

Classification of SD-OCT Volumes with LBP: Application to DME Detection

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Abstract

This paper addresses the problem of automatic classification of Spectral Domain OCT (SD-OCT) data for automatic identification of patients with Diabetic Macular Edema (DME) versus normal subjects. Our method is based on Local Binary Patterns (LBP) features to describe the texture of Optical Coherence Tomography (OCT) images and we compare different LBP features extraction approaches to compute a single signature for the whole OCT volume. Experimental results with two datasets of respectively 32 and 30 OCT volumes show that regardless of using low or high level representations, features derived from LBP texture have highly discriminative power.

Moreover, the experiments show that the proposed method achieves better classification performances than other recent published works.

Keywords: Diabetic Macular Edema, Optical Coherence Tomography, DME, OCT, LBP

[☆]Document source available in GitHub [1]

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1. 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 [2]. Moreover, the prevalent cases of DR are expected to grow exponentially affecting over 300 M people worldwide by 2025 [3]. Early detection and treatment of DR and DME play a major role to prevent adverse effects such as blindness. Indeed, the detection and diagnosis of retinal diseases are based on the detection of vascular abnormalities or lesions in the retina.

In past decades, Computer Aided Diagnosis systems devoted to ophthalmology, have been developed focusing on the automatic analysis of fundus images [4, 5]. However, the use of fundus photography is limited to the detection of signs which are correlated with retinal thickening such as hard and soft exudates, hemorrhages or micro-aneurysms. However, 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 [6]. Therefore, fundus photography cannot always identify the clinical signs of DME; for example cysts, which are not visible in the retinal surface. In addition, it does not provide any quantitative measurements of retina thickness or information about cross-sectional retinal morphology.

Recently, Optical Coherence Tomography (OCT) has been widely used as a valuable diagnosis tool for DME detection. OCT is based on optical reflectivity and produces cross-sectional and three-dimensional images of the central retina, thus allowing quantitative retinal thickness and structure measurements. The new generation of OCT imaging, namely Spectral Domain OCT (SD-OCT) offers higher resolution and faster image acquisition over conventional time domain OCT. SD-OCT can produce 27,000 to 40,000 A-scans/seconds with an axial resolution ranging from 3.5 μm to 6 μm [7].

Many of the previous works on OCT image analysis have focused on the

I don't think that's the way to introduce it

problem of retinal layers segmentation, which is a necessary step for retinal thickness measurements [8, 9]. However, few have addressed the specific problem of DME and its associated features detection from OCT images.

In this research we focus on the latter problem and propose an automatic
35 framework for identification of DME patients versus normal subjects using OCT volumes. The proposed method, which is an extension of our previous work [10], is based on Local Binary Patterns (LBP) features to describe the texture of OCT images and dictionary learning using the Bag-of-Words (BoW) models [11]. We propose to extract 2D and 3D LBP features from OCT images and volumes, re-
40 spectively. The LBP descriptors are further extracted from the entire sample or local patches within individual samples. In this research beside the comparison of 2D and 3D features, we also compare the effects of common pre-processing steps for OCT data, and different classifiers.

In the following of this paper, first in Sect. 2 a summary of the related studies
45 is presented.

This paper is organized as follows, Section 2 presents a summary of the related studies. The proposed framework is explained in Sect. 3, while the experiments and results are discussed in Sect. 4. Finally, the conclusion and avenue for future directions are drawn in Sect. 5.

50 2. Related Work

This section reviews the works straightly addressing the problem of classifying OCT volumes as normal or abnormal. A summary can be found in 1.

Srinivasan *et al.* [12] proposed a classification method to distinguish DME, Age-related Macular Degeneration (AMD) and normal SD-OCT volumes. The
55 OCT images are pre-processed by reducing the speckle noise by enhancing the sparsity in a transform-domain and flattening the retinal curvature to reduce the inter-patient variations. Then, Histogram of Oriented Gradients (HOG) are extracted for each slice of a volume and a linear Support Vector Machines (SVM) is used for classification. On a dataset of 45 patients equally subdivided into the

60 three aforementioned classes, this method leads to a correct classification rate of 100%, 100% and 86.67% for normal, DME and AMD patients, respectively.

Venhuizen *et al.* proposed a method for OCT images classification using the BoW models [13]. The method starts with the detection and selection of keypoints in each individual B-scan, by keeping the most salient points corresponding to the top 3% of the vertical gradient values. Then, a texton of size 65 9×9 pixels is extracted around each keypoint, and Principal Component Analysis (PCA) is applied to reduce the dimension of every texton to get a feature vector of size 9. All extracted feature vectors are used to create a codebook using k -means clustering. Then, each OCT volume is represented in terms of this 70 codebook and characterized as a histogram that captures the codebook occurrences. These histograms are Then, the obtained codebook from the training is used to represent each OCT volume as a feature vector occurrence histogram^{glm}. Finally, this histogram is^{sik} used as feature vector to train a Random Forest (RF) with a maximum of 100 trees. The method was used to classify OCT volumes 75 between AMD and normal cases and achieved an Area Under the Curve (AUC) of 0.984 with a dataset of 384 OCT volumes.

