

Automatic Red-eye Detection and Removal

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Abstract

Red-eye is a very common problem in flash photography which can ruin a good photo by introducing color aberration into the subject's eyes. Previous methods to deal with this problem include special speedlight apparatus or flash mode that can reduce the red-eye effect, as well as post-capture red-eye correction software. This paper presents a new approach to detect and correct red-eye defects automatically by combining flash and non-flash digital images. It is suitable to be incorporated into compact digital cameras that support continuous shooting. Such a camera would eliminate red-eye immediately after image capture. Unlike existing approaches, our method is simple, fast and can recover the true color of the eyes.

1. Introduction

When photographing a person under insufficient illumination, a flash is often used to illuminate subjects to avoid under-exposure. The use of flashlight, however, often results in the subject's eyes being red, ruining the photograph. This phenomena is referred to as "red-eye" and it happens more often in compact cameras than in big professional cameras. The cause of red-eye is a basic fact of human biology — human pupils expand and contract in response to surrounding light. In a low light environment, the pupils enlarge. When the flash goes off, the subject's pupils are not able to shrink quickly. The light from the flash travels through the big dilated pupil and reflects off the red blood vessels behind the retina and then back into the camera. The color of the blood vessels produces this red-eye artifact. Figures 2(a), 3(a1), and 3(b1) show some examples.

Two hardware approaches to reduce red-eye are often used by camera manufacturers. The first approach is to increase the distance between the flash lamp and the optical axis of camera lens. Examples include Yaichi [10] and Adams [2]. In practice, red-eye can be greatly reduced by providing the distance of at least 60 mm [10]. The second approach is to use pre-flashes to contract the subject's pupils before a final flash is used to expose and capture the photo. Examples include Hara [4], Teremy [8] and Yokonuma [11]. It is commonly found in most digital cameras today: the so-

called "red-eye reduction (flash) mode". Unfortunately, this only reduces red-eye, but does not completely eliminate it. Pre-flashes also drain battery power.

Software solutions have also been attempted. Most digital cameras come with photo editing software, such as Adobe Photoshop™, which allows for manual correction of red-eye. Our experience with a number of these show that (1) they are not easy to use (marking the red-eye region is tedious), (2) they do not give a satisfactory result. Recently, a number of automatic solutions have been proposed [1, 3, 7, 9]. All the automatic red-eye detection and correction algorithms can be divided into two stages: detection and correction. The detection stage attempts to locate the abnormal red eye region, sometimes with the help of a face detector and/or eye detector [7, 6, 9]. Clearly, the success of these methods depend on the accuracy of the face/eye detector. In the correction stage, these methods change the redness to a preset color e.g. gray [1, 3, 9] or simply desaturate the redness [7, 6]. Ideally, the red-eye should be replaced with the true eye color including pupil and iris. But this may be lost because the entire eye region could be red, with no pupil and iris color visible. It is clear therefore that existing methods are unsatisfactory.

In this paper, we present a novel approach to detect and remove red-eye phenomenon automatically by combining flash and non-flash digital images. The basic idea is to replace the red-eye in the flash image with the true eye color obtained from the non-flash image. Our method may be easily incorporated into the camera itself, thereby eliminating red eye at the source.

2. Flash vs. Non-flash

First, let's understand flash versus non-flash photography. An image is formed when light energy from the scene is integrated by the camera sensor over a time interval. (For digital camera, the sensor is CCD, CMOS or LBCAST.) Therefore, the image intensity is controlled by scene light, camera aperture, shutter speed and the sensor sensitivity setting:

$$I = \int_0^T L(t) \cdot (A \cdot ISO) dt$$

where I denotes the amount of light sensed by the camera, L is the scene irradiance, denoted as a function of time t , A is the size of aperture (lens opening area), ISO (International Organization for Standardization) denotes the sensitivity or speed of imaging sensor, and T is shutter speed (the time interval that imaging sensor exposed to light).

The I value should be within a suitable range to ensure that the final photo we got won't be too dark (under-exposure) or too bright (over-exposure). So when ambient light is low, that is, L is small, we can either use a flash to illuminate the scene or increase A , T or ISO setting to avoid under-exposure. Each of these:

- T — A large T (long exposure time) tends to cause motion blur and noise.
- A — A large A (big lens opening area) will make the depth-of-field shallow (background becomes blurred).
- ISO — Fast ISO will decrease the Signal-to-Noise Ratio(SNR), i.e. introduce noise.
- L — Using a flash tends to introduce artifacts such as red-eye.

For a dark scene, let us assume that the low ambient light $L(t)$ is above a minimum level for the light to be sensed. This minimum level is determined by the SNR characteristics of the camera hardware.

Now let us capture two images for the same scene, a non-flash image I_{nf} using high ISO, big aperture and a flash image I_f . If we convert both of the images into CIE La^*b^* color space as $I_{nf}(L_{nf}, a_{nf}^*, b_{nf}^*)$ and $I_f(L_f, a_f^*, b_f^*)$, we can find that the luminance and contrast information in the L channel may be different between I_{nf} and I_f , while the chroma information in the a^* and b^* channels are similar. Here we assume that the ambient light is able to reveal the true colors of the scene. It should not be strongly monochromatic, e.g. in a photography dark room illuminated by red light. Fortunately, this assumption is usually satisfied in real life. The chroma information of a^* and b^* may have a small color cast due to ambient light color or inaccurate white balance setting of the camera. Then, we can formulate the relationship of chroma between flash and non-flash images as follows:

$$a_f^* = a_{nf}^* + \Delta a + N; \quad (1)$$

$$b_f^* = b_{nf}^* + \Delta b + N. \quad (2)$$

where Δa and Δb are the possible color cast, and N is additive zero-mean noise.

