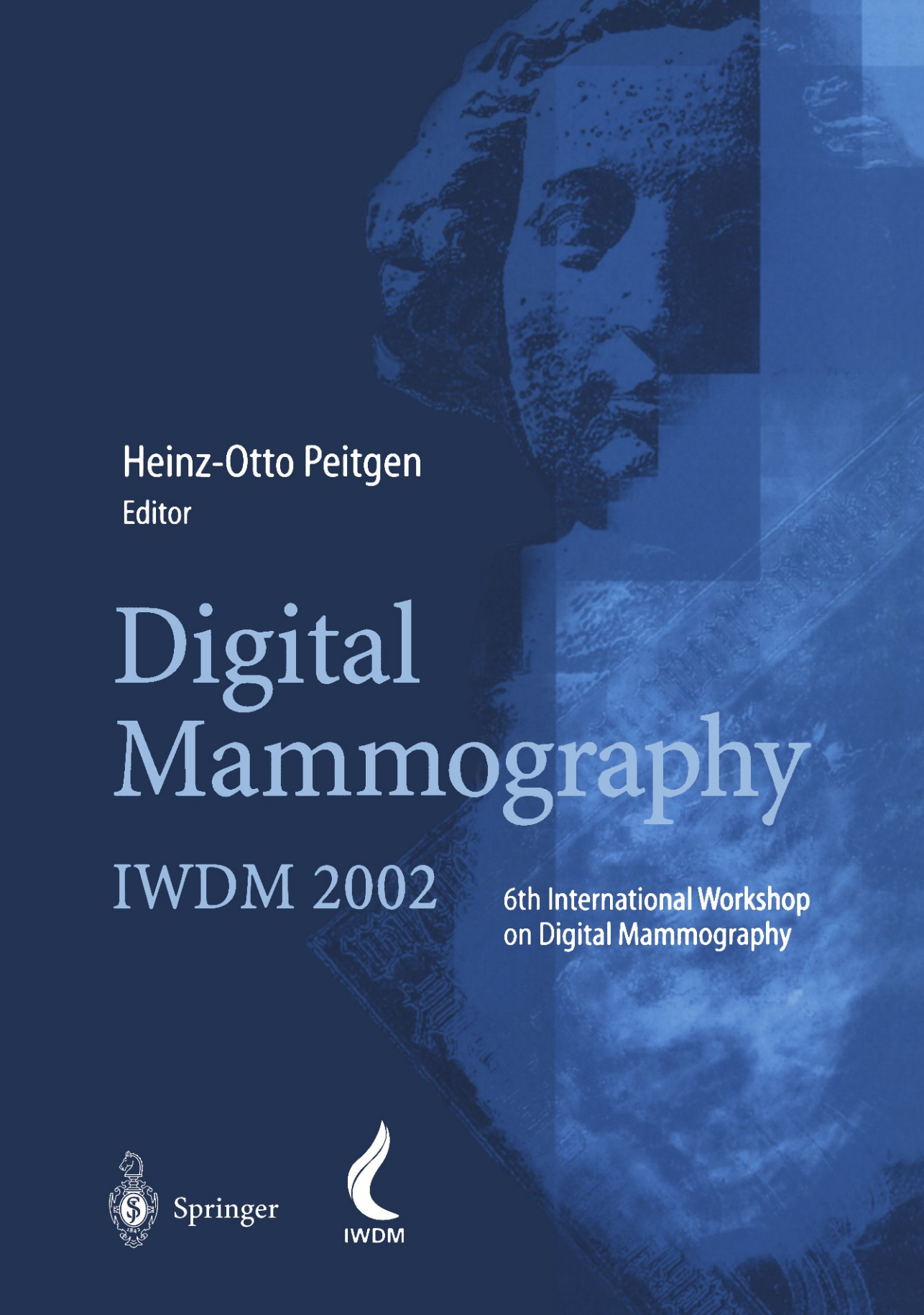

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Rapid Segmentation of Calcification Clusters using Multi-resolution Guided Fuzzy C-Means and Wavelet Processing

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Work presented here focuses on employing wavelets, multi-resolution guided fuzzy c-means (FCM), and coarse-to-fine feature analysis for rapid detection of microcalcification clusters in uncropped images. FCM segmentation is guided through a multi-resolution approach to rapidly distinguish medically relevant tissue from background. Sets of overlapping sub images, containing only relevant tissue, are extracted from the image for further high-resolution analysis. A minimum number of features are used in a simple fuzzy system to detect candidate microcalcifications. This coarse detection is shown to provide high detection rates while minimizing the data points requiring further feature analysis. Feature extraction and classification is performed with a radial basis function (RBF) neural network. Cluster analysis provides final detection.

1. Introduction and Methodology

The goal of this research is to explore methodologies for improving execution times while maintaining good detection and specificity for calcifications in an uncropped, full-resolution mammogram image. This is done by applying fuzzy c-means algorithm (FCM) in a multi-resolution fashion and combining wavelet processing to rapidly segment candidate calcifications [1]. The overall design of the algorithm employed in this research is detailed in Figure 1. FCM is used to initially extract medically relevant tissue from background. FCM is applied to a low-resolution, down-sampled image (1:4096 pixels) to develop a set of prototypes, which are applied to another down-sampled version of the image (1:16 pixels). The classified (1:16) down-sampled image is dissected into a set of overlapping sub images and each sub image is analyzed to determine if it contains tissue or background. Those containing relevant tissue guide extraction of a high-resolution sample from the original image for calcification analysis.

