A novel segmentation algorithm for the detection of abnormalities in human eye's retina

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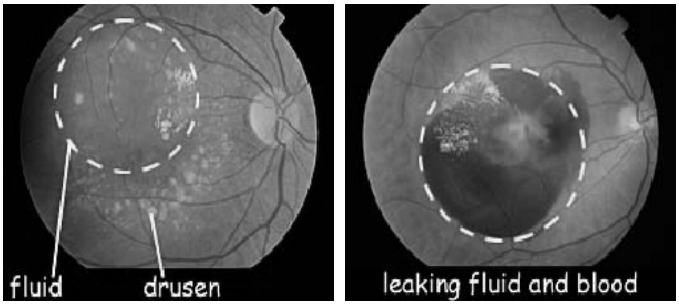
ABSTRACT: Assessment of the risk for the development of Age related Macular Degeneration requires reliable detection of retinal abnormalities that are considered as precursors of the disease. Typical symptoms of the later are the so called drusen, which appear as abnormal white-yellow deposits on the retina. Conventional image processing techniques are inappropriate for the segmentation of these features, since they are sensitive to non-uniform illumination and non-homogeneous background. This paper presents a novel segmentation technique for the automatic detection of drusen in retina images acquired with the aid of a digital fundus camera. Homomorphic filtering and adaptive histogram equalization are used for non-uniform illumination compensation and enhancement. For the detection of drusen in retina images, we develop a novel segmentation technique, the *Histogram-based Adaptive Local Thresholding (HALT),* which extracts the useful information from an image without being affected by the presence of other structures. We provide experimental results from the application of our technique to real images, where certain abnormalities (drusen) have slightly different characteristics from the background and are hard to be segmented by other conventional techniques.

INTRODUCTION

Age-related macular degeneration (AMD) is a disease that causes progressive damage to the macula, a specialized part of the eye that allows us to see fine details clearly. When the macula malfunctions, blurring or darkness in the center of vision is experienced and tasks such as reading and driving are affected. AMD is the leading cause of irreversible vision loss in people over 65 in the U.S. There are two forms of AMD, namely dry (also called atrophic, non-neovascular, or nonexudative) and wet (also called exudative). Dry AMD is the most common form of the disease and accounts for 90% of all AMD cases. The key identifier for dry AMD is small, round, white-yellow deposits called drusen that build up in the macula (Fig. 1).



(a) (b)

Figure 1 Retinal photographs showing (a) dry and (b) wet form of AMD

Even for the most experienced doctor, it is hard to detect the AMD symptoms. The varying retina curvature causes different light absorption and produces images with non-uniform illumination, which in conjunction with low contrast make the discrimination of the drusen from the background difficult, in terms of light intensity. Additionally, the different drusen sizes and their tendency to diffuse and join together creating larger intensity areas further deteriorate the ability for successful examination by the doctor. Consequently, the establishment of a robust computer-automated unsupervised method to evaluate the extent of drusen in the macula will provide the examiner with a useful tool for objective and standardized examination. Additionally, automated quantitation of fundus features in AMD, including drusen, will facilitate the development of routine, efficient, fast and accurate clinical tests for the prevention of AMD and similar diseases, as well as the evaluation of the effectiveness of different treatment or therapeutic schemes.

The problem of automated, unsupervised drusen detection has received considerable attention by various research groups [2, 3, 4]. However acceptable performance has not yet been achieved mainly due to the inability to compensate satisfactorily for poor contrast and non-uniform illumination. A recent work is presented in [5] that proposes an automated, supervised fundus image analysis technique. David S. Shin et al face the common problems of fundal images (non-uniform illumination, poor contrast) in two algorithmic steps, namely preprocessing and segmentation. Their method requires supervision to achieve high accuracy and robustness.

The goal of our research is the off-line processing of retinal images, acquired with a depth vision camera, so as to detect the presence of drusen and help the examiner meet the right decision. An efficient automated inspection tool would relieve him from the examination process and provide a fast and accurate tool for diagnosis of AMD. The purpose of this paper is to propose, analyze and test a complete system for the detection of drusen in human eye's retina.

METHODOLOGY FOR DRUSEN DETECTION

The main steps of the proposed algorithm are the following: non-uniform illumination compensation, enhancement and segmentation. Both the enhancement and thresholding operators for drusen segmentation are adaptive and based on histogram analysis. In particular, the local thresholding

operator is designed from a rigorous analysis of the local histogram, as to exploit the important characteristics of the signal distribution that differentiate drusen from background and overcome the inefficiencies of other histogram based segmentation schemes.