Liu *et al.* proposed a methodology for detecting macular pathology in OCT images using LBP and gradient information as attributes [14]. The method starts by aligning and flattening the images and creating a 3-level multi-scale 80 spatial pyramid. The edge and LBP histograms are then extracted from each block of every level of the pyramid. All the obtained histograms are concatenated into a global descriptor whose dimensions are reduced using PCA. Finally a SVM is used as classifier. The method achieved good results in detection OCT scan containing different pathology such as DME or AMD, with an AUC of 0.93 85 using a dataset of 326 OCT scans.

Our later study proposes a standard classification procedure to differentiate between DME and normal SD-OCT volumes [1]The data is pre-processed using Non-Local Means (NL-means) filtering. The volumes are mapped into discrete set of structures namely: local, when these structures correspond to patches; or 90 global, when the structures correspond to volume slices or the whole volume.

These structures are described in terms of texture using LBP or LBP from Three Orthogonal Planes (LBP-TOP) and encoded using histogram, PCA or BoW to produce a single feature vector in order to present the volumes to a RF classifier. This methodology was tested against Venhuizen *et al.* [13] using public and non-public datasets showing an improvement within the results achieving a Sensitivity (SE) of 87.5% and a Specificity (SP) of 75%.^{sik}

In our latest study [10], we proposed a classification framework for differentiating DME and normal SD-OCT volumes. In this work, we proposed to pre-process the volumes using NL-means filtering and mapped them either into a set of structures, corresponding to patches from slices or volumes (local) or a single structure per slice or volume (global). From the considered structures we proposed to extract LBP and LBP-TOP features and represent them using histogram, PCA or BoW algorithm. The represented features were then classified using RF classifier. This methodology was tested on public and non-public dataset and the obtained results revealed improvement against Venhuizen *et al.* [13] algorithm by achieving the SE and SP of 87.5% and 100%, respectively. The obtained results from this study is listed in Sect. 4. As stated in previous section, this research is a continue of our previous work, where we intend to evaluate the influence of different pre-processing, BoW representation and various classifiers. Our proposed pipeline with detail description of each step is presented in the following section ^{moj}

Table 1: The summary of the state of the art methods

| Ref | Task | | Data size | | Pre-processing | | | Features | Classifier | Evaluation | | |
|-------------------------------|------|-----|-----------|-----|----------------|---------|----------|----------|------------|-----------------|-----|-------|
| | AMD | DME | Normal | | De-noise | Flatten | Aligning | Cropping | | SE | SP | AUC |
| Srinivasan <i>et al.</i> [12] | ✓ | ✓ | ✓ | 45 | ✓ | ✓ | | ✓ | SVM | 86.7%,100%,100% | | |
| Venhuizen <i>et al.</i> [13] | ✓ | | ✓ | 384 | | | | | RF | | | 0.984 |
| Liu <i>et al.</i> [14] | ✓ | ✓ | ✓ | 326 | | ✓ | | ✓ | SVM | | | 0.93 |
| Lemaître <i>et al.</i> [10] | | ✓ | ✓ | 32 | ✓ | | | | RF | 87.5% | 75% | |

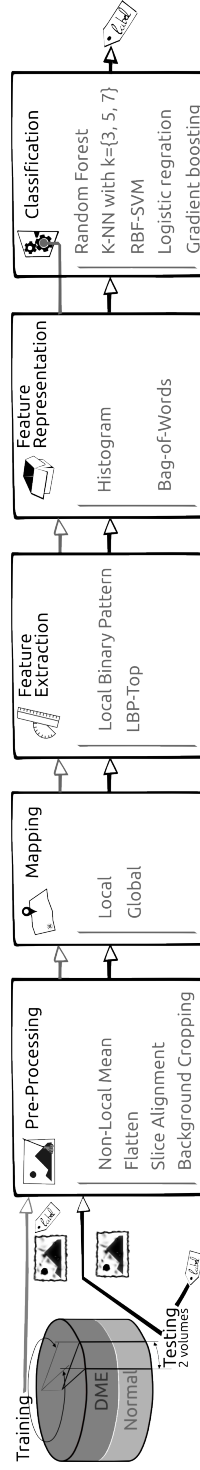


Figure 1: Machine learning classification basic scheme

3. Materials and Methods

The proposed method, as well as, its experimental set-up for OCT volume
115 classification are outlined in Fig. 1. The methodology is formulated as a standard classification procedure, through 5 steps. First, the OCT volumes are pre-processed as presented in details in Sect. 3.1. The mapping stage is used to determine a discrete set of elements (or structures) which is used for representing the OCT volume. For this work two mapping strategies are defined: (i) *global*
120 and (ii) *local* mapping. In the global mapping approach, a single structure is computed for the image/volume while in the local mapping, a set of structures is defined by sliding a window through the image/volume. Then, a descriptor is computed for each structure. The feature extraction and representation are presented in depth in Sect. 3.2 and Sect. 3.3, respectively. Finally the classification
125 step is presented in Sect. 3.4.

3.1. Image pre-processing

This section describes set of pre-processing techniques which are provided by our framework. These approaches can be arbitrarily combined. Combinations of these technologies and the influence of these combinations are reported in
130 experimentation section 4.