A 4 level biorthogonal wavelet analysis is performed for each high-resolution (~500 x ~500 pixels) sub image. The level 1 detail and level 4 approximation coefficients are removed, and level 4 detail coefficients are rescaled to reconstruct a "contrast" image.

FCM with 3 clusters is performed on the 4^{th} level approximation coefficients, directly, and then prototypes are applied to the wavelet reconstruction of the 4^{th} level approximation coefficients only. Noise equalization, as a function of intensity, is performed by estimating the standard deviation of the contrast image corresponding to the 3 segmented areas in the "smoothed" 4^{th} level approximation image.

Next, fuzzy images are created for each of the intensity and contrast images using a trapezoidal membership function. The intensity membership function scales intensity values between the 2^{nd} and 3^{rd} FCM prototypes to 0 and 1, and the contrast membership function scales contrast values between 0.9σ and 6.5σ to 0 and 1. A minimum function is then employed for a fuzzy "AND" to combine intensity and contrast. This final step appears to have additional equalizing properties adjusting for the fact that average contrast is higher in the areas of darker intensities [1].

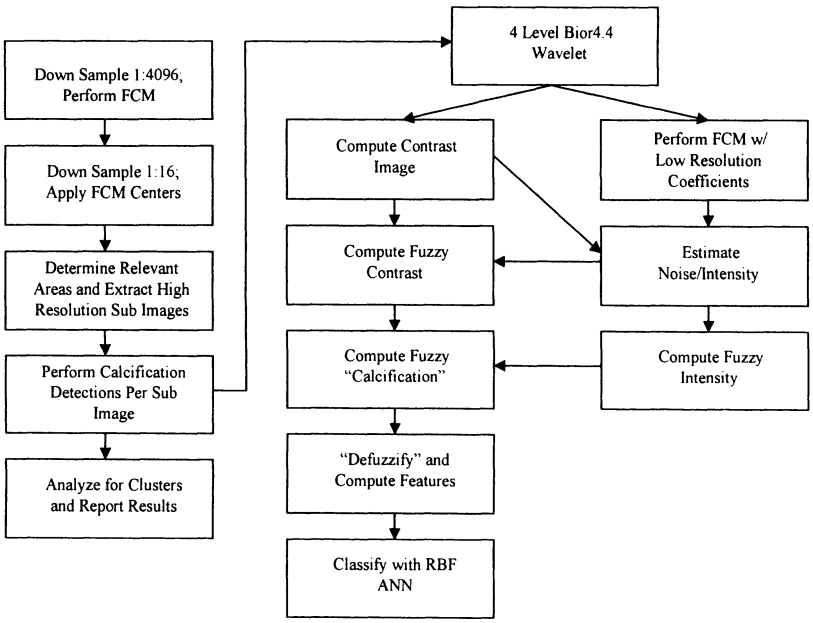

Fig. 1. Overflow of calcification detection algorithm.

Several features are extracted from candidate calcifications using 20 x 20 pixel regions to include (1) area, (2) contrast, (3) maximum wavelet contrast value, and (4) four different Law's texture measures (R5R5, L5S5, L5E5, S5S5). The Law's energy measures is computed for both background and foreground pixels. Due to the size of the analysis regions, it is possible for neighboring calcifications to appear as foreground pixels. The Law's energy features and contrast are measured with the extraneous detections as both foreground pixels and background pixels. A radial basis function (RBF) network is then used to classify the candidates. Cluster analysis determines cluster locations and density with thresholds set at 3 calcifications/cm^2.

2. Results and Conclusion

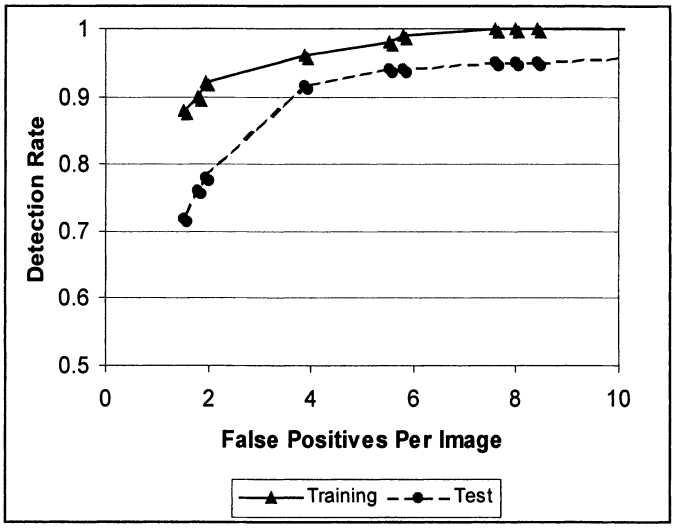

Fig. 2. ROC detection performance.

Results for four training images and twenty testing images with malignant microcalcifications from the Digital Database for Screening Mammography (DDSM) [2] are shown in figure 2. While Karssemeijer reports a processing time of 3 minutes, our average processing time per image was 4.5 minutes running in MATLAB on a Sun Ultra60 with 1GB of RAM. However, our times are based upon processing of higher resolution data, automatic extraction of relevant tissue from background, and running within an interpretive language environment. This algorithm also does not outperform results reported by Karssemeijer [3] for the long-range interaction model in terms of specificity. False positives from our algorithm appear to be attributed to linear structures and vascular calcification detections. Future work includes porting to a non-interpretive language where a multi-fold increase in image throughput is expected. We are also seeking input from clinicians who have access to the R2 ImageChecker® system.

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