2.1. Preprocessing

The shape irregularity of the retina creates shading across the field of view when illuminated with a bright source, as with a depth vision camera. The effect of non-uniform illumination can be compensated by a commonly used technique, namely the homomorphic filtering.

The next processing step aims at enhancing the contrast of the retina's image. Several histogram-based global & local enhancement techniques have been established in the literature. The general form of a local transformation is expressed as follows:

$$g(x,y) = A(x,y) * \left[f(x,y) - m(x,y) \right] + m(x,y) \quad (1)$$

where $A(x,y) = k \dfrac{M}{\sigma(x,y)}$ $0 < k < 1$

m(x, y): gray level mean in neighborhood centered at (x, y)
σ(x, y): gray level standard deviation of local neighborhood
M: global image mean

Application of the local gain factor A(x, y) to the difference between f(x, y) and the local mean amplifies local variations. Because A(x, y) is inversely proportional to the standard deviation, areas with low contrast receive larger gain. The mean is added back to restore the average intensity level of the image in the local region. In practice, by adding back only a fraction of the local mean and restricting the variations of A(x, y) between two limits (A_{min}, A_{max}) we can balance large deviations of intensity in isolated regions.

We tested commonly used techniques like the adaptive contrast enhancement filters (ACE) [6], the Wallis statistical differencing [7], the exponential & logarithmic ACE [8] and an iterative local enhancement technique presented in [9]. The ACE filters are based on the following variation of (1)

$$g(x,y) = k1 * \left[f(x,y) - m(x,y) \right] + k2 * m(x,y)$$

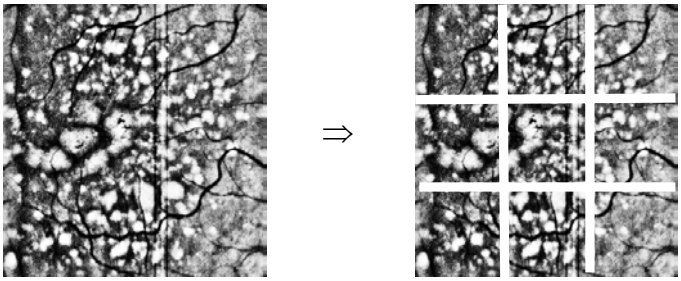
f(x,y): pixel brightness value of the original image
m(x,y): arithmetic mean brightness value of an $(n \times n)$ window that is centered on the pixel position (r,c)
k1: local gain factor
k2: local mean factor

The form of statistical differencing for enhancement is $g(x,y) = \dfrac{f(x,y)}{S(x,y)}$ where $S(x,y)$ is the standard deviation estimated at pixel's neighborhood. Wallis suggested a generalization of this operator in which the enhanced image is forced to desired first order and second order moments [7]. The operator is defined by

$$g(x,y) = \left[\frac{AS_d}{AS(x,y) - S_d} \right] \left[f(x,y) - m(x,y) \right] + \left[rM_d + (1-r)m(x,y) \right]$$

M_d: desired mean
S_d: desired standard deviation
A: gain factor that prevents overly large output values when $S(x,y)$ is small
r: mean proportionality factor controlling the ratio of the edge to background deviation

The main drawback of these techniques is their complexity in parameter selection that renders them inappropriate for enhancing a large set of retinal images. In order to avoid the selection of parameters for each retina image we process, we develop the *MultiLevel histogram Equalization (MLE)* technique, shown at Fig. 2, based on sequential applications of histogram equalization. In fact, it is a multilevel (hierarchical) scheme that progresses from the entire image to smaller regions defined via windows. The algorithm proceeds as follows: The 1st stage of equalization uses a window equal to images's size (global). The 2d stage splits the image into nine non-overlapping windows and applies the same operation to each part (block) of the previous result.



(a) (b)

Figure 2 (a), 1st level of histogram equalization (global) applied to entire image; (b) 2d level of histogram equalization applied to regions of previous result

2.2. Segmentation

Although non-uniform illumination has been almost compensated and the image has been enhanced, the definition of a single "good" global threshold is hard to achieve for effective drusen segmentation. Parts of the drusen are still difficult to distinguish from the background in terms of their intensity because of the brightness similarity; especially when considering drusen near to vessels. Alternatively, in our study we define thresholds for smaller regions, either based on local region properties or on local histogram information.

