ANALYSIS OF CORNEAL IMAGES FOR ASSESSING CONTACT LENS TRAUMA

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ABSTRACT

Contact lens wearers are often affected by a condition known as conjuctival hyperaemia. This condition is characterised by dilated blood vessels visible in the sclera (the white portion of the eye). Optometrists need to be able to detect changes in the level of redness and to repeatably assess the absolute levels of redness found in a patient's eye in order to prescribe and evaluate treatment. The goal of this paper is to develop an automated method for grading the level of redness in human eyes. The selected features examine the average redness and length of arterial edges. The computed features are correlated with expert data collected to train the redness estimator.

1. INTRODUCTION

One symptom used to determine ocular health is the level of redness evident in the sclera (the white portion of the eye). This condition is known as conjunctival hyperaemia and is commonly the result of irritation from contact lenses. It is important to be able to reliably measure changes in the level of conjunctival hyperaemia present in a person's eye over time, since optometrists base their assessment of a particular treatment on the rate of such changes.

Because of the considerable interest in such assessments, optometrists have proposed many scales to judge the level of conjunctival hyperaemia in an eye. However, some of these scales are limited merely to descriptors with no quantifiable rating. Even with those scales that produce numbers, the results can be inconsistent from one clinician to the next (or even worse, the estimates from a single clinician can vary considerably over time) [3,4]. A visual representation of this inconsistency can be seen in Figure 2.

This paper presents the development of an automated estimator for conjunctival hyperaemia. The goal of the estimator is to reproduce the overall trend (but eliminate the inconsistent and irreproducible details) of the expert ratings. A field study is in progress that is conducted by means of an automated survey, accessible at http://www.eng.uwaterloo.ca / projects / sd_eyes. The eye

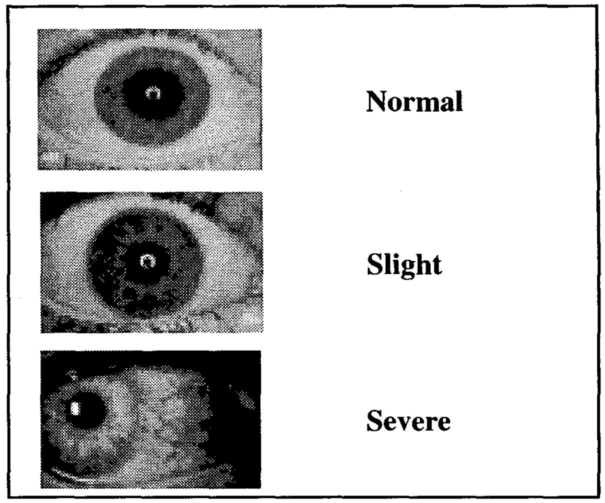

Fig. 1: Image of normal, slight and severe levels of conjunctival hyperaemia.

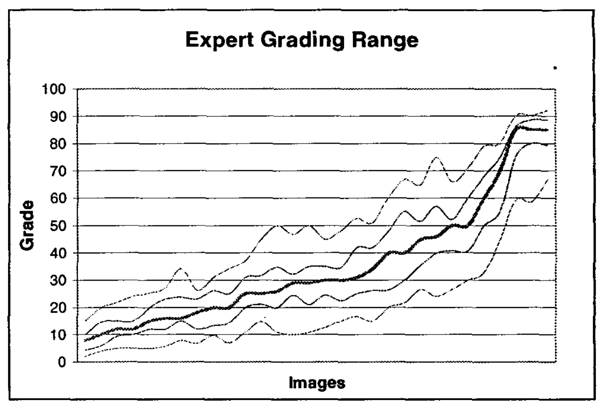

Fig. 2: Expert grade range for set of ocular images at the 10th, 30th, 50th, 70th and 90th percentiles

images were analysed for quantifiable redness features, which were correlated with the expert grading data to produce an estimator that is accurate, consistent, and repeatable.

