the original image intensity changes from 0 to Ng-1, MaZda converts this image internally, such that its intensity changes from 1 to Ng. Consequently, the summation indices in the formulas listed below span the range from 1 to Ng.

2. Co-occurrence matrix-derived parameters

The second-order histogram is defined as the co-occurrence matrix $h_{d\theta}$ (i,j). When divided by the total

number of neighboring pixels R(d,θ) in ROI, this matrix becomes the estimate of the joint probability, $p_{d\theta}$

(i,j), of two pixels, a distance d apart along a given direction θ having particular (co-occurring) values i and j. Formally, given the image f(x,y) with a set of Ng discrete intensity levels, the matrix $h_{d\theta}$ (i,j) is defined such that its (i,j)th entry is equal to the number of times that

$$f(x_1, y_1) = i \; and \; f(x_2, y_2) = j, \tag{1}$$

where

$$(x_2, y_2) = (x_1, y_1) + (dcos\theta, dsin\theta) \tag{2}$$

This yields a square matrix of dimension equal to the number of intensity levels in the image, for each distance d and orientation θ;. In MaZda, the distances d = 1, 2, 3, 4 and 5 pixels with angles θ; = 0°, 45°, 90° and 135° are considered. Reduction of the number of intensity levels (by quantization to fewer levels of intensity) helps increase the speed of computation, with some loss of textural information. The co-occurrence matrix-derived parameters computed by MaZda are defined by the equations that follow, where μ_x, μ_y and σ_x, σ_y denote the mean and standard deviations of the row and column sums of the co-occurrence matrix, respectively [related to the marginal distributions $p_x(i)$ and $p_y(j)$].

Contrast:

$$\mathrm{Contrast} = \sum_{n=0}^{N_g-1} n^2 \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} p(i,j)^2 \tag{3}$$

Contrast is a measure of the local intensity variation, favoring values away from the diagonal (i=j)(i=j). A larger value correlates with a greater disparity in intensity values among neighboring voxels.

Correlation:

$$Correlat = \frac{\sum_{i=1}^{N_g} \sum_{j=1}^{N_g} ijp(i,j)^2 - \mu_x \mu_y}{\rho_x \rho_y} \tag{4}$$

Correlation is a value between 0 (uncorrelated) and 1 (perfectly correlated) showing the linear dependency of gray level values to their respective voxels in the GLCM.

Inverse difference moment:

$$InvDfMom = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} \frac{1}{1 + (i-j)^2} p(i,j) \tag{5}$$

Inverse difference moment is a measure of the local homogeneity of an image. With more uniform gray levels, the denominator will remain low, resulting in a higher overall value.

Difference Variance:

$$DifVarnc = \sum_{i=0}^{N_g-1} \left(i - \mu_{x-y}\right)^2 p(i,j) \tag{6}$$

Where μ_{x-y} is a mean value of the difference distribution p_{x-y}

$$p_{x-y}(k) = \sum_{i=1}^{N_g} \sum_{j=1}^{N_g} p(i,j) \qquad k = 0,1,\ldots,N_g - 1 \text{ e } |i-j| = k. \tag{7}$$

Difference Variance is a measure of heterogeneity that places higher weights on differing intensity level pairs that deviate more from the mean.

Difference Entropy:

$$DifEntrp = -\sum_{i=1}^{N_g} p_{x-y}(i) \log(p_{x-y}(i)) \tag{8}$$

Difference Entropy is a measure of the randomness/variability in neighborhood intensity value differences.