Principal Component Analysis based Colour Scheme Optimisation in Eye Fundus Images

Contrast Enhancement for Detection and Evaluation of Drusen in Age Related Macular Degeneration Patients' Follow up

Algimantas Kriščiukaitis[1], Robertas Petrolis[1], Daiva Stanislovaitienė[2] and Dalia Žaliunienė[2]

[1]*Lithuanian University of Health Sciences, Eiveniu str. 4, Kaunas, Lithuania*

[2]*Eye Clinics of Lithuanian University of Health Sciences, Eiveniu str. 2, Kaunas, Lithuania*

Keywords: Principal Component Analysis, Eye Fundus Imaging, Drusen, Age Related Macular Degeneration.

Abstract: Efficiency of the patient status monitoring in Age Related Macular Degeneration cases, based on evaluation of morphological properties eye fundus images, can be significantly increased by specific contrast enhancement in the images. Objects of interest - drusen (focal deposits of extracellular debris located between the basal lamina of the retinal pigment epithelium and the inner collagenous layer of Bruch membrane) usually are represented by various intensity but the same unique color in the image. Construction of the optimal color scheme to increase the contrast of drusen can be realized by means of Principal Component Analysis, which transforms original RGB color representation into principal components space. The study demonstrates that proposed method can increase contrast-to-noise ratio of the drusen areas 10-fold or more.

1 INTRODUCTION

Age related macular degeneration (ARMD) is a degenerative disease usually occurring in people over the age of 50 years. Condition and severity of ARMD is classified according to diagnostic features obtained from eye-fundus images. Such features are estimates characterizing morphology and area covered by drusen, focal deposits of extracellular debris located between the basal lamina of the retinal pigment epithelium (RPE) and the inner collagenous layer of Bruch membrane (Spaide, 2010). The main forms of ARMD are defined according to specific lesions, the characteristics of drusen plays an important role here (Bird, 1995). Evaluation of drusen properties is used for monitoring of patient status dynamics. Area covered by drusen and sizes of them are usually estimated by means of various heuristic morphometric algorithms. Efficiency of such algorithms mostly depends on contrast between drusen area and background. Therefore preprocessing of images usually starts from selection of optimal spectral domain maximizing this contrast. Spaide with coauthors (Spaide, 2010) introduces optico-physical model based spectral characteristics for differentiation of drusen types classified by Gass (Gass, 1997): discrete yellow-white punctate elevations (“hard” drusen); large pale-yellow “placoid or dome-shaped structures” (“soft” drusen) are seen in the eye fundus singly or in groups. The color of the drusen depends on its main substance and optical characteristics of the covering layers. It is reported that all types of drusen contain one main substance called “lipoprotein-derived debris”, a lipid-rich material (Curcio, 2009); (Russel, 2000). So it is expected that the certain type of drusen observed in particular eye fundus image probably will have unique, but the same color. Due to its structure and location in regard to illuminating light source and camera the intensity could vary, however the color will remain the same.

Determination of optimized color combinations for blood vessels detection in eye fundus images is reported in (Patasius, 2009). The performance of the method was estimated by sensitivity (proportion of correctly identified blood vessel pixels) and specificity (proportion of correctly identified non-blood vessel pixels). Optimization algorithm maximizing area under ROC curve obtained using

Kriščiukaitis A., Petrolis R., Stanislovaitienė D. and Žaliunienė D..
Principal Component Analysis based Colour Scheme Optimisation in Eye Fundus Images - Contrast Enhancement for Detection and Evaluation of Drusen in Age Related Macular Degeneration Patients' Follow up.
DOI: 10.5220/0004910500660069
In *Proceedings of the International Conference on Bioimaging* (BIOIMAGING-2014), pages 66-69
ISBN: 978-989-758-014-7

training set images gives optimized color scheme. Determination of special color scheme for detection of drusen described in (Patasius, 2009-2). However efficiency of universal predetermined color scheme is sensitive to particular image registering conditions and color distortions (e.g. white balance). Individualized color scheme for every particular eye fundus image can reveal even more important diagnostic details related with preliminary detected drusen. In this study we aimed to elaborate such method.

