

Classifying DME vs Normal SD-OCT volumes: A review

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Abstract—This article reviews the current state of automatically classify Spectral Domain OCT (SD-OCT) data to identify Diabetic Macular Edema (DME) versus normal subjects. Addressing this classification problem has valuable interest since early detection and treatment of DME play a major role to prevent eye adverse effects such as blindness.

Despite previous works addressing this problem, this article points out the lack of publicly available data and benchmarking suited for this particular task of identify DME vs. normal SD-OCT volumes. The main contribution of this article is to cover these deficiencies by providing a common benchmark, dataset, and a collection of our own implementation of the most relevant methodologies found in the literature.

Index Terms—

I. INTRODUCTION

Eye diseases such as Diabetic Retinopathy (DR) and Diabetic Macular Edema (DME) are the most common causes of irreversible vision loss in individuals with diabetes. Just in United States alone, health care and associated costs related to eye diseases are estimated at almost \$500 M [1]. Moreover, the prevalent cases of DR are expected to grow exponentially affecting over 300 M people worldwide by 2025 [2]. Given this scenario, early detection and treatment of DR and DME play a major role to prevent adverse effects such as blindness. DME is characterized as an increase in retinal thickness within 1 disk diameter of the fovea center with or without hard exudates and sometimes associated with cysts [3]. For many years, fundus images have been the modality of choice to reveal most of eye pathologies [4, 5]. However, Optical Coherence Tomography (OCT) has recently shown to provide useful additional information about cross-sectional retinal morphology [6] (see Fig. [1]), reflected by the growing interest in developing methodologies for this modality. In this sense, great efforts have been placed in retinal layers segmentation, which is a necessary step for retinal thickness measurements [7, 8].

However, few studies have addressed the specific problem of DME automatic detection in OCT, revealing large ground to be covered in terms of: (i) manipulating OCT volumes, (ii) finding radiomix pathology signs, or (iii) appropriated classification strategies.

Advances in any of those regards is of great interest since (i) manual evaluation of Spectral Domain OCT (SD-OCT) volumetric scans is expensive and time consuming [9]. (ii) SD-OCT acquisition has some deficiencies due to eye movement during the scan [10], the reflectivity nature of the retina [11], the fact that OCT suffers from high levels of noise and the overall image quality is inconsistent [12]. (iii) Coexistence of multiple pathologies [10], easy to miss pathology signs [9], or large variability within the pathology treats which difficult to obtain proper radiomix to facilitate the task of classification.

The rest of this article is structured as follows: Section II offers a general idea of the literature state-of-the-art in SD-OCT volume classification. Section III reviews some publicly available datasets and states the need for another one that suits the classification task here described. Section IV proposes an experimental benchmark to compare different methodologies presented in Sect. II. Section V reports and discusses the obtained results, while Sect. VI wraps up our thoughts regarding this work and its possible direction.

II. BACKGROUND

This section reviews works straightly addressing the problem of classifying OCT volumes as normal or abnormal, regardless of the targeted pathology. The methods are categorized in terms of their learning strategy, namely supervised or semi-supervised learning.

A. Supervised methods

Supervised learning is based on a fully annotated and labeled training set. In this approach, the labeled training data are used to train the classifier function later used for prediction. Figure 1 illustrates a prevalent framework for supervised learning. Each SD-OCT volume undergoes: (i) *pre-processing* to reduce noise and other acquisition deficiencies which alter the images; (ii) *feature detection* to quantify visual cues like appearance, texture, shape, etc.; (iii) *mapping* in which a sample is either considered as whole (i.e., global) or partitioned into a set of sub-elements (i.e., local dense/sparse patches, pyramid, etc.); (iv) *feature representation* to associate a descriptor (e.g., concatenation, statistics, histogram,

Principal Component Analysis (PCA), Bag-of-Words (BoW), etc.) for each element from the *mapping-stage*. This descriptor packages the visual cues related to the sample; (v) *classification* to determine the associated class of each sample.

Venuhuizen *et al.* propose a classification method to distinguish between Age-related Macular Degeneration (AMD) and normal SD-OCT volumes using BoW models [9]. A set of keypoints are detected and selected at each individual B-scan, by keeping the salient points included in the top 3% of the vertical gradient values. Around each of these keypoints, a $9 \text{ px} \times 9 \text{ px}$ texton is extracted, generating a feature vector of 81 dimensions, later reduce to 9 using PCA. All extracted feature vectors are used to create a codebook using k -means clustering. Then, each OCT volume descriptor is represented as a histogram that captures the codebook occurrences and are classified by a Random Forest (RF) composed of 100 trees. The method is tested using a publicly available dataset of 384 OCT volumes [13], achieving an Area Under the Curve (AUC) of 0.984.

