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Ensemble based adaptive over-sampling method for imbalanced data learning in computer aided detection of microaneurysm

Fulong Ren[a,b], Peng Cao[a,b,*], Wei Li[b], Dazhe Zhao[a,b], Osmar Zaiane[c]

[a] College of Computer Science and Engineering, Northeastern University, Shenyang, China
[b] Key Laboratory of Medical Image Computing of Ministry of Education, Northeastern University, Shenyang, China
[c] Computing Science, University of Alberta, Edmonton, Alberta, Canada

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ABSTRACT

Diabetic retinopathy (DR) is a progressive disease, and its detection at an early stage is crucial for saving a patient's vision. An automated screening system for DR can help in reduce the chances of complete blindness due to DR along with lowering the work load on ophthalmologists. Among the earliest signs of DR are microaneurysms (MAs). However, current schemes for MA detection appear to report many false positives because detection algorithms have high sensitivity. Inevitably some non-MAs structures are labeled as MAs in the initial MAs identification step. This is a typical "class imbalance problem". Class imbalanced data has detrimental effects on the performance of conventional classifiers. In this work, we propose an ensemble based adaptive over-sampling algorithm for overcoming the class imbalance problem in the false positive reduction, and we use Boosting, Bagging, Random subspace as the ensemble framework to improve microaneurysm detection. The ensemble based over-sampling methods we proposed combine the strength of adaptive over-sampling and ensemble. The objective of the amalgamation of ensemble and adaptive over-sampling is to reduce the induction biases introduced from imbalanced data and to enhance the generalization classification performance of extreme learning machines (ELM). Experimental results show that our ASOBoost method has higher area under the ROC curve (AUC) and G-mean values than many existing class imbalance learning methods.

1. Introduction

Diabetic retinopathy (DR) is a chronic progressive disease of the retinal microvasculature which is the most common cause of blindness in the past 50 years. Due to the burden of diabetes over the past decades, the prevalence of DR is expected to grow exponentially and affect over 366 millions people worldwide by 2030 (Erbas et al., 2011). Despite the high risk factor, it has been established that early detection and timely treatment can reduce the development of severe vision loss in 60% of cases. In order to prevent the damage of this severe complication to patients' vision, it is very important to diagnose diabetic retinopathy and provide appropriate treatment to minimize further deterioration as early as possible.

Since microaneurysms (MAs) are regarded as early signs of DR and are caused by the focal dilatations of thin blood vessels, the detection of MAs in the fundus of the eye is essential. Moreover, the grading performance of computer-aided DR screening systems highly depends on MA detection. Therefore, there has been extensive research on effective detection and localization of these abnormalities in retinal images (Antal and Hajdu, 2013). MAs appear as small circular dark spots on the surface of the retina. The variation in size, shape, intensity, and presence of other retina structures further complicate the problem of detecting MAs from fundus images. Fig. 1 shows a retinal image containing the signs of DR-specific lesions, such as MAs, hard exudates (HE), hemorrhages (H) and soft exudates/cotton wool spots (SE/CWS).

Automatic methods have been developed to help reduce the burden on specialists (Dupas et al., 2010a). Current computer aided diagnosis (CAD) schemes for microaneurysms have achieved high sensitivity levels, whereas current schemes for microaneurysms detection appear to report many false positives (Mrinal, 2015; Akram et al., 2013; Walter et al., 2007; Mizutani et al., 2009).

Many methods have been developed specifically to deal with the problem of false positive detections. For example, in Mizutani et al. (2009), the numbers of false positives per image (FPI) decreases from 183.38 (initial detection) to 27.04 (false positive reduction using ANN); in Walter et al. (2007), the segmentation algorithm

* Corresponding author at: College of Computer Science and Engineering, Northeastern University, Shenyang, China.
E-mail address: caopeng@ise.neu.edu.cn (P. Cao).

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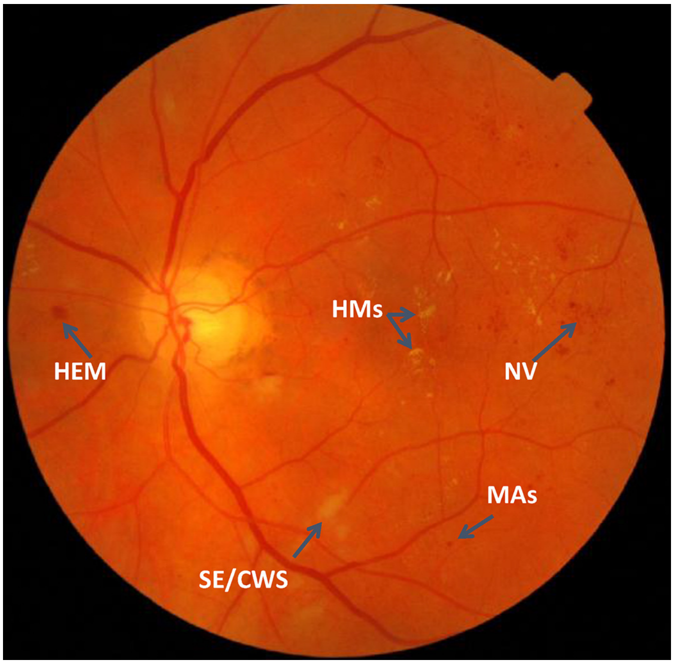

Fig. 1. Retinal image and MAs.

gave 8837 candidates, containing 373 MA, 92 doubtful objects (which were discarded) and 8372 false positives, false positive reduction yields a sensitivity of 89.0% and a FPI value of 2.92.