We propose the *Histogram Adaptive Thresholding (HALT)* technique based on the stochastic analysis of the local histograms. This selection scheme is applied on non-overlapping local regions and also fits well with the region-adaptive approach developed for enhancement. The HALT operator applies different thresholds at regions of the image depending on various shape properties of the corresponding histogram. The analysis of the histogram is based on its symmetry and tendency (short, medium or long- tailed). For each region's histogram we first apply location estimators on the distribution of intensity and then derive dispersion measures around this estimator, in order to characterize the distribution. The histogram's mean, median and mode in conjunction with kurtosis and skewness are used as central tendency estimators and symmetry quotients [1]. More specifically, the $|\text{mean} - \text{median}|$ difference is a first measure of

symmetry, while the $|\text{mean}-\text{mode}|$ difference is chosen as a measure of histogram's main lobe spread as shown at figure 4. Subsequently, the skewness in conjunction with the kurtosis are used as measures of the histogram's tendency. These measures can further increase the confidence with which drusen (outliers on the assumed normal distribution of the background) are detected.

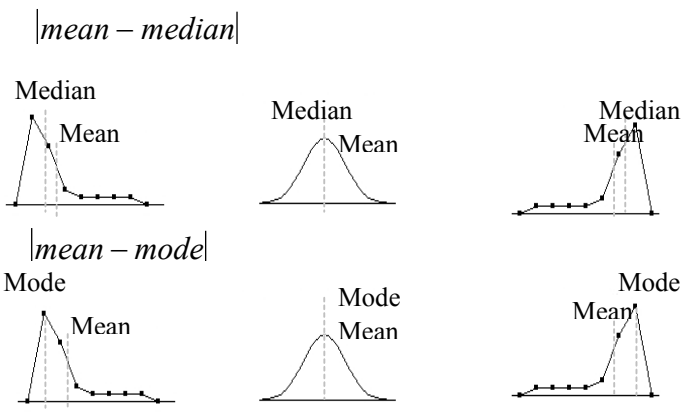


Figure 4 Three typical cases of histogram shape (negatively skewed, symmetric, positively skewed) and relative positions of corresponding features.

A more analytic consideration of symmetry and histogram analysis in the HALT algorithm is given below and is summarized in Tables 1 and 2 (attached at the end of the paper). Recall that crude symmetry indicators are used as first level discriminants and the categorization is refined through histogram-shape indices.

A. Histogram is totally or almost symmetric (Table 1)

• A totally symmetric gray level distribution signifies areas that are mainly occupied by background regions; uniform large regions, which surround anomalies. However, small drusen may be present, so setting 90% as threshold would be adequate to remove background and leave whole or part of the anomalies.

• The class of platykurtic distributions may be misleading. Generally, symmetric distributions signify background areas. Nevertheless, the platykurtic feature signifies interaction of distributions that jointly preserve symmetry. For example, if background areas' and anomalies' gray levels are normally and equally distributed, histogram will still appear symmetric. So, in order to avoid removal of drusen, we use Otsu method for thresholding.

• In case of sharp-peaked (leptokurtic) almost symmetric histograms we observe high concentration of pixels around the mean value. These sections appear with almost uniform background. Leptokuric distributions allow the existence of only small drusen as outliers that do not alter the general uniformity of the intensities. Using Otsu thresholding, that is obtaining a threshold value close to mean, would retain anomalies and big part of the background. So, setting 90% as threshold would remove background areas and retain, if existing, small drusen.

• The case of mesokurtic and positively skewed histograms requires particular attention. The mesokurtic characteristic most likely arises from the background distribution. The positive skewness indicates interaction with another distribution, which is observable but not significant one to alter drastically the background statistics. This distribution is detected at high intensity values indicating the existence of object(s), whose intensity however interacts with that of the background. Thus, their direct segmentation may be inefficient. Using Otsu's threshold may leave large areas of the background, whereas using the 90% threshold may delete a good portion of the object's structure. So, an additional step of local thresholding is used, which is actually the application of HALT method focused on smaller areas of first level's region. This helps in obtaining better distinction of anomalies and background at corresponding histograms.

B. Histogram is totally or almost asymmetric (Table 2)

• A positively skewed distribution of this class notifies the presence of many small or large drusen. In fact, bright gray levels that generally characterize anomalies dominate the histogram. Otsu technique is best suited to this case, since the distinction of bright and darker areas (background) is obvious.

• In general, an asymmetric distribution signifies the presence of drusen. The asymmetric platykurtic and mesokurtic distributions can result as combinations of similar distributions, characterizing background and abnormalities (drusen). The leptokurtic distribution describes an area dominated by background (with highly concentrated values) and less drusen.

RESULTS & CONCLUSIONS

The detection of anomalies in human eye's retina is a biomedical problem, appropriate for image processing and automated pattern recognition, whose solution is intended to help the ophthalmologists in their decision making process. The paper considers histogram-based techniques for the problem of automatic AMD evaluation. Use of the proposed detector reduces false negatives, compared with other schemes, and gives reliable detection accuracy in both position and mass size.

