A FULLY AUTOMATIC RED-EYES DETECTION AND CORRECTION ALGORITHM BASED ON UNIFORM COLOR METRIC AND BINOCULAR GEOMETRIC CONSTRAINT

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Abstract: Red-eye is a highly objectionable defect that often occurs in digital images taken with a flash by modern small cameras. Although many red-eye reduction algorithms were proposed and equipped in most of the digital cameras, none of these algorithms is effective enough. In this paper, an algorithm for automatic detection and correction of red-eyes is proposed. The color detector based on uniform color metric is developed to locate regions of major colors including red-eye color and skin tone. The structure of major colors is adopted to locate candidate red-eye regions. The geometric relationship between the dimension of the human pupil and binocular distance is employed to eliminate most false positives (image regions that look like red-eyes but are not). More than one pairs of red-eyes snapped in different view angles are detected by the proposed algorithm. Detected red-eyes are then corrected by modifying chroma, hue angles and luminance of the associated pixels such that red color is removed while maintaining a natural look of the eye. Simulation results show that the proposed algorithm is pretty robust and effective.

1 INTRODUCTION

Red-eye is a common problem in digital photography. When an image is captured with flash illumination by a camera that has an illumination source very close to the camera lens, the bright flash light reflected from the blood vessels on the retina, giving the human eyes in the image an unnatural red hue. Red-eye is a hardly acceptable defect that significantly reduces the value of an image.

For this reason, many efforts have been made to prevent it from occurring, or to detect and correct it in the post-capture processing. A straightforward way of preventing red-eye is to increase the distance between the illumination source and the camera lens. Another solution for red-eye prevention is the use of a pre-exposure flash that decreases the size of the subject's pupil followed by a second flash for capturing the image. The drawback of this approach is the great consumption of power that shortens the battery life. Moreover, this approach sometimes can only reduce, but not eliminate, the red-eye artifacts. Many research results have been developed and implemented as software products such as "Picture Maker" from Eastman Kodak Company and "iPhoto" from Apple. These products require manual manipulation to outline the red-eye region for correction. It is obviously impractical and inefficient to process a large number of images manually. A fully automatic red-eye detection and correction algorithm is therefore needed. Furthermore, it is highly expected that this automatic algorithm can be realized as a piece of hardware and planted in digital cameras. Recently, a number of researches on automatic red-eye detection and correction have been conducted (Schildkraut and Gray, 2002)-(Zhang, Sun, Li, and Zhang, 2004). The AREA algorithm proposed by Eastman Kodak Company uses features based on red-eye defects to automatically detect only a pair of red-eyes in each image (Schildkraut and Gray, 2002). In (Matthew and Robert, 2002), the face must be successfully detected before the red-eye detection where the information of color, intensity and dimension is utilized. In (Ioffe, 2003), a learning-based face detector is also adopted for the detection of red-eye defects. In these approaches, the face detection itself is another challenging problem to be solved (Xin, Xu, and Du, 1998). In (Zhang, Sun, Li, and Zhang, 2004), a heuristic algorithm is used to detect candidate red-eye

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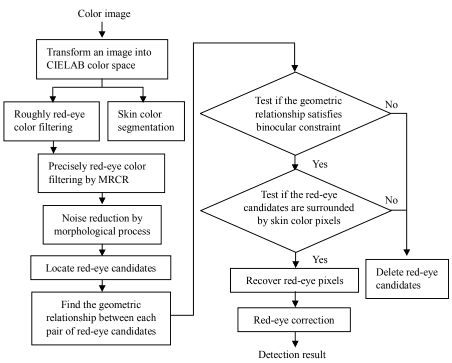


Figure 1: The function block diagram of the proposed red-eye detection algorithm.

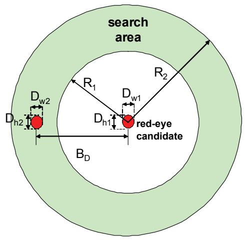


Figure 2: Binocular geometric relationship between a pair of red-eyes.

regions, and then an eye classifier is utilized to confirm whether the candidate region is a red-eye.

Color is important information to the detection and correction of red-eye artifacts. In this paper, color classifiers based on uniform color metric are first designed to detect colors of red-eyes, skin tones and colors without red hue. The relationship among these colors and the geometric constraints inherent in pairs of human eyes are exploited to eliminate false positives. Finally, the information of hue, chroma and luminance is utilized to restore the red-eye color to a natural tone.