Srinivasan *et al.* propose a classification method to distinguish DME, AMD, and normal SD-OCT volumes [14]. Each OCT slice is pre-processed using Block Matching 3D filtering (BM3D) to reduce the speckle noise and is flattened to reduce the inter-patient retinal curvature variations. A multi-resolution pyramid is generated for each pre-processed slice and a Histogram of Oriented Gradients (HOG) feature is computed for each layer. These features are classified using a linear Support Vector Machines (SVM). Note that each individual B-scan is classified into one of the three categories, namely DME, AMD, and normal, and a volume is label to a given class by taking the majority vote of all B-scans. This method is also tested using a publicly available dataset, composed of 45 patients equally subdivided into the three targeted classes. Correct classification rates of 100%, 100% and 86.67% are obtained for normal, DME, and AMD patients, respectively.

Extending the previous work, Alsaih *et al.* aggregate Local Binary Patterns (LBP) to HOG in order to add texture information and reduce the number of dimension using PCA [15].

Lemaître *et al.* propose a method based on LBP features to describe the texture of OCT images and dictionary learning using the BoW models [16]. In this method, the OCT images are first pre-processed using Non-Local Means (NLM) filtering, to reduce the speckle noise. Then, the volumes are mapped into a discrete set of structures: (i) local corresponding to patches, or (ii) global corresponding to volume slices or the whole volume. According to the chosen mapping, LBP or LBP from Three Orthogonal Planes (LBP-TOP) texture features are extracted and represent each volume through histogram, PCA, or BoW representation. The final feature descriptors are classified using RF classifier. This methodology is tested against Venuhuizen *et al.* [9] using public and non-public datasets showing an improvement within the results by achieving a Sensitivity (SE) of 87.5% and a Specificity (SP) of 75%.

Liu *et al.* propose a methodology aiming at classifying B-

scan rather than volume. The classification goal is to distinguish between macular pathology and normal OCT B-scan images using LBP and gradient information as attributes [10]. Each OCT slice are flattened before to create a 3-level multi-scale spatial pyramid. From each layer of this pyramid, edges are extracted and LBP descriptors are computed for the flattened slice and the edge map. All the obtained histograms are concatenated into a global descriptor whose dimensions are reduced using PCA. Finally, a SVM with an Radial Basis Function (RBF) kernel is used as classifier. A detection rate with an AUC of 0.93 is achieved, using a dataset of 326 OCT scans with various pathologies.

Albarraak *et al.* propose another classification framework to differentiate AMD and normal volumes [17]. Each OCT slice undergoes two pre-processing routines: (i) a joint denoising and cropping step using the split Bregman isotropic total variation algorithm and (ii) a flattening step by fitting a second-order polynomial using a least-square approach. Then, LBP-TOP and HOG combined with LBP-TOP features are extracted from individual sub-volumes from each original cropped volume. These features are concatenated into a single feature vector per OCT volume and its dimension is reduced using PCA. Finally, a Bayesian network classifier is used to classify the volumes. The classification performance of the framework in terms of SE and SP achieve 92.4% and 90.5%, respectively, outperforming the method of Liu *et al.* [10], using a dataset composed of 140 OCT volumes.

Anantrasirichai *et al.* propose to detect glaucoma in OCT images based on a variety of texture descriptor [18]. The texture information is described through LBP, Gray-level co-occurrence matrix (GLCM), wavelet, granulometry, run length measures, and intensity level distributions in combination with retinal layer thickness estimation, without any pre-processing. Each feature vector is projected using PCA before to be classified using an SVM with both linear and RBF kernel. Testing with rather a small dataset of 24 OCT voluem, their proposed method achieved an Accuracy (ACC) of 81.95% while using layer thickness information.

B. Semi-supervised methods

Sankar *et al.* propose to use a semi-supervised strategy to classify DME vs. normal OCT volumes based on appearance modeling of normal OCT images using Gaussian Mixture Model (GMM) [19]. The main difference between this method and the supervised methodologies lies in the fact that only normal volumes are used to train the system.