The ordinary pixel of the color image is represented as point in orthogonal RGB space. All pixels of the same color but different intensity will appear along certain direction in the RGB. It is possible to find an optimal transform of given RGB space that one of the axes of new coordinate system will go along this direction representing color of the drusen. Such transform could be found using Principal Component Analysis (PCA). The aim of this study was to show how PCA could be used to find an optimal transform of representation of eye fundus image in RGB space into optimal space, maximizing contrast of drusen.

2 METHODS

Eye fundus images were taken using fundus camera (Carl Zeiss Meditec AG, Germany) in 134 ARMD patients who underwent treatment in Eye Clinics of Lithuanian University of Health Sciences. Image processing was performed using elaborated programs in MatLab computation environment.

The experts (experienced Ophthalmologists) have marked drusen areas in original eye fundus images for further analysis. Contrast-to-noise ratio of representation of drusen was evaluated according following criteria:

$$C = \frac{|M_d - M_b|}{s_b}, \tag{1}$$

where M_d - mean of pixel values in drusen area; M_b - mean of pixel values in non-drusen area; s_b - standard deviation of pixel values of non-drusen area.

Original representation of eye fundus images - three-dimensional arrays representing pixel values in red, green and blue colors, were transformed into two dimensional arrays, concatenating all rows of one color of the image into one. The resulting array consisted of three rows representing pixel values in red, green and blue colors respectively:

$$X = \begin{bmatrix} x_{r1} & x_{r2}\cdots & x_{rn} \\ x_{g1} & x_{g2}\cdots & x_{gn} \\ x_{b1} & x_{b2}\cdots & x_{bn} \end{bmatrix}, \tag{2}$$

Principal Component Analysis transforms original representation into new space of variables maximizing variation and concentrating correlated original variables (Jollife, 2002). If pixel values of drusen area make enough big contribution to total variance of image pixel values, we can expect that first, or at least one of the first new variables (principal components) will maximize contrast of drusen areas versus the rest of the image. Spatial correlation of original image representation X can be estimated as:

$$R_X = \frac{1}{3N} X \cdot X^T. \tag{3}$$

The eigenvector equation for R_X is:

$$R_X \cdot \Psi = \Psi \cdot \Lambda, \tag{4}$$

where Λ denotes the eigenvalue matrix with the eigenvalues sorted in descending order, and Ψ is the corresponding eigenvector matrix. The matrix Ψ defines an orthonormal transformation, which is applied to the original data X

$$Y = \Psi^T \cdot X \tag{5}$$

to obtain the transformed representation, rows of which contain principal components of X.

Principal components were trasformed back to two-dimensional arrays and shown to the experts. Contrast-to-noise ratio was evaluated according to formula (1) in principal component in which drusen areas were most clearly visible.

3 RESULTS

Example of typical eye fundus image containing drusen presented in Figure 1 and original representation of its pixel values in orthogonal RGB space on Figure 2. Pixel values of drusen areas form prolonged cluster marked by the arrow. As one can see, maximal variance of this part of the pixels is in the direction close to the direction of G axis. It complies with the results reported by (Patasius, 2009-2) that biggest part of information for drusen detection should be taken from green color. On the other hand, it confirms our expectations that drusen areas due to their physicochemical properties probably will have different intensity but the same color. So we can expect that PCA will find an optimal representation space where one axis will go along this linearly looking cluster of the pixel values.

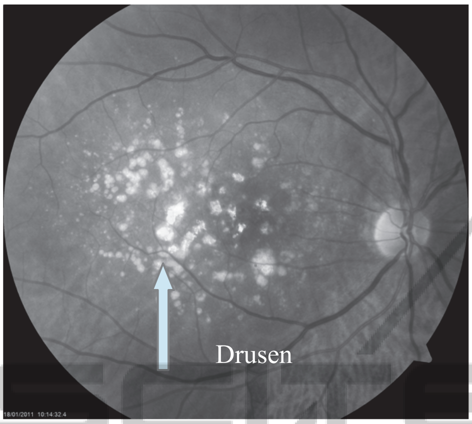

Figure 1: Original representation of the eye fundus image. Drusen are white spots on the image marked by arrow.

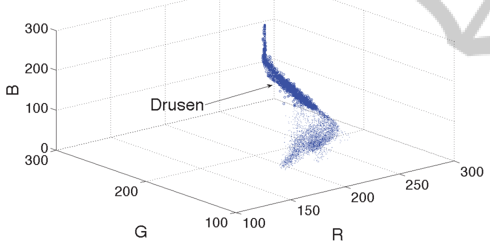

Figure 2: Original representation of the pixel values of eye fundus image in RGB space. Drusen area pixels form linearly prolonged cluster.