2 UNIFORMITY OF THE CIELAB COLOR SPACE

Color is a visual perception of the light in the visible region of the electromagnetic wave spectrum incident on the human retina. By the theory of trichromacy, any color in a color space can be represented by a triple of numbers called tristimulus values (CIE, 1986), (Sangwine and Horne, 1998). However, colors in many color spaces, such as RGB, XYZ, YUV, and YC_bC_r, are not uniformly distributed in a sense that the same perceptual color difference does not correspond to the same distance enumerated in the tristimulus space (Sangwine and Horne, 1998), (Sharma and Trusell, 1997). If a color space is perceptually uniform, the perceptual difference between any two colors can be ideally represented as the Euclidean distance between their coordinates. The CIELAB color space is such a color space to overcome the non-uniform color metric that had been discussed by MacAdam (MacAdam, 1943). In this paper, the color transformation to CIELAB color space is

3 THE PROPOSED RED-EYE DETECTION ALGORITHM

The functional block diagram of the proposed red-eye detection algorithm is shown in Figure 1. The color image is first transformed to CIELAB color space. Through the uniformity in the CIELAB, the red-eye color and skin color are roughly extracted. According to the database containing all kinds of red-eye samples, a more precise red-eye color filter is then developed by the method of K-mean clustering and just-noticeable color difference in the CIELAB color space. The correlation between the size of the human eyeball and binocular distance is finally employed to eliminate most false positives

Through statistically analyzing the manually extracted red-eye color pixel and skin color pixel from various color images, the distribution of red-eye colors and skin colors in CIELAB color space can be found. For each pixel in the color image, the tristimulus values of red-eye color pixels in CIELAB color space satisfy

$$\begin{cases} L > 30 \\ 20 < a < 80 \\ -25 < b < 50 \end{cases}, \tag{1}$$

and the tristimulus values of skin color pixels in CIELAB color space satisfy

$$\begin{cases} L > 30 \\ -5 < a < 20 \\ -5 < b < 25 \end{cases}. \tag{2}$$

In this paper, the skin color is the reference information that is used to delete image regions that look like red-eyes but are not.

The method of K-means clustering is used to calculate the centroid in the red-eye set as the major red-eye color. Clustering in pattern recognition is the process of partitioning a set of pattern vectors into subsets called clusters. In this paper, the number of centroids found by the clustering method is 32. As described in Section 2, the perceptual difference

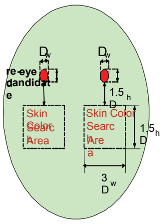


Figure 3: The surrounding skin color pixels of red-eye candidates.

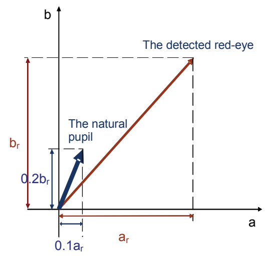


Figure 4: The color relationship between red-eye and its natural appearance on color-opponent ab plane.

between any two colors can be ideally represented as the Euclidean distance between their coordinates in the CIELAB color space, and loci of colors which are perceptually indistinguishable from a particular color form a sphere centralized at this color's coordinate. In this color space, two colors are considered perceptually distinguishable if the Euclidean distance between these two colors' coordinates exceeds a threshold of just-noticeable color difference (JNCD). That is

$$\Delta E = \left(\Delta L^2 + \Delta a^2 + \Delta b^2\right)^{1/2} \geq JNCD_{\text{Lab}} \tag{3}$$

where $JNCD_{\text{Lab}}$ has been found around 3.0. Therefore, the major red-eye color region (MRCR) can be defined as a sphere for each major red-eye color. The colors locating in the MRCR of each centroid are selected as the color pixel in the red-eye.

In previous detection steps, some noises occur in the preliminary red-eye segmentation area. To reduce the noise, morphological process is utilized. In this paper, two morphology operations, including dilation "D" and erosion "E", are used. The former operation adds pixels to the object boundaries, while the later operation removes pixels on object boundaries in an image. The two operations are combined to build a higher order opening operation "O" for removing noises from the red-eye segmentation area while preserving the shape and size of this red-eye segmentation area in the image.

$$\mathrm{O}(I, B_E, B_D) = \mathrm{D}(\mathrm{E}(I, B_E), B_D) \tag{4}$$

where I is the binary image that marks the location of selected red-eye pixel, B_E the structuring element for erosion, and B_D the structuring element for dilation. The structuring element of dilation is smaller than that of erosion such that the morphological process can reduce noises that occur in the red-eye segmentation area and avoid losing the red-eye candidates.

