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# Contour-independent detection and classification of mammographic lesions

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ABSTRACT

We present a multistage approach to detection and classification of mammographic lesions that is independent of accurate extraction of their contours. The ultimate goal is to discriminate malignant tumors from benign lesions and normal parenchymal tissue in a realistic scenario of lesion candidates automatically detected in mammograms. Local analysis of the Gaussian curvature and of the phase response of multidirectional Gabor filters is performed for identification of suspicious focal areas. The detection of lesions and the classification of malignant tumors are performed in series, respectively, via a differential approach to analysis of the tissue surrounding the candidates and via quantification of nonstationarity and spatial dependence of pixel values within circular and annular regions of interest. A unified 3D free-response receiver operating characteristic framework is applied for global analysis of the two binary categorization problems in series. The system was tested on a total of 2105 full-field digital and screen-film mammograms from three different datasets, including abnormal mammograms with 560 malignant tumors and 639 benign lesions, masses, or architectural distortion, and 1010 normal mammograms. For sensitivity of detection of malignant tumors in the range of 0.70–0.81, the range of falsely detected malignant tumors was 0.82–3.47 per image, with a series of two stages of classification, including stepwise logistic regression for selection of features, Fisher linear discriminant analysis, and two-fold cross-validation.



## 1. Introduction

Computer-aided diagnosis (CAD) is a strategy alternative to double reading to help radiologists in the interpretation of mammograms and improve the performance of mammography in detecting breast cancer [1]. Progression of cancer and delays in needed treatment can result if malignant lesions are not detected or are misinterpreted as being benign (false-negative diagnosis). The causes of such errors are low prevalence of the disease in a screening population and the subtle or indistinct nature of features of malignancy in lesions as they appear on mammograms [2]. Also, unwarranted biopsies and increased costs occur if benign lesions or normal parenchymal structures are assessed as being malignant (false-positive or FP diagnosis), with consequent anxiety for the patient and even increased morbidity [3]. Hence, a clinically effective CAD system should provide an estimate of the degree of malignancy of the detected lesions in order to prompt the radiologist for further assessment and treatment in the presence of pathological processes. Several studies [4–6] investigated the effects of computerized systems on radiologists' performance in differentiating benign and malignant masses, and have reported a statistically significant increase in the area under the receiver operating characteristic (ROC) curve for the estimation of the likelihood of malignancy while using a CAD system.

The classification of masses as benign lesions or malignant tumors can start with hand-drawn contours of the lesions [7,8] or manually extracted regions of interest (ROIs) [9]. This initial procedure is usually followed by segmentation [10–12] and characterization of the lesions in terms of margins, shape, and texture and subsequent classification [13]. If based on accurate estimation of the contours of the lesions, either drawn by a radiologist or extracted by dedicated segmentation procedures, the systems are

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prone to fail in the presence of obscured or ill-defined boundaries of tumors. Intraexpert and interexpert variability in identifying or validating the margins of lesions may compromise the robustness of such systems [13]. An alternative approach to overcome this issue is represented by content-based image retrieval techniques which consist of searching for similarity based on visual content between query ROIs and a dataset of previously diagnosed ROIs [14]. Such systems, however, are conventionally tested on labeled datasets where positive instances of query ROIs are manually centered on malignant tumors or benign lesions [15,16]. Additional strategies and analysis are required to combine automatic detection and classification of mammographic lesions. In fact, the characterization of automatically detected lesions or ROIs in terms of malignancy leads to further complexity as a result of the integration of methods for detection, dealing with benign and malignant masses without distinction [17–19], and classification [13] in a unified system. A few works in the literature have addressed this open issue [20–22], but many challenges are still to be tackled for improved global performance levels and transparency of the automated decision process [13]. The main difficulties with CAD in mammography arise due to the large variability of the abnormalities present and to their similarity with the normal mammographic appearance, especially in the presence of dense breasts where the superimposition of normal parenchymal structures may disguise a pathological process. The final performance assessment of the classification stage should also take into account the performance of detection in order to provide a realistic interpretation of the obtained results.

In this work, the development of a comprehensive and multistage system for automatic detection and classification of malignant tumors is addressed in a realistic scenario of a three-class environment, i.e., in the presence of normal parenchymal tissue, benign lesions, and malignant tumors. The system has been designed so that accurate extraction of the contours of the lesions to be detected and classified is not needed. The following main contributions are presented.