In order to identify possible features of the sclera, the sclera itself must first be segmented from the rest of the

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eye. Since the number of images to be analyzed in most clinical settings is modest, we propose a supervised approach to the segmentation.

The proposed segmentation, shown in Figure 3, uses eight user-defined points to isolate the sclera and then the centre point to split the image into the nasal and temporal halves for feature extraction. The proposed features are discussed in the next section, followed by an assessment of the classifier.

2. FEATURE EXTRACTION

Once the sclera has been isolated and segmented into nasal and temporal scleral regions S_n and S_t, for each eye image I, the key problem is the determination of image features to obtain a quantitative assessment of the eye. By visual comparison of the ocular images with expert grades, two redness and one edge feature were selected as representative of how the experts quantified redness. In addition, the website asked experts to speculate what features they were influenced by when determining grades for the images.

Conjunctival hyperaemia is characterized by the expansion of capillary arteries just below the surface of the eye; severe cases may lead to swelling in larger blood vessels. As the blood vessels swell they become much larger and easily detected as a red line on a white scleral background. We propose an adaptive edge-detector (e.g. Canny [1]) to measure the total length of visible arteries. However the smallest capillaries are resolvable neither by the pixels in a CCD camera, nor by the human eye, so a mild onset of hyperaemia begins as a diffuse reddening with no discernible edges. For such cases we propose an integrated measure of redness, undetected by edge detection.

2.1. Edge Feature

A variety of image edge detection algorithms were tested, with the Canny detection approach with a threshold value of 0.04 selected as the most effective. The edge feature value $f_e(S)$ corresponding to scleral region S in image I is given by the total number of edge pixels detected divided by the total number of scleral pixels:

$$f_e(S) = \frac{\sum_{i \in S} e_i}{|S|} \qquad (1)$$

where the edge generator e is applied to the greyscale image.

The resulting values for $f_e(S)$ range from 2.7 x 10^{-3} to 0.16. Obvious extensions to this feature include thresholding arteries below a certain diameter, or measuring artery spatial density rather than total length.

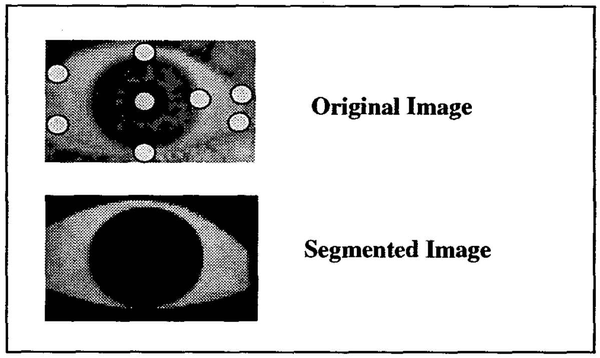

Fig. 3: User-defined points and sclera isolation

2.2. Redness Feature

The overall degree of redness $f_r(S)$ in the sclera is easily computed as the sum of the redness of each pixel. The pixel redness is normalized for convenience such that a healthy sclera (white) has zero redness, and an affected sclera (red) has a redness of one:

$$f_r(S) = \frac{\sum_{i \in S} \left(\frac{2(I_R)_i - (I_G)_i - (I_B)_i}{2(I_R)_i + 2 + (I_G)_i + 2(I_B)_i} \right)}{|S|} \qquad (2)$$

where any black pixels (which have no defined colour) have been removed from S. The resulting values for $f_r(S)$ range from 1.7 x 10^{-3} to 0.21. Extensions to this feature include only considering redness values above a certain threshold or varying the ratio of which the red, green and blue colour channel values contribute to $f_r(S)$.

2.3. Other Features

One problem encountered by using purely edge or redness based features it that a clinician may be influenced by the *distribution* of trauma in the sclera. An eye with localised trauma may have the same overall percent redness as an eye with an even distribution of redness across the sclera, yet the expert may grade the two quite differently. As a result, preliminary work began on a feature that accounted for the distribution of redness in the sclera. The feature summed the number of 9x9 windows in the sclera that had an average redness value above a predefined threshold and normalised for scleral area. Initial results showed a correlation with expert grades of 0.90 for the nasal side and 0.73 for the temporal side, but the results were not quite as good as those of the redness and edge features.