By using color information and morphological process, red-eye candidates are located. However, many detected image regions that look like red-eyes but are not. The color pixels in such regions are called false positive candidates. Hence, geometric relationship between each pair of red-eye candidates is considered. Since the distance between a pair of red-eyes is useful to eliminate the false positive candidate, binocular geometric relationship is used to develop binocular geometric constraint for removing false positives. For a red-eye candidate shown in Figure 2, the green circular region centralized at this candidate is used to test whether its red-eye counterpart locates in this region. From the statistical analysis of a large number of data sets, the range of the green circular region is constrained by

$$R_1 > 4D_{w1}, \tag{5}$$

$$R_2 < 10D_{w1}. \tag{6}$$

The pair of red-eye candidates is further tested if its width and height can satisfy

$$0.75 < D_{w2}/D_{w1} < 1.30, \tag{7}$$

$$0.75 < D_{h2}/D_{h1} < 1.30. \tag{8}$$

If the width and height of the pair of red-eye candidates cannot satisfy Eq. (7) and (8), the pair of red-eye candidates will be removed.

Finally, the pair of red-eye candidates that pass through the binocular geometric constraint is tested if it is surrounded by pixels of skin color tones. The surrounding skin color pixels of red-eye candidates are simply defined as two areas as shown in Figure 3. The width and height of the area are $1.5D_h$ and $3D_w$, respectively. The area is recognized as skin color if the amount of skin color pixels, N_{skin}, that satisfy Eq. (2) is high enough, or

$$N_{skin}/(1.5D_h \times 3D_w) > 0.8. \tag{9}$$

4 RECOVERY AND COLOR CORRECTION OF RED-EYES

Since some red-eye color pixels are removed from the red-eye candidates in the previous processes, it is therefore required to retrieve the lost red-eye color pixels. The region of the red-eye candidate is simply extended by its neighboring red-eye color pixels. That is, the boundary of the red-eye candidate region centered on its center location is enlarged pixel by one pixel to form a perfectly retrieved region of the candidate.

Once the location and size of the red-eyes have been detected, color correction of red-eyes is applied to the detected red-eyes to obtain the natural appearance of the pupil. To maintain the natural appearance of the pupil at the location of red-eyes, the value of luminance (L component) of the detected red-eye is slightly adjusted and the values of hue and chroma (a and b components) are adjusted based the color relationship between red-eye and the corresponding natural appearance of pupils on color-opponent ab plane. For simplicity, the adjustment for color correction is to scale down the value of a component of red-eyes by a factor of 0.1 and to scale down the value of b component of red-eyes by a factor of 0.2 as shown in Figure 4. The value of luminance of the detected red-eye is adjusted by a factor of 0.9. That is,

$$L_{corrected} = 0.9 \times L_r \quad (10)$$

$$a_{corrected} = 0.1 \times a_r \quad (11)$$

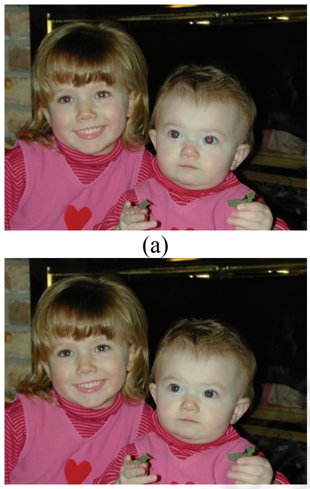
$$b_{corrected} = 0.2 \times b_r \quad (12)$$

where (L_r, a_r, b_r) and ($L_{corrected}$, $a_{corrected}$, $b_{corrected}$) are tristimulus values of the detected red-eye color pixel and its corrected color pixel, respectively.

5 SIMULATION RESULTS AND CONCLUSIONS

To evaluate the performance of the proposed algorithm, the simulation of the red-eye detection algorithm that is applied to red-eye digital images with different size and quality is conducted. In Figure 5, the "Pinksisters" image that has more than one pairs of red-eyes is also detected and corrected by using the proposed algorithm. In our experiments, over 200 red-eye digital photographs are tested and more than 80% red-eyes are efficiently detected. The experimental results show that the proposed algorithm is robust and effective under a variety of shooting conditions and backgrounds.

In this paper, a fully automatic red-eyes detection and correction algorithm is proposed. In the proposed algorithm, a robust color classifier for detecting red-eye color and other major colors in digital images with red-eyes is developed and a multi-stage criterion for detecting each single red-eye is designed. The detected red-eyes are successfully corrected by modifying chroma, hue angles and luminance of the associated pixels such that red color is removed while maintaining a natural look of the eye. The proposed system has very low false detection rate. Simulation results show that more than 80% of red-eyes can be detected and only 5% are false alarm.



(a)

Figure 5 (a): "Pinksisters" image with red-eyes, (b) the image after correcting red-eye colors.

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