1. Analysis of the Gaussian curvature of the mammographic appearance of the breast region, which is represented as a three-dimensional (3D) surface of intensity values and as a function of spatial coordinates for the extraction of suspicious focal areas.
2. Rejection of the oriented structures of the normal breast parenchyma, such as portions of the skin-line, vessels, and breast ducts, via analysis of the phase response of multidirectional Gabor filters.
3. Extraction of circular ROIs (C-ROIs) and subsequent adaptive determination of annular regions including the lesion candidates.
4. Detection of lesions based on quantification of the differences in texture and density between the suspicious focal areas and the surrounding tissue.
5. Design of contour-independent feature descriptors for the classification of automatically detected malignant tumors, including space and intensity as explanatory variables to analyze the local nonstationarity [23] and spatial dependence [24] of pixel values in the angular and radial directions starting from circular or annular regions depicting a lesion.
6. Application of a unified 3D free-response receiver operating characteristic (FROC) framework for evaluation and analysis of two binary classification problems in series, i.e., the detection of lesions and their subsequent classification as malignant tumors, benign lesions, or normal tissue, to assess the cumulative performance and error of a CAD system in detecting breast cancer with respect to falsely detected tumors (including benign lesions and normal tissue).
7. Validation of the system on a diversified set of images including full-field digital mammograms (FFDMs) and digitized screen-film mammograms (SFMs) from three different databases and acquired with different devices.

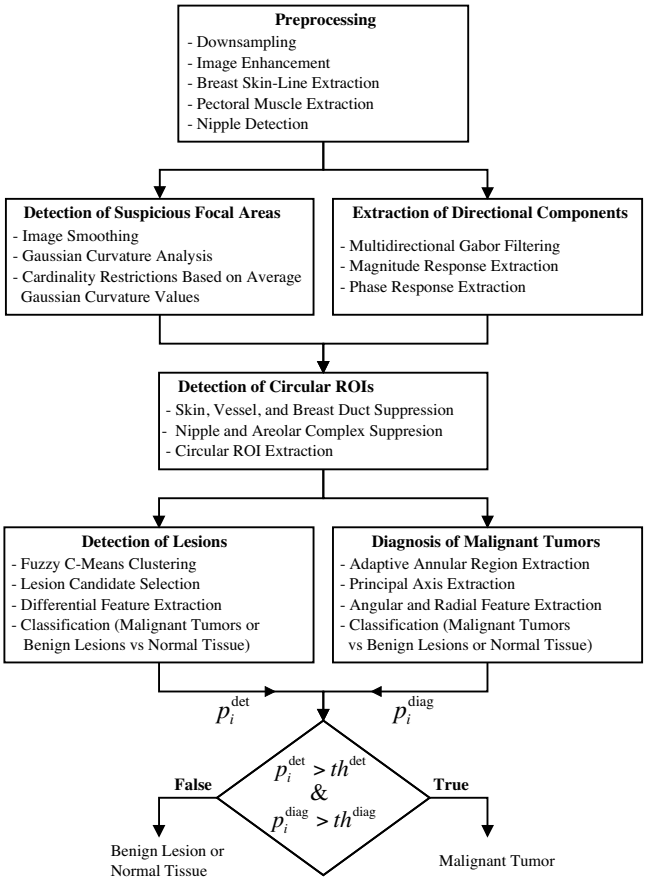


**Fig. 1.** Flowchart of the proposed CAD system for detection and classification of malignant tumors in mammograms. The probabilities of detection, $p_i^{det}$, and diagnosis, $p_i^{diag}$, represent the probability of being a lesion and of being a malignant tumor, respectively. The two probabilities are combined together using thresholds for detection, $th^{det}$, and classification, $th^{diag}$.

A flowchart of the algorithm is illustrated in Fig. 1 for an overview of the main methodologies used in this study. The present paper includes revised and updated methods from our preliminary reports listed as references [25–27]. All the analysis and results provided with previous reports were related to the FFDM dataset only. In this work, we present extended and more detailed description of methodology and related results on automatic detection and classification of mammographic lesions in a unified CAD system for mammography, including 1949 additional mammograms from publicly available databases. The use of some empirically determined parameters has been replaced by fuzzy c-means data clustering of pixels within automatically extracted C-ROIs. The contour-independent features have been normalized to make them invariant to the size of the lesions. Moreover, given the increased number of tested images, two-fold cross-validation and Fisher linear discriminant analysis are used for validation and classification, respectively. We also present a detailed analysis in terms of margins of the lesions and BI-RADS [28] density values of the SFMs, which include a significant number of lesions with obscured or ill-defined margins. Such information was not available for the FFDM database and could not be used for all the related analysis. Instead, given the independence of the proposed methods from the extraction of accurate contours, it was possible to include additional mammograms including regions of architectural distortion, which were used for testing the system together with mammograms including