It is highly desirable to eliminate these false positives (FPs) because of two reasons: (1) The initial MA detection algorithms have high sensitivity that some non-microaneury structures are erroneously labeled as microaneurysms in the initial microaneurysms identification step, resulting in low values for specificity. Massive MA candidates bring much work and burden for radiologists, since the radiologists must examine each identified object. (2) The accurate grading of diabetic retinopathy (DR) depends on the number of lesions involving MAs, haemorrhages or exudates. The excessive false positives (capillary blood vessels and noise regions) of MAs negatively influence the accurate diagnosis of diabetic retinopathy.

Therefore, a fine level algorithm (usually a supervised classifier) is critical to remove the potentially false detections based on some assumptions about MAs after a coarse level initial microaneurysms identification. It is a binary classification between the MAs and non-MAs. In machine learning, the aim of classification is to learn a system capable of the prediction of the unknown output class of a previously unseen instance with a good generalization ability. The false-positive reduction step, or classification step, is a critical part in the microaneurysms detection system.

However, the two classes are skewed in the classification and have extremely unequal misclassification costs, which is a typical class imbalance problem (Chawla et al., 2004; He and Garcia, 2009). Class imbalanced data has detrimental effects on the performance of conventional classifiers. Typically classifiers attempt to reduce global error rate without taking the data distribution into consideration. As a result, all instances are misclassified as negative for high classification accuracy. However, in the potential MA detection and classification, this problem has attracted less attention.

Extreme learning machines (ELM) (Huang et al., 2006), as an effective and efficient machine learning technique, has attracted tremendous attention from various fields in recent years. ELM have been extensively studied and have shown remarkable success in many applications. However the success of ELM is very limited when it is applied to the problem of learning from imbalanced datasets. Much work has been done in addressing the class imbalance problem. The proposed methods can be grouped in two categories: the data perspective and the algorithm perspective. The re-sampling technique is the most straightforward and effective method for dealing with imbalance, since it is not dependent on the classifier and is simple to implement. In addition to re-sampling methods, ensemble methods (Galar et al., 2012) have also been used to improve performance on imbalanced datasets. They combine the power of multiple classifiers trained on similar datasets to provide accurate predictions for future instances. In order to improve microaneurysm detection, we propose an adaptive SMOTE (Synthetic Minority Over-sampling TEchnique), and incorporate the over-sampling technique with different ensemble frameworks to acquire better classification performance and generalization capability. We propose three different ensemble methods combined with adaptive SMOTE, to overcome the drawback of ELM on the imbalanced data learning and improve the performance of false positive reduction of MA candidates.

Specifically, the contributions of this paper are highlighted as follows:

1. Based on the ideas of the adaptive weighting (He et al., 2008) and probability function estimating (Cao et al., 2014), we extend SMOTE to generate appropriate synthetic instances for imbalanced data learning.
2. In this paper, we propose three different ensemble classifiers (boost, bagging and random subspace) combined with an adaptive over-sampling algorithm. In addition, ELM classifier is employed as base classifier and incorporates the evaluation measures (AUC and G-mean) of imbalanced data directly into the optimization of the intrinsic parameters to improve the performance of the classification.
3. Comprehensive experiments have been conducted to demonstrate the effect of over-sampling and ensemble learning for false positive reduction of MA. Moreover, we empirically compare the proposed three ensemble framework with adaptive SMOTE with existing state-of-the-art algorithms for imbalanced data learning algorithms and false positive reduction of MA candidates.
4. We implement a complete automated systems for the detection of MAs. The workflow of our system is shown in Fig. 2. The system involves the steps of initial detection of MAs candidate, feature extraction and classification.
5. The proposed methods have been tested on three publicly available Messidor DiaretDB1 and ROC datasets. The results verify the effectiveness of our automated microaneurysm detection system.

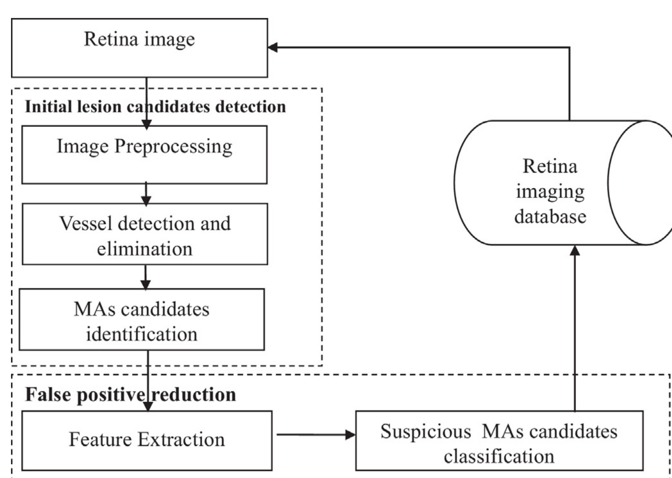

Fig. 2. The stage of MA detection.