3.1.1. Non-Local Means (NL-means)

OCT images are known to be affected by a speckle noise [15]. Subsequently, NL-means [16] filtering has been successfully used in Ultra-Sound (US) images to filter similar noise [17] and is used in our framework to denoise each B-scan
135 (i.e. each $x - z$ slice) of the OCT volumes (see in Fig. 2(a)). In this regard (For this reason, Due to this reason), we use the NL-means filtering which has been successfully used on US images to remove similar noise [17]. This filter is applied on each B-scan (i.e. each $x - z$ slice) for the OCT volumes (see in Fig. 2(a)).^{moj} NL-means filtering offers the advantage to use all the possible
140 self-predictions that the image can provide rather than local or frequency filters

Mention texture here, rework where the sections are called

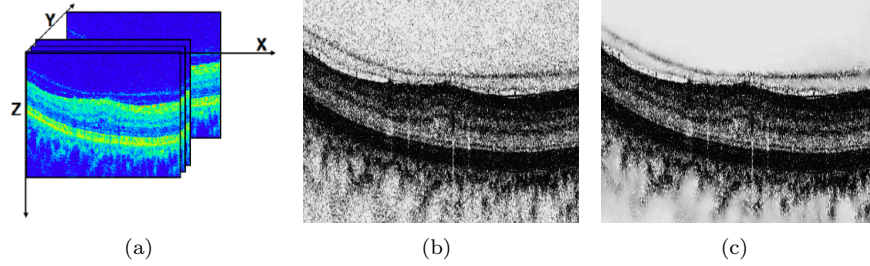


Figure 2: OCT: (a) Organization of the OCT data - (b) Original image - (c) NL-means filtering.

such as Gaussian, anisotropic or Wiener filters [16]. An example of filtering using NL-means filter on OCT image is depicted in Fig 2(b) and Fig. 2(c).

3.1.2. Flatten

Texture descriptors characterize spatial arrangement of intensities. Therefore, to ensure a consistent characterization of the tissue disposition regardless of the location within the retina, the natural curvature of the retina needs to be taken into account. This can be done in different manners:

- using a descriptor allowing for a wide number of textures, so that each texture orientation accounts for each own descriptor.
- using a rotation invariant descriptor.
- by unfolding the curvature of the retina.

This process of unfolding the curvature of the retina is known as image flattening. When flattening, an estimation of the Retinal Pigment Epithelium (RPE) layer is used to modify the volume by imposing that the RPE should be flat. Our implementation modifies the proposal of Liu *et al.* [14], as illustrated in Figure 3. Otsu thresholding is used to segment the retina from the background. A line is fitted to the bottom part of the segmentation hull, since it is assumed to be parallel to the RPE. The image is corrected based on this line.

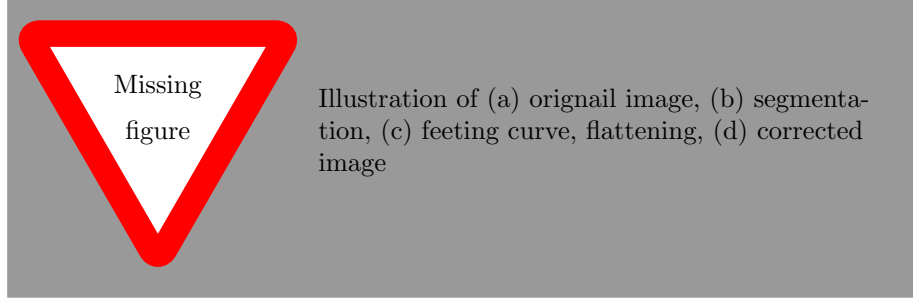


Figure 3:

3.1.3. Slice alignment

160 Similarly, when using 3D texture, misalignment between the slice introduce error to the texture descriptor. In this case the slices are also aligned based on the segmentation's hull.

3.1.4. Background cropping

Cropping out the background allows for less texture to be encoded

165 3.2. Features extraction

This a generic description. Shall we place it for our images with some picture? (maybe we don't have time)

In this research we chose to extract simple and efficient LBP texture features with regards to each OCT slice and volumes.^{moj} LBP is a texture descriptor based on the signs of the differences of a central pixel with respect to its neighboring pixels [18]. These differences are encoded in terms of binary patterns as
170 in Eq. (1):

$$LBP_{P,R} = \sum_{p=0}^{P-1} s(g_p - g_c)2^p, \quad s(\cdot) = \begin{cases} 1 & \text{if } (g_p - g_c) \geq 0 \\ 0 & \text{otherwise} \end{cases}, \quad (1)$$

where g_c , g_p are the intensities of the central pixel and a given neighbor pixel, respectively. P is the number of sampling points in the circle of radius R . Figure 4(a) illustrates the meaning of P and R .

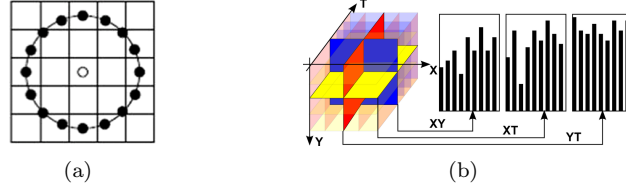


Figure 4: The different LBP descriptors: (a) LBP with ($R = 2, P = 16$) - (b) LBP-TOP [19].

175 Ojala *et al.* further extend the original LBP formulation to achieve rotation
 invariance at the expense of limiting the texture description to the notion of
 circular “uniformity” [18]. Volume encoding is later proposed by Zhao *et al.* by
 computing LBP descriptors in each orthogonal planes, so called LBP-TOP [19].