Future work on possible features could look at ways to improve this distribution-dependant feature or perhaps some combined edge and redness metric could be devised.

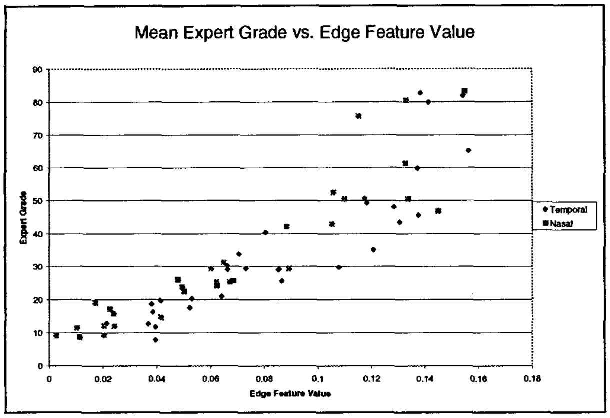

Fig. 4: Distribution of the mean expert grade vs. the edge feature value for 30 test images, assessed separately for the temporal and nasal sides

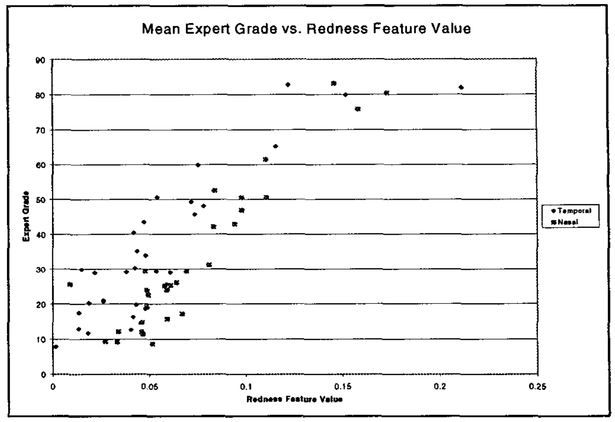

Fig. 5: Distribution of the mean expert grade vs. the redness feature value for 30 test images, assessed separately for the temporal and nasal sides

Any progress in determining feature values would greatly benefit from additional test images, particularly in the higher end of the grade scale.

4. ESTIMATOR DESIGN

In order to reduce bias and human error, grading of conjunctival hyperaemia performed by experts in the field of optometry should be automated in order to ensure consistency and accuracy in the field. In order to produce this automated estimator, information gathered from the experts as well as the feature values described above was needed.

Our survey collected data from 59 experts, each of whom graded both the nasal and temporal sides of 30 different eye images. As the data was collected, a weighted mean for the data was devised to represent the expert grade. An accuracy percentage was calculated by determining the percentage of an expert's given grades that fell within one standard deviation of the real mean were calculated. Each of the expert grades was multiplied by the accuracy percentage. The resulting weighted grades were added together and divided by the percent weightings to get a weighted expert grade.

Figure 4 shows the results of the edge feature graphed against the mean expert grade for each eye. Similarly, Figure 5 shows the redness feature results graphed against the mean expert grade. The shape of these graphs helped to guide the regressions that were performed on the data.

The following section details the results of the various regressions that were completed and, finally, gives the grading equation that produced the best correlation with expert data.

5. RESULTS AND DISCUSSION

Single variable linear least-squares regression, with the constant term forced to zero, was performed between the weighted grades and each of the feature values. The regression analysis was performed on the temporal and nasal sides of the eyes separately. The regression resulted in coefficients that could be used in expressions for calculating grades based on the feature values. Correlation coefficients were used to determine the relative success of the regression expression at grading the eyes. For the nasal side of the eye, the resulting coefficients for the redness and edge features were 0.93 and 0.92 respectively. For the temporal side of the eye, these coefficients were 0.88 and 0.90 respectively.