For each OCT volume, the B-scans are denoised using NLM filtering, flattened, and resized to ensure homogeneous dimension across all volumes. Each B-scan is vectorized and projected into a lower-dimensional space wiht p dimensions using PCA. Subsequently, normal B-scans are modelled using a GMM in which the number of mixture components K is determined on a validation set. At the testing stage, a scan is classified as normal or DME depending of its Mahalanobis distance to the learnt model; if the distance is greater than the 97.5% quantile of the Chi-squared distribution with p degree

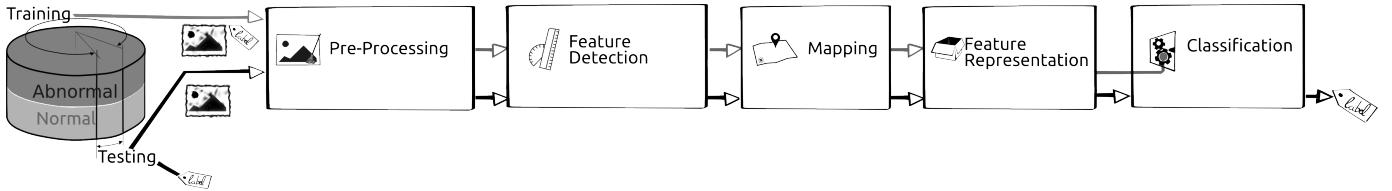


Fig. 1. Common framework

of freedom. Therefore, a volume is classified as abnormal if the number of abnormal slice is greater than a given threshold, previously determined during the validation procedure. A SE and SP of 93.8% and 80.0 are respectively achieved on a cohort of 32 patients.

III. DATA

A common dataset is required to compare different methodologies. Despite the fact that lack of public data is a common claim in the medical image community [20], the ophthalmic community has recently made available public dataset, mainly gathered at Duke University [13, 14]. Although these datasets have been used by Venhuizen *et al.* [9] and Srinivasan *et al.* [14], they are not suitable for our problem.

Venhuizen *et al.* have evaluated their framework on a large public dataset of 384 OCT annotated volumes classified either as AMD or normal cases. Our goal, however, remains to focus on the detection of DME rather than AMD, despite the interest of testing the frameworks against a large dataset.

In the contrary, Srinivasan *et al.* have tested their framework using a public dataset containing AMD, DME, and normal volumes [14]. The data, however, have been denoised, aligned, and cropped, without access to the original set of images.

Therefore, we use the Singapore Eye Research Institute (SERI) dataset to conduct this study [21]. This dataset has been acquired by the SERI, using CIRRUS TM (Carl Zeiss Meditec, Inc., Dublin, CA) SD-OCT device. The dataset consists of 32 OCT volumes, subdivided into 16 DME and 16 normal cases. Each volume contains 128 B-scans with a resolution of 512 px × 1,024 px. All SD-OCT images have been read and assessed by trained graders and identified as normal or DME cases, based on evaluation of retinal thickening, hard exudates, intraretinal cystoid space formation and subretinal fluid (see Fig. 2).

IV. EXPERIMENTAL SETUP

The experimental set-up is summarized in Table II. Where the most relevant works in Sect. II are formulated as the as the 5-steps standard classification procedure described in Fig. 1.

A. Implementation details

The experiments, described in this work, are publicly available at [22] allowing for further comparisons and improvements. All the methods table II have been developed using *protoclass* [23], a rapid prototyping toolkit to perform image processing and Machine Learning (ML) tasks. Furthermore,

each method has been implemented as a plug-in to [22], so that all methods can be evaluated in a common framework¹.

Note that Liu *et al.* train the algorithm at the B-scan level, and SERI dataset provides Ground Truth (GT) at volume level only. Thus, two strategies have been explored to solve this issue: (i) similarly to Srinivasan *et al.*, at training stage, all B-scans are considered as abnormal for a DME volume and at testing stage, a majority vote rule is applied to whether label a volume as abnormal or not; (ii) similarly to Alsaih *et al.*, an approach using BoW is used. From the methods reviewed in Sect. II, we decline to implement Albarak *et al.* and Anantrasirichai *et al.*. The former does not provide sufficient implementation details to replicate their results [17]; while, the latter, uses a descriptor based on the layer thickness which require a layer segmentation stage using a generic segmentation algorithm and further user validation [18].

B. Evaluation

All the experiments are evaluated in terms of SE and SP (see Fig. 3) using the Leave-Two-Patient Out Cross-Validation (LTPO-CV) strategy, in line with [16]. Therefore, at each cross-validation iteration, a DME and normal volumes are kept for testing, while the remaining volumes are used as training. The SE evaluates the performance of the classifier with respect to the positive class, while the SP evaluates its performance with respect to negative class.