3.3. Feature representation

180 Each OCT volume can be described by its texture and we employed two
 strategies.

Low-level representation The texture descriptor of an OCT volume is de-
 fined as the concatenation of the LBP histograms. Therefore, for the
 185 LBP-TOP, the feature descriptor is computed through the concatenation
 of the LBP histograms of the three orthogonal planes and for the LBP, the
 descriptor is defined either through concatenation of the LBP histograms
 per each B-scan (*global*-mapping), or per each patch (P) (*local*-mapping).

190 *Global* mapping considers to extract the features from the 2D B-scans for
 LBP and 3D volume for LBP-TOP. Therefore for a volume with d B-scans,
 the *global*-LBP feature leads to a final descriptor of size $d \times LBP_{hist}$ and
global-LBP-TOP feature returns the final descriptor of size $3 \times LBP_{hist}$.
 Here LBP_{hist} refers to the size of uniform and rotation invariant LBP
 195 histogram which it’s number of bins depends on the number of sampling
 points in a given neighborhood. ^{moj}

Are we do-
 ing Rotation
 Invariant
 version??

give the idea
 of a single
 descriptor
 per volume

fab got con-
 fused with
 the Rotation
 invariant,
 and would
 like more
 detail(or re-
 working) of
 the resulting
 descriptor.

In *local* mapping, the features are extracted from a set of 2D patches for LBP and a set of sub-volumes for LBP-TOP. Considering a $(m \times m)$ patch (P) for 2D LBP and $(m \times m \times m)$ sub-volume for LBP-TOP. Using these elements, the *local*-LBP approach provides a final descriptor of size $(d \times N \times LBP_{hist})$ while *local*-LBP-TOP results in a final descriptor of size $\frac{d}{m} \times N \times 3 \times LBP_{hist}$. Here N is the total number of elements in each B-scan, and 3D volume, respectively. ^{moj}

High-level representation According to the chosen mapping strategy, the low-level representation can lead to a high dimensional feature space. High-level representation simplifies this high dimensional feature space into a more discriminant lower space. BoW approach is used for this purpose [11]. This model represents the features by creating a visual dictionary or “codebook”, from the set of low-level features. The set of low-level features are clustered using k -means to create the codebook with k clusters or visual words. After creating the codebook, each of the training example is represented as a histogram of size k . The histogram is obtained by calculating the frequency of occurrences of each of the k words in the extracted features from the training example.

3.4. Classification

Classification corresponds to the mapping of a set of inputs \mathbf{x} into a set of categorical outputs \mathbf{y} using a linear or non-linear function $f(\cdot)$. In supervised learning methods, this function is defined by providing a training set of N samples \mathbf{x}_{tr} with their associated labels \mathbf{y}_{tr} . In the remainder of this section, we briefly summarize the supervised classification methods used in the experiments. Details regarding the parameters used in our experiments are provided in Sect. ??

k -Nearest Neighbor (NN) is a non-parametric classification method in which an unlabeled feature vector x is assigned to the majority class of its k

nearest-neighbors from the training set. To avoid a tie case, the parameter k is set to an odd number.

Logistic Regression (LR) is a linear classifier which uses the logistic function to estimate the probability of x to belong to a particular class c_i [20]. Thus, the posterior probability is expressed as:

$$p(c_i|x) = \frac{1}{1 + \exp(-w^T x)} \quad (2)$$

where w is a vector of the regression parameters to obtain a linear combination of the input feature vector x . The vector w can be inferred by finding the maximum likelihood estimates via optimization methods such as quasi-Newton method [21]. Once the vector w found, an unlabeled feature vector is assigned to the class which maximizes the posterior probability.

Random Forest (RF) is an ensemble of decision trees [22] which generalizes the classification process by applying two types of randomization: at the tree level, each tree is fed by a bootstrap made of S' samples which are built from the original data of size S such that $S = S'$, and at the node level, a subset of feature dimensions m is randomly selected from the original dimension M such that $m \ll M$. The trees in RF are grown to their maximum length without any pruning. In the testing stage, each tree in the ensemble casts a unit vote in the final prediction and the final prediction is based on combination of all the votes.

Gradient Boosting (GB) is a reformulation of AdaBoost [23] in which the problem of finding an ensemble of real-valued weak learners is tackled as a numerical optimization [24]. A strong learner is built by iteratively finding the best pair of real-valued weak learner function and its corresponding weight which minimizes a given differentiable loss function. Common choice for weak learners is decision stumps or regression trees while the loss function is generally an exponential or logarithmic loss [25], minimized via gradient descent or quadratic approximation.

