Computerized Medical Imaging and Graphics 46 (2015) 95–107

Contents lists available at ScienceDirect

Computerized Medical Imaging and Graphics

journal homepage: www.elsevier.com/locate/compmedimag

Multi-scale textural feature extraction and particle swarm optimization based model selection for false positive reduction in mammography

Imad Zyout [a,*], Joanna Czajkowska [b], Marcin Grzegorzek [c]

[a] Communications, Electronics and Computer Engineering Department, Tafila Technical University, Tafila 66110, Jordan
[b] Department of Computer Science and Medical Equipment, Faculty of Biomedical Engineering, Silesian University of Technology, ul. Roosevelta 40, 41-800 Zabrze, Poland
[c] Institute for Vision and Graphics, University of Siegen, Hoerlindstr. 3, 57076 Siegen, Germany

ARTICLE INFO

Article history:
Received 14 November 2014
Received in revised form 24 January 2015
Accepted 16 February 2015

Keywords:
False positive reduction
Mammography
Multi-scale texture analysis
Model selection
Particle swarm optimization
Support vector machines

ABSTRACT

The high number of false positives and the resulting number of avoidable breast biopsies are the major problems faced by current mammography Computer Aided Detection (CAD) systems. False positive reduction is not only a requirement for mass but also for calcification CAD systems which are currently deployed for clinical use. This paper tackles two problems related to reducing the number of false positives in the detection of all lesions and masses, respectively. Firstly, textural patterns of breast tissue have been analyzed using several multi-scale textural descriptors based on wavelet and gray level co-occurrence matrix. The second problem addressed in this paper is the parameter selection and performance optimization. For this, we adopt a model selection procedure based on Particle Swarm Optimization (PSO) for selecting the most discriminative textural features and for strengthening the generalization capacity of the supervised learning stage based on a Support Vector Machine (SVM) classifier. For evaluating the proposed methods, two sets of suspicious mammogram regions have been used. The first one, obtained from Digital Database for Screening Mammography (DDSM), contains 1494 regions (1000 normal and 494 abnormal samples). The second set of suspicious regions was obtained from database of Mammographic Image Analysis Society (mini-MIAS) and contains 315 (207 normal and 108 abnormal) samples. Results from both datasets demonstrate the efficiency of using PSO based model selection for optimizing both classifier hyper-parameters and parameters, respectively. Furthermore, the obtained results indicate the promising performance of the proposed textural features and more specifically, those based on co-occurrence matrix of wavelet image representation technique.

1. Introduction

According to statistics provided by the World Health Organization (WHO) breast cancer was responsible for 458,000 deaths in 2008 worldwide and is a leading cause of women death around the world. Since the effective prevention of breast cancer occurrence is still impossible, the detection and diagnosis of the disease at its early stage is a significant step towards an increased breast cancer survival rate. Mammography, an X-ray based breast imaging modality, is currently the most effective tool for breast cancer screening. However, mammogram interpretation, even done by expert radiologists, is a difficult and error prone task due to the low contrast of the images and the subtle signs of breast cancer early stage. Such a misinterpretation of mammograms not only results in a low positive prediction value of mammography, which in turn leads to many unnecessary invasive biopsies and high recall rates [1], but also causes many life-threatening false negatives.

A double reading or second mammogram interpretation of the same data by another radiologist has shown a significant increase of cancer detection reducing the number of undiscovered lesions [2,3]. However, such a double reading procedure is not always feasible, since it has to be done by an expert radiologists. An alternative to a human double reading is the Computer Aided Diagnosis (CAD) technology, which is intended to provide radiologists with a second opinion by warning them about unnoticed breast abnormalities and by assisting in characterizing the malignancy of detected lesions.

* Corresponding author. Tel.: +962 772105655.
E-mail address: izyout@ttu.edu.jo (I. Zyout).

http://dx.doi.org/10.1016/j.compmedimag.2015.02.005
0895-6111/

Several studies have shown that CAD technology has the potential to significantly improve the early detection of breast cancers [3]. Gromet et al. [4] reported that combining a CAD system with a single reading by radiologists has improved the detection sensitivity of breast cancer by 10% with small increase of the recall rate.

Due to the fact that the detection of breast masses, which resemble normal breast parenchyma, is more challenging than the detection of microcalcifications, some of the CAD systems have been clinically approved and are currently used for calcifications detection but not for masses. However, even for calcifications, the main drawback of existing CAD technology is the high number of false positives [3]. A false positive of mammogram interpretation occurs, when a normal breast region is marked suspicious and consequently an increase of unnecessary breast biopsies is encountered. Such a low detection specificity (or high false positives rate) is mostly the reason behind the argument concerning the role of CAD technology.

Rather than developing new mass detection algorithms which produce satisfactory cancer detection results, several studies [5–12], have recently devoted efforts to develop False Positive Reduction (FPR) methods that aim to improve the specificity of mass detection and the efficacy of CAD technology, and its potential as a mammography double reading stage. Generally, a FPR algorithm can be seen as post-processing or complementary stage, which is intended to reduce the false positive results produced by a predecessor computer aided detection system. Similar to most CAD systems, FPR algorithms solve the pattern recognition problem of discriminating a suspicious mammogram region as normal breast parenchyma or breast region with a benign or malignant lesion in three steps: feature extraction, dimensionality reduction by feature selection, and binary classification based on supervised learning. Methods and datasets used for implementing previous FPR systems are the key factors behind the achieved performance levels. A brief review of recent literature on FPR algorithms and methods used for implementation is given subsequently.