The use of LTPO-CV implies that at each round, a pair DME-normal volume is selected for testing while the remaining volumes are used for training. Subsequently, no SE or SP variance can be reported. However, LTPO-CV strategy has been adopted despite this limitation due to the reduced size of the dataset.

V. RESULTS AND DISCUSSION

The entire set of experiments with their associated results can be found in [22], while Table I shows the configuration leading to the best results of each method. The results are reported in terms of SE and SP (see Sect. ??), and sorted left to right in descending order.

Lemaitre *et al.* achieves the best results when using LBP-TOP features, a global mapping, and histogram representation [16]. Alsaih *et al.* performs better when using HOG features with PCA representation [15]. Our interpretation of Liu *et al.*, as proposed in Sect. ??, achieves the best results

¹See table II for standalone repositories of each method. All repositories provide tests to ensure that our implementation comply with the original work.

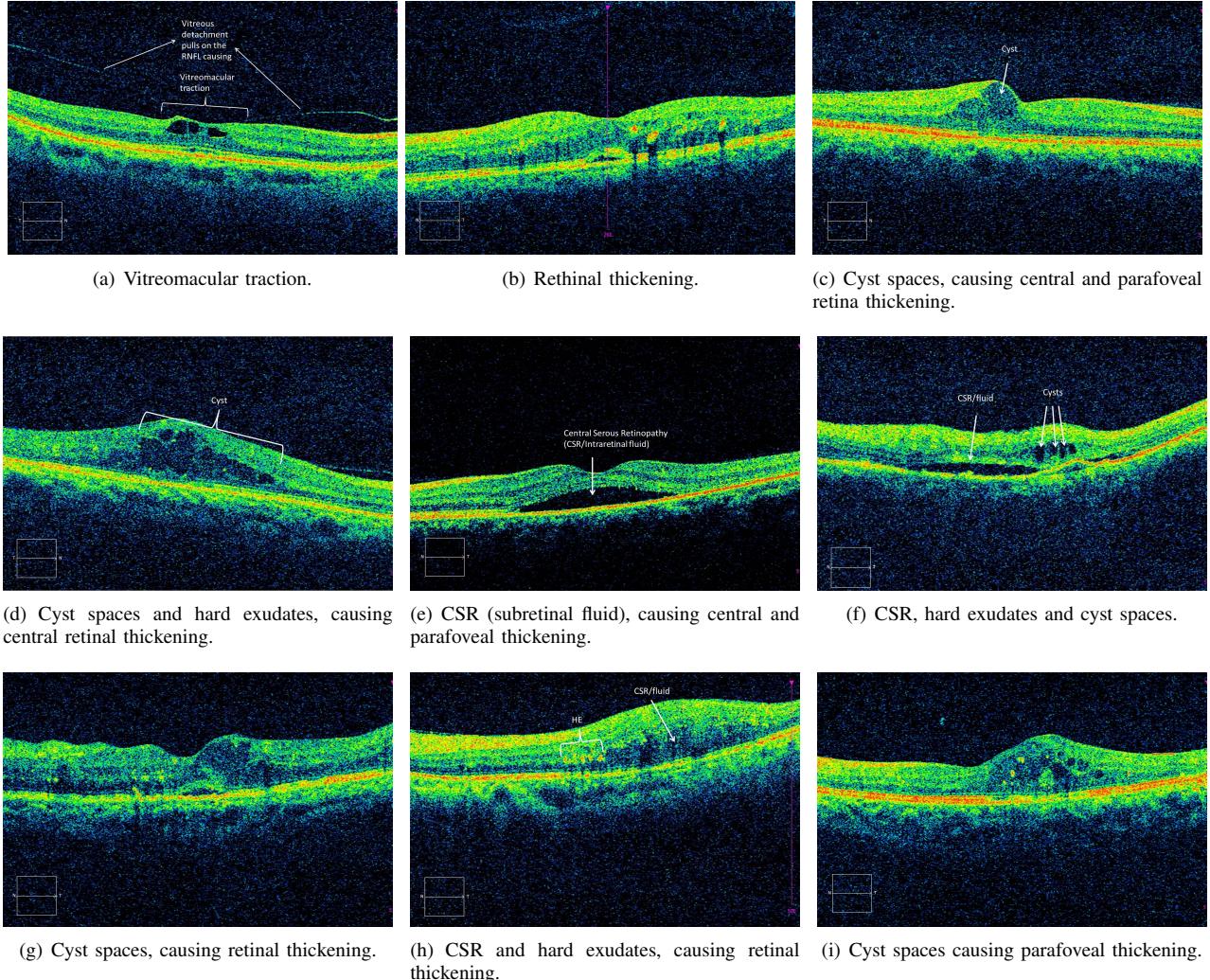


Fig. 2. Examples of DME cases in SERI dataset.