Figure 3 illustrates typical result of PCA on eye fundus image containing drusen. Three images in the left column represent red, green and blue components of original image. Right column of the images represents three principal components of this image. As one can see, maximal visual difference in intensity between drusen area and the rest of the image is in the first principal component. It looks much bigger then in the green component of the original image, recommended by other authors.

Eigenvector matrix calculated for the image shown in figure 1 is presented in table 1. Values used to construct first principal component of this image (shown in italics) correspond to the coefficients for construction of optimal color combination proposed by (Patasius, 2009-2): 0.0287; 0.6975; -0.2738 for R, G and B components respectively. Eigenvector values of the other analysed pictures were in the same range.

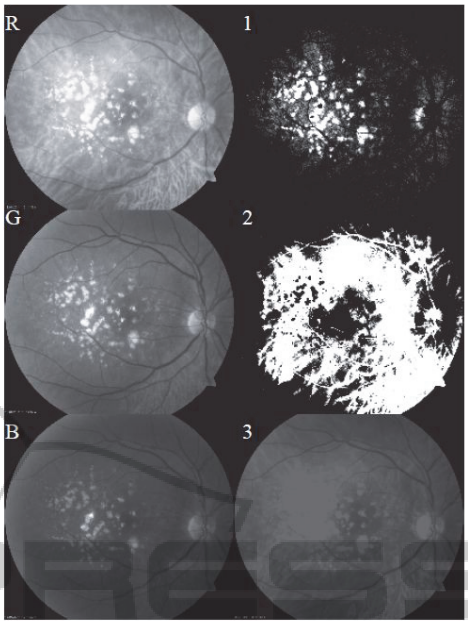

Figure 3: Example of PCA on typical eye fundus image containing drusen. Original R, G and B components of the image presented on the left column. Three principal components of the image are prsented on the right column.

Table 1: Eigenvector matrix calculated for image presented in Figure 1.

-0,15	0,62	0,77
0,68	-0,5	0,53
-0,72	-0,61	0,35

Values of the contrast-to-noise estimates for this image are presented in table 2. The maximal contrast-to-noise estimate value 4.37 is for green component of the original image, however the same estimate reaches 98.56 for Y1 principal component, showing significant increase in contrast after PCA procedure. In majority of images increase in contrast was at least 10 fold or more.

Table 2: Mean pixel values of drusen and non-drusen areas and contrast-to-noise estimates C.

	Drusen		Non-drusen		C
	Mean	StDev	Mean	StDev	
R	237,84	84,89	173,52	581,13	2,67
G	184,81	796	116,07	247,82	4,37
B	109	505,44	74,68	92,96	3,56
Y1	248,1	137,29	39,84	4,46	***98,56***
Y2	179,84	84,39	351,63	184,09	12,66
Y3	102	0.51	88,12	462,43	0,65

Visual inspection of the images showed good compliance between areas of highest intensity pixels in first principal component with drusen areas marked by the experts in original images.

4 DISCUSSION

Similarity of values in the first eigenvector used to construct first principal component to the color coefficients proposed in (Patasius 2009-2) shows that method constructs particular color scheme similar to the universal one. However we expect that our scheme will compensate influence of registering conditions and other technical factors eventually having critical impact on final result. This advantage will be proven in future experiments.

The analyzed raw data are homologous in all initial dimensions because of the same origin (the same type of registering equipment only in different colors). Therefore is no need to perform any normalization and we can't expect any better results from higher-level multivariate methods (e.g. Kernel PCA).

Usage of certain principal component instead of original image can increase the performance of automatic drusen area evaluation algorithms. Visual evaluation of this principal component can reveal more image details for the expert.

The usage of the method is not limited to the drusen. It could be used to increase contrast of other unicolor objects in the images as well.

Limitations of the method: We have only three original variables determining limited space for calculated principal components. So one should be sure that part of the variance corresponding to drusen should be at least amongst top three, otherwise PCA will ignore it. It means that some critical minimal area of the image should be covered by the drusen, exact percentage of it will be determined in further investigations.

5 CONCLUSIONS

Principal component analysis based eye fundus image preprocessing is significantly increasing contrast-to-noise ratio of drusen area for further automatic detection or visual examination.

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