Angelini et al. [5] reduced false positive results of mass detection using a wavelet based image representation and SVM classifier with polynomial kernel. In this study, wavelet coefficients from discrete and over-complete (without the decimation step) wavelets based on Haar filters were used. Evaluating both pixel based and wavelet based approaches on 5000 mammograms (1000 regions depicting masses and 4000 representing normal breast tissue) they demonstrated the advantage of using pixel based representation over wavelet based method. Rashed et al. [6] used wavelet based image analysis of mammograms with a fraction of wavelet coefficients (the biggest coefficients) as a feature vector to classify different types of breast abnormalities including speculated lesions. Oliver et al. [7] used 2D Principal Component Analysis (2DPCA) image representation and combined decision tree and k-nearest neighbour classifier. Varela et al. [9] discriminated mammographic regions depicting true masses from normal regions using a combination of shape and texture features, and Back-Propagation Neural Network (BPNN) classifier. Local Binary Patterns (LBP) of gray-level image and SVMs with a polynomial kernel were used to improve the specificity of mass detection in [8]. Ramos et al. [10] evaluated and compared the performance of a small number of Haralick descriptors computed from co-occurrence matrices of gray level, wavelet, and ridgelet image representations. For the feature selection task they incorporated Genetic Algorithm (GA) and, in the ROIs classification stage, they suggested the random forest method. Hussain et al. [11] presented a FPR algorithm using texture features acquired through Multi-Scale Weber Law Descriptor (MSWLD) and SVM classifier. The obtained results proved better performance of MSWLD approach compared to LBP based technique used by Lladó et al. [8]. Recently, Braz et al. [12] used biologically inspired diversity indices as texture descriptors to discriminate mass from none-mass regions.

Although the low positive predictive value is a common problem for CAD systems supporting different breast lesions, existing FPR algorithms have focused on improving the specificity of mass detection only. However, even for this, existing algorithms require further improvements. Particularly, the feature extraction and parameter selection methods used for solving the FPR problem need several important steps to be done to achieve the desired performance. Some studies [5,6] used wavelet coefficients or a fraction of the coefficients as descriptors, or computed a few descriptors with one wavelet basis function to generate the multi-scale image analysis [10]. However, wavelet based feature extraction has not been well examined with respect to the techniques used for computing multi-scale textural descriptors and for the wavelet basis functions to produce multiresolution analysis.

In this paper, breast tissue is characterized using different multi-scale textural features based on first and second order statistics of gray level and wavelet image representations. More specifically, First Orders Statistics of Wavelet Coefficients (FOSWC) based on energy and entropy features, co-occurrence (or Haralick) descriptors of both image gray levels, and wavelet coefficients are introduced. Although the application of wavelet theory and co-occurrence matrices for texture analysis of mammograms is not new, this paper represents a substantial improvement of the existing studies [5,6]. That is, this work examines more wavelet functions for generating multiresolution image representation, evaluates different global descriptors [13–15] obtained from different scales rather than directly using wavelet coefficients as features [5] or even use a single wavelet function, and assesses a few Haralick descriptors [10]. Moreover, this work presents and appraises new multi-scale Gray-Level Co-occurrence Matrices (GLCM) descriptors by combining different pixel distances.

Good generalization capacity, low classification errors on different classes and low data over-fitting are required for an efficient FPR algorithm. Hence, proper methods for performing pattern classification, feature selection and classifier performance optimization need to be adopted. For accomplishing the classification stage along with the feature selection and classifier parameters tuning, PSO-SVM is an efficient alternative [16]. Further performance improvement and design flexibility can be achieved by extending PSO based parameter tuning to a full model selection process [17]. Another key and important contribution of this paper is the application of PSO based model selection to solve FPR problem. The proposed model selection improves the performance by optimizing the feature extraction process, accomplishing feature selection, and by choosing optimal hyper-parameters and parameters for the SVM classifier. Although there are several methods for accomplishing parameter selection, the ease of implementation and simplicity of PSO based heuristic search make it more attractive than GA, grid, and exhaustive search techniques [18,17]. The PSO algorithm, introduced by Eberhart and Kennedy in 1995, is a biologically and population-based heuristic search approach, where a group of individuals located in the parameter space of an objective function searches for the optimal solution. Since the introduction of the PSO algorithm several refinements [40,41] and applications [17,19,42–44] have been proposed. An ensemble particle swarm model selection was applied for the determination of leukaemia type using morphology of the bone marrow. Dheeba et al. [43] employed a PSO algorithm to optimize a neural network classifier that, subsequently, is used for textural-based detection of mammographic microcalcification. Guarniz et al. [44] proposed the modification of the wavelet analysis by applying PSO method to optimize the wavelet filter basis function and