Support Vector Machines (SVM) is a sparse kernel classification method

255 which aims at finding the best linear hyperplane which separates two
 classes by maximizing the margin between them [26]. Maximizing the
 margin is equivalent to minimizing the norm of the normal vector of the
 hyperplane:

$$\min_{\mathbf{w}, \omega_0} \frac{1}{2} \|\mathbf{w}\|^2 \quad \text{s.t.} \quad y_i(\mathbf{w}^T \mathbf{x}_i + \omega_0) \geq 1, i = 1 : N \quad (3)$$

260 This constraint intends to force all the point to be in the correct side of
 the decision boundary (hyperplane) with a minimum distance of 1. This
 assumption is only valid if the data is linearly separable. Thus for general
 cases a slack variable $\xi_i \geq 0$ is introduced, which is $\xi_i = 0$, if the points
 are on/or inside the correct margin boundary, is $0 < \xi_i \leq 1$ if the points
 are inside the margin but in the correct side of the decision boundary and
 265 otherwise if they lie in the wrong side of decision boundary is $\xi_i > 1$.
 This assumption introduces the *soft margin constraints*. Therefore the
 optimization problem of SVM classifier is presented by:

$$\min_{\mathbf{w}, \omega_0, \xi} \frac{1}{2} \|\mathbf{w}\|^2 + C \sum_{i=1}^N \xi_i$$

$$\text{s.t.} \quad \xi_i \geq 0, \quad y_i(x_i^T \mathbf{w} + \omega_0) \geq 1 - \xi_i, i = 1 : N \quad (4)$$

In Eq. 4, the $\sum_i \xi_i$ term, describes the upper bound on the number of
 misclassified points and C is the regularization parameter that controls
 270 the tolerance of the classifiers on the number of errors [27].

4. Experiments and Validation

To evaluate the effects and influence of different stages of our framework,
 we perform various tests using two datasets. A detailed description of the
 275 used datasets can be found in Section 4.1. For all the experiments, LBP and
 LBP-TOP features are extracted for different sampling points of 8, 16, and 24

for radius of 1, 2, and 3, respectively. As previously mentioned, two different mapping strategies, *local* and *global*, are used, where for *local* mapping, we consider a (7×7) patch (P) for 2D LBP and $(7 \times 7 \times 7)$ sub-volume for LBP-TOP.

The *global* and *local* extracted features are then presented in low or high level representation. As previously mentioned, BoW approach is used for high-level representation.

Four experiments are presented in the reminder of this section. Experiment #1 presents the obtained results from our primary study [10] where the framework was tested with one pre-processing, one classifier, and fixed number of visual words. In this regard in the next experiment #2, we perform a preliminary test in a search for the optimal number of “visual-words” (k). In experiment #3, using the obtained number of words, we test the performance of different classifiers with regards to different pre-processing steps for high-level represented features and finally in experiment #4 we compare the performance of different classifiers with respect to different pre-processing for low-level represented features.

Beside experiment #1, where the primary pipeline is tested on SERI and Duke dataset, the rest of the experiment are performed only on SERI dataset and for the sake of the comparison, these three experiments are performed using all the aforementioned classifiers. However only the relevant part and results related to our experiment is represented within the paper, while the rest are mentioned in online [repository](#).

The pipeline in each experiment is evaluated using Leave-One-Patient Out Cross-Validation (LOPO-CV) strategy. In this validation, at each round a pair DME-normal volume is selected for testing while the rest of the volumes are used for training. The use of this method implies that no variance in terms of SE and SP can be reported. However, and despite this limitation, LOPO-CV has been employed due to the small size of the dataset.

The obtained results of all the experiments except experiment #1 is represented in terms of SE and SP. These statistics are driven from the confusion

| | | Actual | |
|-----------|----|---------------------|---------------------|
| | | A+ | A- |
| Predicted | P+ | True Positive (TP) | False Positive (FP) |
| | P- | False Negative (FN) | True Negative (TN) |

Figure 5: Confusion matrix with truly and falsely positive detected samples (TP, FP) in the first row, from left to right and the falsely and truly negative detected samples (FN, TN) in the second row, from left to right.

matrix (see Fig. 5).

The former evaluate the performance of the classifier with respect to the positive class, while the later evaluate it's performance with respect to negative class. These measurements are formulated as:

$$SE = \frac{TP}{TP + FN} \quad SP = \frac{TN}{TN + FP} \quad (5)$$

In experiment #1 we use Accuracy (ACC) and F1-score (F1) instead. Accuracy is used to have a overall sense of classifier performance, and F1 is used to see the trade off between SE and precision. Equation. 6 shows the formulation of these measurements.

$$ACC = \frac{TP + TN}{TP + TN + FP + FN} \quad F1 = \frac{2TP}{2TP + FP + FN} \quad (6)$$

4.1. Datasets

310 The majority of the development of our framework has been carried out using our own dataset (SERI) and to facilitate further comparison we use the Duke public dataset to evaluate our optimal configurations.

SERI - datasets were acquired by Singapore Eye Research Institute (SERI), using CIRRUS TM (Carl Zeiss Meditec, Inc., Dublin, CA) SD-OCT de-
315 vice. The datasets consist of 32 OCT volumes (16 DME and 16 normal cases). Each volume contains 128 B-sane with dimension of 512×1024 pixels. All SD-OCT images are read and assessed by trained graders and

identifies as normal or DME cases based on evaluation of retinal thickening, hard exudates, intraretinal cystoid space formation and subretinal fluid.

Duke - datasets published by Srinivasan et al. [12] were acquired in Institutional Review Board-approved protocols using Spectralis SD-OCT (Heidelberg Engineering Inc., Heidelberg, Germany) imaging at Duke University, Harvard University and the University of Michigan. This datasets consist of 45 OCT volumes (15 AMD, 15 DME and 15 normal). In this study we only consider a subset of the original data containing 15 DME and 15 normal OCT volumes.