TABLE I
SUMMARY OF THE CLASSIFICATION PERFORMANCE IN TERMS OF SE AND SP IN (%).

Lemaitre <i>et al.</i> [16]	Sankar <i>et al.</i> [19]	Alsaih <i>et al.</i> [15]	Srinivasan <i>et al.</i> [14]	Liu <i>et al.</i> [10]	Venuhizen <i>et al.</i> [9]
SE	87.5	81.3	75.0	68.8	68.8
SP	75.0	62.5	87.5	93.8	58.8

when using majority voting instead of BoW models. Refer to Table II for configuration details of the resting methods.

Results in [22] indicate two methodology factors with major impact in the results: (i) features describing the entire volume rather than each B-scan are more discriminative; and (ii) a pre-processing stage with denoising is fundamental.

Other observations include the facts that (i) to represent B-scans, local mapping in conjunction with dimension reduction, either using PCA or BoW, improve the results. However, the combination of both decreases the performance in comparison to non reduced histogram representation; (ii) building BoW models from concatenated detected features, might lead to the

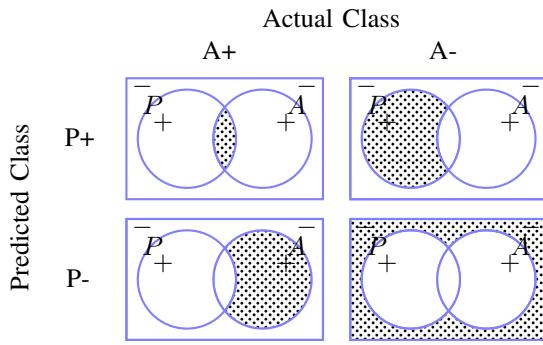
curse of dimensionality, which would explain why the RBF-SVM overfits in [15, 24]. (ii) building BoW models from the concatenation of all detected features for each B-scan [15, 24], might lead to the curse of dimensionality since 128 samples per volume is not enough to describe a space with a number of dimensions of the order of millions; which could explain the over-fitting using RBF-SVM as in.

VI. CONCLUSION AND FURTHER WORK

The work here presented states the relevance of developing methodologies to automatically differentiate DME vs. *normal* SD-OCT scans. This article offers an overview of the state-of-

TABLE II
CORRESPONDENCE BETWEEN THE MOST RELEVANT METHODOLOGIES REVIEWED IN SECT. II AND THE PROPOSED EXPERIMENTAL FRAMEWORK.

Ref	Pre-processing	Features	Mapping	Representation	Classification
Venuizen <i>et al.</i> [9, 25]		Texton	Local	PCA BoW	RF
Srinivasan <i>et al.</i> [14, 26]	Denoising (BM3D) Flattening Cropping	HOG	Global		Linear-SVM
Lemaitre <i>et al.</i> [16, 27]	Denoising (NLM)	LBP LBP-TOP	Local Global	PCA BoW Histogram	RF
Alsaih <i>et al.</i> [15]	Denoising (BM3D) Flattening Cropping	LBP HOG	Local	PCA Histogram	Linear-SVM
Liu <i>et al.</i> [10]	Flatten Aligned	Edge LBP	Local	PCA	RBF-SVM
Sankar <i>et al.</i> [19, 28]	Denoising (NLM) Flattening Cropping	Pixel intensities	Global	PCA	Mahalanobis -distance to GMM



(a) Confusion matrix with truly and falsely positive samples detected (TP, FP) in the first row, from left to right and the falsely and truly negative samples detected (FN, TN) in the second row, from left to right.

The figure shows two equations for evaluation metrics. On the left, a circle is divided into a blue (top) and black (bottom) region. The formula $SE = \frac{TP}{TP+FN}$ is shown below it. On the right, another circle is divided into a black (top) and blue (bottom) region. The formula $SP = \frac{TN}{TN+FP}$ is shown below it.

(b) SE and SP evaluation, corresponding to the ratio of the doted area over the blue area.

Fig. 3. Evaluation metrics: (a) confusion matrix, (b) SE - SP

the-art methodologies and provides a public benchmarking to facilitate further studies. In this regard, there are two crucial aspects to improve the work here presented: (i) enlarge the dataset. (ii) reach out for the original authors of those methods in Sect. II that could not be included in Sect. IV because our implementation could not be tested against the original data or we did not achieve the original results.

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