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Automatic classification of the interferential tear film lipid layer using colour texture analysis

B. Remeseiro[a,*], M. Penas[a], N. Barreira[a], A. Mosquera[b], J. Novo[a], C. García-Resúa[c]

[a] Departamento de Computación, Universidade da Coruña, Campus de Elviña S/N, 15071 A Coruña, Spain
[b] Departamento de Electrónica y Computación, Universidade de Santiago de Compostela, Campus Universitario Sur, 15782 Santiago de Compostela, Spain
[c] Escuela de Óptica y Optometría, Universidade de Santiago de Compostela, Campus Universitario Sur, 15782 Santiago de Compostela, Spain

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ABSTRACT

The tear film lipid layer is heterogeneous among the population. Its classification depends on its thickness and can be done using the interference pattern categories proposed by Guillon. This papers presents an exhaustive study about the characterisation of the interference phenomena as a texture pattern, using different feature extraction methods in different colour spaces. These methods are first analysed individually and then combined to achieve the best results possible. The principal component analysis (PCA) technique has also been tested to reduce the dimensionality of the feature vectors. The proposed methodologies have been tested on a dataset composed of 105 images from healthy subjects, with a classification rate of over 95% in some cases.

1. Introduction

The preocular tear film is a complex and dynamic structure of lipids, proteins and mucins, riding on the hydrophobic surface of the epithelium [1]. Classically, it is described as a trilaminar structure composed of a superficial lipid layer, an intermediate aqueous phase and an underlying mucous layer [2]. The tear film provides a smooth optical surface by compensating for the micro irregularities of the corneal epithelium [3]. Furthermore, it plays an essential role in the maintenance of ocular integrity by removing foreign bodies from the front surface of the eye, supplying antimicrobial and mechanical protection to the corneal epithelium [4].

The lipid layer of the tear film plays a major role in limiting evaporation during the inter-blink period and also affects the tear film stability. The lipid layer thickness can be evaluated by the observation of the interference phenomena [5], which correlates with tear film quality [6], since a thinner lipid layer speeds up water evaporation decreasing the tear film stability.

* *Corresponding author*. Tel.: +34 981167000x1330; fax: +34 981167160.
E-mail addresses: bremeseiro@udc.es (B. Remeseiro), mpenas@udc.es (M. Penas), nbarreira@udc.es (N. Barreira), antonio.mosquera@usc.es (A. Mosquera), jnovo@udc.es (J. Novo), carlos.garcia.resua@usc.es (C. García-Resúa).
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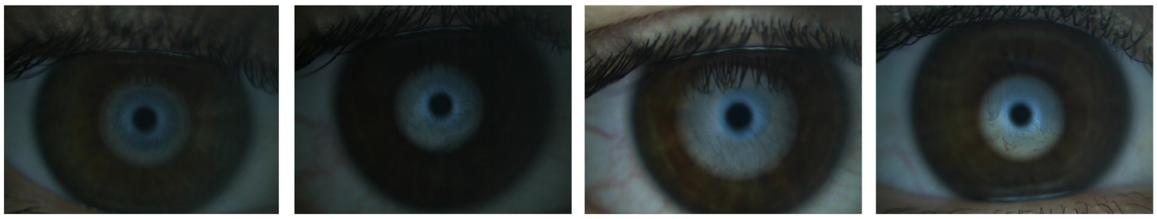

Fig. 1 – Lipid layer interference patterns: (a) Open meshwork. (b) Closed meshwork. (c) Wave. (d) Colour fringe.

Consequently, a deficit of this layer can cause the *evaporative dry eye syndrome*. This condition affects a wide sector of the population, specially among contact lens users, and worsens with age.

The Tearscope plus is the instrument designed by Guillon for rapid assessment of lipid layer thickness [5]. This device projects a cylindrical source of cool white fluorescent light onto the lipid layer and it is commonly used in conjunction with a biomicroscope to obtain high magnification. It enables tear film assessment within the clinical and the laboratory settings, and provides information regarding the thickness of the lipid layer. Thus, in order to classify the tear film lipid layer as a function of its thickness, we consider the five main grades of lipid layer thickness interference patterns proposed by Guillon [5]: open meshwork, closed meshwork, wave, amorphous and colour fringe. The amorphous pattern has not been considered in this work due to the lack of images from this category in the clinical image dataset used for validation. Fig. 1 depicts the four categories considered in this study. Thicker lipid layers ($\geq$90 nm) are readily observed since they result in colour and wave patterns. In contrast, thinner lipid layers ($\leq$60 nm) are difficult to observe, since the colour fringes and other distinct morphological features are not present. If the lipid layer is $\leq$50 nm, only a gray or white surface, without other relevant features, is observed.

The classification is commonly affected by the subjective interpretation of the observer and sometimes difficult to perform, specially with thinner lipid layers that lack distinct features. This has led to the development of techniques to objectively calculate the lipid layer thickness using sophisticated optic systems [7], or techniques that use an interference camera to assess the lipid layer thickness by the analysis of the interference colours [8]. However, Tearscope plus offers a technique more suitable for clinical settings. Although Tearscope lipid layer evaluation has hitherto been affected by subjective interpretation, good agreement between observers has been found, which has proved its validity. Notice that Tearscope plus is also a useful system to evaluate other common clinical tests, such as *noninvasive tear break-up time test* (NIBUT) using a fine grid [9]. Furthermore, it is the best way to observe the tear meniscus without the need for fluorescein instillation [10].

As previously mentioned, the lipid layer thickness can be evaluated by the observation of the interference phenomena. This work shows how the interference phenomena can be characterised as a texture pattern and the tear film lipid layer can be automatically classified into four of the categories enumerated by Guillon. Thus, we present a methodology that, from a photography of the eye, detects a region of interest and extracts its low-level features, generating a feature vector that describes it, to be finally classified in one of the target categories. We will compare different texture feature extraction methods in different colour spaces as well as their combinations. Finally, we analyse the feature vectors to reduce their dimensionality and improve the classification accuracy. This automatic classification is very important to the experts, who do this subjective time-consuming task by hand.

This paper is organised as follows. Section 2 describes the methodology, including the acquisition of the image, the extraction of the region of interest and the colour texture analysis. Section 3 shows the experimental results obtained by different texture and colour analysis methods, their combination and principal components analysis (PCA). And section 4 briefly exposes and discusses the conclusions of this work.

2. Methodology

The methodology we describe in this section consists of four stages. The first stage entails the acquisition of the input image. The second stage involves the extraction of the region of interest that will be subsequently analysed. In the third stage, the underlying texture and colour are analysed. Finally, the last stage classifies the images into the categories previously mentioned. In the following sections, we explain the methodology in detail.

2.1. *Image acquisition*

The input image acquisition was carried out with the Tearscope plus [11] attached to a Topcon SL-D4 slit lamp [12]. The Tearscope plus was designed by Guillon [5] as an instrument for rapid evaluation of the lipid layer thickness in clinical settings. This instrument projects a cylindrical source of cool white fluorescent light onto the lipid layer illuminating almost all of the corneal surface area. The interference patterns were observed through a slit-lamp microscope (see Fig. 2), with magnification set at 200X.

In the process to obtain *lipid layer pattern* (LLP) images, the Tearscope plus is attached to a slit lamp support of R900 Goldmann applanation tonometer. First, the LLP is focus with the slit lamp and, once that is done, the Tearscope plus is approached toward the patient's eye. The closer the Tearscope plus to the subject is, the higher the LLP area is. It has been figured out that LLP is more difficult to categorise in clear eyes