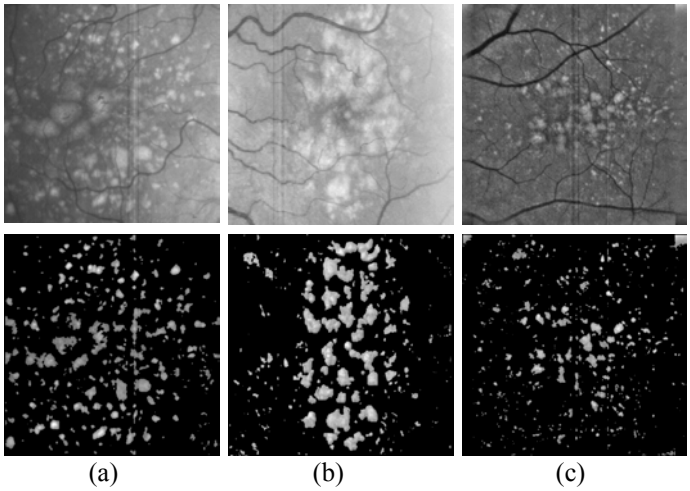


Figure 5 Results of drusen extraction in retinas of (a)-(c) different persons. The first row shows the original images and the second row presents the segmented ones

We tested our algorithm using a set of images acquired by a Fundus camera. The proposed method was able to detect actual drusen in all cases. Even in hard-to-diagnose cases, where many small and vague drusen exist, our method

succeeded in isolating them from background. Few segmentation examples are shown at figure 5. The first row shows the acquired images and the second row the segmented ones. Initially, we experienced problems with the presence of vessels and their interaction with drusen. After applying the proposed algorithm we eliminate this problem and we don't experience false detection, due to vessels, in the entire test set of images. Large drusen, covering usually the central part of the eye, are hard-to-segment. Nevertheless, most of the images, containing such drusen, are correctly segmented and the drusen are accurately detected. Generally, our test set of images covers a wide range of possible drusen sizes and formations, including vague, non-canonical shaped and thin ones.

We propose a histogram-based local enhancement technique (MLE), which uses histogram equalization as its core operator and a histogram-based segmentation technique (HALT) to segment areas that differ slightly from their background regions. Furthermore, we establish an unsupervised and non-parametric method for drusen extraction and consider its effectiveness through several examples.

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Table 1: Symmetric Distribution

Skewness / Kurtosis	**< 0**	**≈ 0**	**> 0**
Platykurtic	Mainly background 90%	Can result as combination of two or more distributions Otsu	Otsu
Mesokurtic	Mainly background 90%	Mainly background and maybe some drusen or just large drusen (one distribution) 90%	Drusen and background are hard to distinguish Application of HALT in smaller regions
Leptokurtic	Mainly background 90%	Almost constant background 90%	Can signify the case of only a small portion of drusen. To segment small drusen of high intensity use threshold 90%

Table 2: Asymmetric Distribution

Skewness / Kurtosis	**< 0**	**≈ 0**	**> 0**
Platykurtic	Mainly background ⇓ 90%	Drusen are present Otsu	Drusen & background are almost equally distributed ⇓ Otsu
Mesokurtic	Mainly background ⇓ 90%	Drusen & background are almost equally distributed ⇓ Otsu	Mainly drusen ⇓ Otsu
Leptokurtic	Mainly background ⇓ 90%	Mostly background, less drusen ⇓ Otsu	Drusen & background ⇓ Otsu

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Short biography……

Michael Zervakis holds a Ph.D degree from the University of Toronto, Department of Electrical Engineering, since 1990. He joined the Technical University of Crete on January 1995, where he has been recently promoted to full professor at the department of Electronic and Computer Engineering. He served as Associate Editor in the "IEEE Transactions on Signal Processing" from 1994 to 1996. He was an assistant professor with the University of Minnesota-Duluth, USA, from September 1990 to December 1994. Prof. Zervakis is the director of the Digital Image and Signal Processing Laboratory (DISPLAY) at the Technical University of Crete. Under his direction, the lab is involved in research on modern aspects of signal processing, including estimation and constrained optimization, multi-channel and multi-band signal processing, wavelet analysis for data/ image processing and compression, biomedical imaging applications, neural networks and fuzzy logic in automation applications. He was the director of the Signals and Research Center at the University of Minnesota, Duluth. He has been involved in more than 20 USA and European projects in various areas of image processing, biomedical imaging, and automation. He has published more than 60 papers in related areas.

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