4.2. Experiment #1

As previously stated, this experiment was performed with our primary framework which is presented in [10]. This experiment was performed to evaluate the effects of different features representation. In this experiment, the OCT volumes of our own dataset, were only de-noised using NL-means method and BoW approach was used with fix number of words ($k = 32$). Then the low or high level represented features were classified using RF classifier with 100 un-pruned trees. For the sake of comparison, the same classification were performed for the extracted *global* and *local* LBP-TOP, and *local*-LBP features from Duke dataste. As previously mentioned, this dataset is provided with cropped volumes, which vary in sizes. Thus it was impossible to create a descriptor based on the *global*-LBP features for this dataset. The obtained results from this experiment is listed in Table. 2.

Once again in order to evaluate the proposed pipeline the proposed method by Venhuizen *et al.* [13] was developed and tested on the two dataset. The comparison of the obtained results with the highest performance achieved by our framework is shown in Table. ??

4.3. Experiment #2

This experiment, conducted on SERI dataset, is performed to find the optimal number of words for BoW high-level feature representation. *Global* and

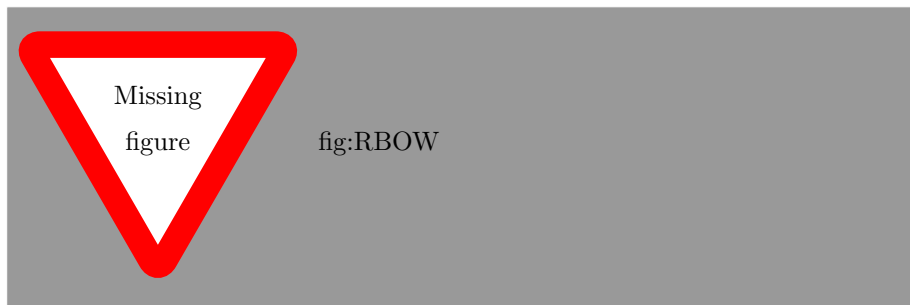


Figure 6:

local-LBP and *local*-LBP-TOP feature descriptors are re-represented using BoW approach. In this experiment, the BoW algorithm is performed using various
 350 number of words in the range of $\{10, 20, 30, \dots, 100, 200, \dots, 500, 1000\}$. The words are randomly selected using *k*-means++ algorithm and the features are mapped to their nearest word to create the final clusters. In order to assess the effect of number of words, simple linear classifier such as LR is used. The number of words associated with highest ACC and F1 score, is selected as the
 355 optimum number of words. Table 4 shows the obtained results of this experiment. The optimum number of words and the achieved ACC and F1 of LR classifier for different configurations are listed in this table.

Figure. 6 shows the obtained graphs for some of the configurations.

360 4.4. Experiment #3

This experiment is performed for high-level features on SERI dataset. Using the optimum number of words which are obtained from the previous experiment, the low-level feature sets with regards to different pre-processing configurations are re-represented using BoW and *k*-means clustering approach and are classified
 365 using different classifiers such as *k*-NN, RF, GB, and SVM. The *k*-means algorithm is initialized using *k*-means++ method and is performed with 5 iteration for each codebook. The RF and GB classifier are trained using 100 un-pruned trees, while SVM classifier is trained with Radial Basis Function ker-

nel. The regularization and soft-margin parameters of this classifier are chosen
370 with grid-search method. Finally the k -NN classifier is trained by considering
the 3 nearest neighbor. Table 5 shows the obtained results from this experiment.

Table 2: Obtained results using SERI datasets.

| Features | SERI dataset | | | | | | Duke dataset | | | | | |
|------------------------|--------------|-------------|-------------|-------------|-------------|------|--------------|-------------|-------------|------------|-------------|------|
| | 8^{riu2} | | 16^{riu2} | | 24^{riu2} | | 8^{riu2} | | 16^{riu2} | | 24^{riu2} | |
| | SE | SP | SE | SP | SE | SP | SE | SP | SE | SP | SE | SP |
| <i>global</i> -LBP-TOP | 56.2 | 62.5 | 87.5 | 75.0 | 68.7 | 68.7 | 80.0 | 93.3 | 73.3 | 86.6 | 73.3 | 86.6 |
| <i>local</i> -LBP | 75.0 | 87.5 | 81.2 | 75.0 | 68.7 | 62.5 | 80.0 | 86.6 | 86.7 | 100 | 93.3 | 86.6 |
| <i>local</i> -LBP-TOP | 62.5 | 68.7 | 56.2 | 37.5 | 37.5 | 43.7 | 80.0 | 86.6 | 86.6 | 86.6 | 60.0 | 80.0 |

Table 3: Comparing the proposed method by [13] on SERI and Duke datasets.

| Data sets | SERI | | Duke | |
|--|------|------|------|-------|
| | SE | SP | SE | SP |
| Venhuizen <i>et al.</i> [13] | 61.5 | 58.8 | 71.4 | 68.7 |
| $\{local\text{-LBP}\}, 16^{riu2}$ | 81.2 | 75.0 | 86.6 | 100.0 |
| $\{global\text{-LBP-TOP}\}, 16^{riu2}$ | 75.0 | 87.5 | 80.0 | 86.6 |