As was anticipated earlier, it is not obvious that keeping either feature value, omits own, represents an optimal strategy: the edge redness features concentrate on different aspects of the development of the hyperaemia. Consequently there is considerable motivation for developing a multivariate estimator of grade, based on all features.

Furthermore, as is obvious from Figures 4 and 5, the relationship between the expert grades and the features is not linear. The plot for the redness feature implies a square-root behaviour, whereas the edge feature was roughly linear. Consequently a new regression was performed between the edge feature and the square of the redness; the calculated coefficients resulted in the following expression for calculating the grades:

$$Grade = 1436 * f_r(S)^2 + 316 * f_e(S) \qquad (3)$$

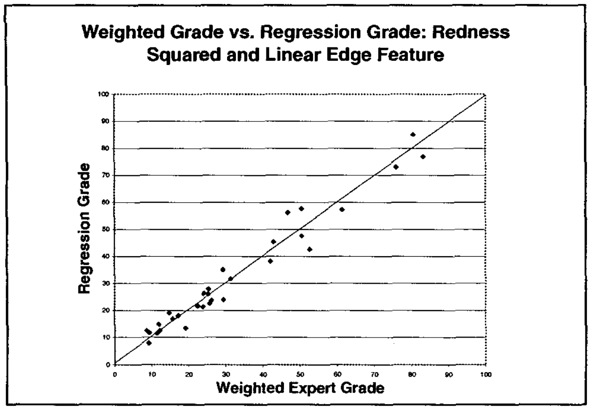

Fig. 6: Comparison of regression grades vs. Weighted expert grades for 30 test images assessed for the nasal side

Given the above equation, the correlation coefficient for the new grades of the nasal side of the eyes was 0.98. Following a similar procedure for the temporal side, the best results were obtained by regressing linear values for the redness and edge features. The resulting correlation coefficient for the temporal side of the eyes was 0.96. Table 1, below, summarizes the correlation coefficients that result from a number of multivariate tests.

Regression	Correlation Coefficient	
	Nasal	Temporal
$f_r(S)$	0.93	0.88
$f_e(S)$	0.92	0.90
$f_r(S)^2$	0.92	-
$f_r(S)^2$ and $f_e(S)$	0.98	-
$f_r(S)$ and $f_e(S)$	-	0.96

Table 1: Summary of Correlation Coefficients

The correlations between the final multivariate regression and the weighted grades were very good. This indicates that it is very possible to use image-processing techniques to determine features that can characterise the level of irritation of an eye. Figure 6 plots the weighted expert grades vs. the estimated grades to show the effectiveness of the final estimator on the nasal side of the eye. Finally, Figure 7 shows a contour graph with the grade boundaries and the data points representing the 30 eyes' feature values for the nasal portion of the eye.

The ability to obtain high correlation coefficients using relatively simple redness features suggests that the automated grading process outlined here is promising. In fact, the school of optometry at the University of Waterloo has shown interest in developing a working prototype of the system.

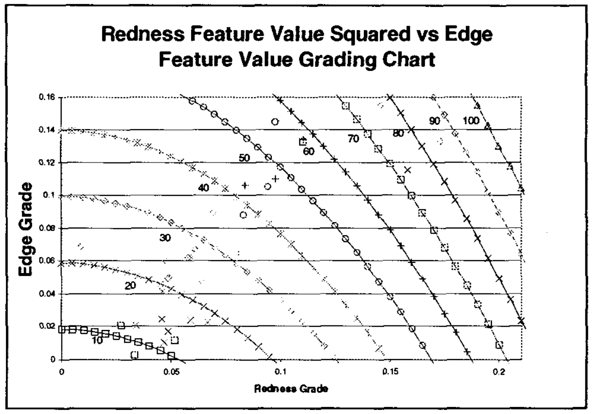

Fig. 7: Contour grading plot resulting from regression analysis plotted against 30 test image feature values

6. ACKNOWLEDGEMENTS

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