Table 4: The obtained results of experiment #1. Optimum number of words for each configuration as a result of LR Classification, for high-level representation of *global* and *local*-LBP, and *local*-LBP-TOP features with different pre-processing. The pre-processing includes: NF, F, F+A, and F+A+C.

| Features | Pre-processing | 8^{riu2} | | | 16^{riu2} | | | 24^{riu2} | | |
|-----------------------|----------------|------------|------|-----|-------------|-------|-----|-------------|------|-----|
| | | ACC% | F1% | W# | ACC% | F1% | W# | ACC% | F1% | W# |
| <i>global</i> -LBP | NF | 81.2 | 78.5 | 500 | 62.5 | 58.06 | 80 | 62.5 | 62.5 | 80 |
| | F | 71.9 | 71 | 400 | 68.7 | 66.7 | 300 | 68.7 | 66.7 | 300 |
| | F+A | 71.9 | 71 | 500 | 71.9 | 71 | 200 | 75 | 68.7 | 500 |
| <i>local</i> -LBP | NF | 75 | 75 | 70 | 65.6 | 64.5 | 90 | 62.5 | 60 | 30 |
| | F | 75 | 73.3 | 30 | 71.8 | 61 | 70 | 62.5 | 62.5 | 100 |
| | F+A | 75 | 69 | 40 | 71.9 | 71 | 200 | 68.7 | 66.7 | 10 |
| <i>local</i> -LBP-TOP | NF | 68.7 | 68.7 | 400 | 75 | 75 | 500 | 71.9 | 71 | 60 |
| | F | 68.7 | 68.7 | 300 | 68.7 | 66.7 | 50 | 75 | 76.5 | 80 |
| | F+A | 75 | 73.3 | 100 | 75 | 73.3 | 90 | 75 | 69 | 70 |

Table 5: The obtained results of experiment #2. k -NN and SVM classification with BoW for the *global* and *local* LBP and *local* LBP-TOP features with different pre-processing. The optimum number of words were selected based on the previous experiment.

| Features | Pre-processing | k -NN | | | | | | SVM | | | | | |
|-----------------------|----------------|------------|------|-------------|------|-------------|------|------------|-------|-------------|------|-------------|------|
| | | 8^{riu2} | | 16^{riu2} | | 24^{riu2} | | 8^{riu2} | | 16^{riu2} | | 24^{riu2} | |
| | | SE% | SP% | SE% | SP% | SE% | SP% | SE% | SP% | SE% | SP% | SE% | SP% |
| <i>global</i> -LBP | NF | 43.7 | 93.7 | 43.7 | 87.5 | 43.7 | 62.5 | 68.7 | 87.5 | 62.5 | 62.5 | 50.0 | 56.2 |
| | F | 43.7 | 56.2 | 50.0 | 75.0 | 62.5 | 56.2 | 56.2 | 56.2 | 56.2 | 75.0 | 56.2 | 68.7 |
| | FA | 56.2 | 62.5 | 43.7 | 81.2 | 68.7 | 56.2 | 56.2 | 68.7 | 68.7 | 68.7 | 56.2 | 75.0 |
| <i>local</i> -LBP | NF | 75.0 | 87.5 | 50.0 | 68.7 | 43.7 | 43.7 | 75.0 | 93.7 | 50.0 | 75.0 | 56.2 | 56.2 |
| | F | 56.2 | 56.2 | 50.0 | 50.0 | 50.0 | 43.7 | 81.2 | 93.7 | 68.7 | 68.7 | 68.7 | 75.0 |
| | FA | 56.2 | 43.7 | 50.0 | 75.0 | 50.0 | 62.5 | 75.0 | 93.75 | 75.0 | 68.7 | 68.7 | 68.7 |
| <i>local</i> -LBP-TOP | NF | | | | | | | | | | | | |
| | F | 62.5 | 43.7 | 37.5 | 68.7 | 43.7 | 62.5 | 81.2 | 81.2 | 75.0 | 68.7 | 81.2 | 68.7 |
| | F+A | 56.2 | 56.2 | 68.7 | 50.0 | 43.7 | 62.5 | 62.5 | 75.0 | 68.7 | 75.0 | 62.5 | 81.2 |
| Features | Pre-processing | 8^{riu2} | | 16^{riu2} | | 24^{riu2} | | 8^{riu2} | | 16^{riu2} | | 24^{riu2} | |
| | | SE% | SP% | SE% | SP% | SE% | SP% | SE% | SP% | SE% | SP% | SE% | SP% |
| | | | | | | | | | | | | | |
| <i>global</i> -LBP | NF | 68.7 | 93.7 | 43.7 | 62.5 | 50.0 | 68.7 | 56.2 | 50.0 | 37.5 | 31.2 | 50.0 | 43.7 |
| | F | 56.2 | 50.0 | 56.2 | 75.0 | 50.0 | 75.0 | 50.0 | 56.2 | 56.2 | 75.0 | 43.7 | 62.5 |
| | FA | 68.7 | 50.0 | 56.2 | 62.5 | 62.5 | 56.2 | 56.2 | 50.0 | 68.7 | 50.0 | 43.7 | 75.0 |
| <i>local</i> -LBP | NF | 81.2 | 81.2 | 62.5 | 56.2 | 56.2 | 56.2 | 75.0 | 62.5 | 68.7 | 87.5 | 50.0 | 75.0 |
| | F | 56.2 | 81.2 | 62.5 | 68.7 | 68.7 | 62.5 | 68.7 | 75.0 | 50.0 | 75.0 | 50.0 | 62.5 |
| | FA | 68.7 | 62.5 | 62.5 | 68.7 | 43.7 | 43.7 | 56.2 | 50.0 | 68.7 | 56.2 | 50.0 | 50.0 |
| <i>local</i> -LBP-TOP | NF | | | | | | | | | | | | |
| | F | 50.0 | 62.5 | 62.5 | 62.5 | 43.7 | 75.0 | 50.0 | 56.2 | 43.7 | 62.5 | 50.0 | 62.5 |
| | F+A | 50.0 | 62.5 | 81.2 | 87.5 | 50.0 | 68.7 | 56.2 | 62.5 | 81.2 | 68.7 | 75.0 | 68.7 |

4.5. Experiment #4

This experiment is conducted for low-level features. The *global* LBP and
375 LBP-TOP features are classified using the same classifiers as previous experi-
ments with the same configurations. The obtained results from this experiment
is listed in Table. 6.

Table 6: The obtained results of experiment #3. Classification results obtained from low-level representation of global LBP and LBP-TOP features with different pre-processing. Pre-processing steps include: NF, F, F+A. Different classifiers such as RF, GB, SVM, and k -NN are used.

| Features | Pre-processing | k -NN | | | | | | k -SVM | | | | | |
|------------------------|----------------|------------|------|-------------|------|-------------|------|------------|------|-------------|------|-------------|-------|
| | | 8^{riu2} | | 16^{riu2} | | 24^{riu2} | | 8^{riu2} | | 16^{riu2} | | 24^{riu2} | |
| | | SE% | SP% | SE% | SP% | SE% | SP% | SE% | SP% | SE% | SP% | SE% | SP% |
| <i>global</i> -LBP | | | | | | | | | | | | | |
| | NF | 37.5 | 50 | 25 | 50 | 37.5 | 68.7 | 56.2 | 62.5 | 56.2 | 43.7 | 56.2 | 68.7 |
| | F | 62.5 | 50 | 56.2 | 75 | 62.5 | 68.7 | 75 | 68.7 | 62.5 | 62.5 | 62.5 | 68.7 |
| | F+A | 56.2 | 50 | 56.2 | 75 | 62.5 | 68.7 | 75 | 68.7 | 62.5 | 62.5 | 62.5 | 68.7 |
| ----- | | | | | | | | | | | | | |
| <i>global</i> -LBP-TOP | | | | | | | | | | | | | |
| | NF | 31.2 | 93.7 | 37.5 | 100 | 37.5 | 81.2 | 62.5 | 75 | 62.5 | 93.7 | 56.2 | 87.5 |
| | F | 50 | 56.2 | 56.2 | 75 | 56.2 | 62.5 | 68.7 | 75 | 43.7 | 68.7 | 68.7 | 56.2 |
| | F+A | 75 | 43.7 | 56.2 | 43.7 | 68.7 | 50 | 68.7 | 62.5 | 62.5 | 56.2 | 56.2 | 68.7 |
| ----- | | | | | | | | | | | | | |
| Features | Pre-processing | RF | | | | | | GB | | | | | |
| | | 8^{riu2} | | 16^{riu2} | | 24^{riu2} | | 8^{riu2} | | 16^{riu2} | | 24^{riu2} | |
| | | SE% | SP% | SE% | SP% | SE% | SP% | SE% | SP% | SE% | SP% | SE% | SP% |
| <i>global</i> -LBP | | | | | | | | | | | | | |
| | NF | 43.7 | 62.5 | 43.7 | 62.5 | 56.2 | 75 | 43.7 | 43.7 | 43.7 | 37.5 | 37.5 | 31.25 |
| | F | 56.2 | 56.2 | 68.7 | 62.5 | 62.5 | 68.7 | 25 | 56.2 | 50 | 43.7 | 25 | 43.7 |
| | F+A | 65.2 | 56.2 | 50 | 50 | 56.2 | 68.7 | 43.75 | 62.5 | 62.5 | 50 | 31.2 | 31.2 |
| ----- | | | | | | | | | | | | | |
| <i>global</i> -LBP-TOP | | | | | | | | | | | | | |
| | NF | 56.2 | 68.7 | 68.7 | 87.5 | 68.7 | 81.2 | 68.7 | 68.7 | 75 | 50 | 56.2 | 43.7 |
| | F | 56.2 | 62.5 | 81.2 | 68.7 | 81.2 | 81.2 | 56.2 | 62.5 | 62.5 | 68.7 | 68.7 | 81.2 |
| | F+A | 68.7 | 62.5 | 75 | 68.7 | 75 | 81.2 | 56.2 | 43.7 | 62.5 | 62.5 | 75 | 75 |

5. Conclusions

380 The work presented here addresses the automatic classification of SD-OCT data to identify subjects with DME versus normal. Based on the reported results, the low level volume 3D features and high level 2D features using patches achieve the most desirable results in the experimental setup presented here. The comparison against different datasets and methodologies, highlights that:
385 regardless of using low or high level representations, volume signatures derived from LBP texture show high discriminative power for distinguishing DME vs normal volumes.

6. Future work

TOMORROW THE MOON !!

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