An example of a flash and a non-flash image of the same scene as well as their corresponding differences in channel a^* and b^* are shown in Figure 2.

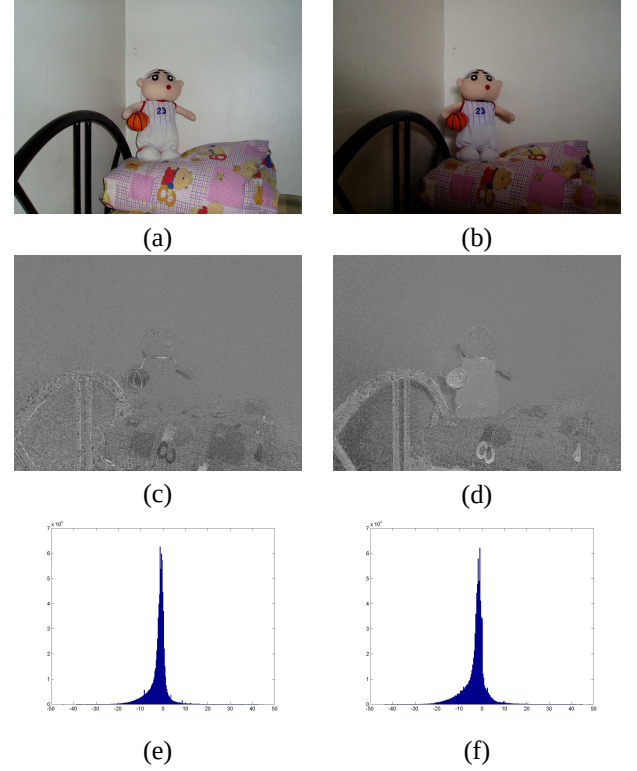


Figure 1: An example of a flash and a non-flash image of the same scene: (a) is the flash image $I_f(L_f, a_f^*, b_f^*)$ (f/3.1, 1/40 sec, ISO-80); (b) is the non-flash image $I_{nf}(L_{nf}, a_{nf}^*, b_{nf}^*)$ (f/2.8, 1/4 sec, ISO-320); (c) shows their difference in channel a^* : $a_f^* - a_{nf}^* = \Delta a + N$ according to Equation (1); (d) shows the difference in channel b^* : $b_f^* - b_{nf}^* = \Delta b + N$ according to Equation (2); (e) is the histogram of $(\Delta a + N)$ shown in (c) ($\mu = -2.058, \sigma = 4.087$); and (f) is the histogram of $(\Delta b + N)$ shown in (d) ($\mu = -2.937, \sigma = 5.090$). Note that $\mu \neq 0$, indicating a slight color cast.

3. Red-eye Detection

Red-eye is a color aberration caused by flash. As we described in section 2, a flash and a non-flash image of the same scene should have similar chroma information except in the eye. We choose CIE La^*b^* color space for red-eye detection after investigating several color spaces. The a^* channel of CIE La^*b^* is a luminosity independent measure of redness.

A similar idea has been used to locate and track of human eyes in video, for instance [5]. But Haro [5] used a special infrared lighting system to generate red-eye and locate it in gray images.

We now describe a conceptual design of a camera that can incorporate our algorithm. This camera can shoot two images in quick succession. One of the two images is

shot with high ISO, a large aperture and reasonable quick shutter speed without flash. The other is shot with flash. The two images also should be captured with the same focal length for ease of alignment. The conceptual idea is easy to implement on today's digital cameras since a lot of digital cameras support "continuous shooting" (For instance, FujiFilm S602 can support 2048*1536 pixels/frame and 5frames/second continuous shooting). If two images of the same scene are shot within a very short time interval, we may assume that there is no motion has occurred. Therefore the images are aligned. In our experiments, we captured the flash and non-flash images by asking the subjects to keep very still in between shots, so alignment processing could be ignored.

To detect red-eye, we use a simple yet effective method. We convert the two images into CIE La^*b^* color space as $I_{nf}(L_{nf}, a_{nf}^*, b_{nf}^*)$ and $I_f(L_f, a_f^*, b_f^*)$, then calculate their differences in channel a^* . If at location (x, y) , the color $a_f^*(x, y)$ is larger than a threshold θ_1 (i.e. indicating that the pixel in flash image is red) and the difference is larger than a threshold θ_2 , the pixel in (x, y) will be regarded as a red-eye pixel candidate:

$$\Delta\tilde{a}(x, y) = a_f^*(x, y) - a_{nf}^*(x, y),$$

$$R_c = \{(x, y) | a_f^*(x, y) > \theta_1 \text{ AND } \Delta\tilde{a}(x, y) > \theta_2\}.$$

where $\Delta\tilde{a}(x, y)$ denotes the difference in channel a^* at location (x, y) , and R_c is the set of candidate red-eye pixels.

The candidate pixels in R_c are grouped into candidate regions. A red-eye region should be like a blob and should not be very small. Anything else is noise. We then use simple morphological operations to remove isolated tiny and narrow regions. We define $R_e = R_c \setminus \{\text{Isolated tiny Or Narrow regions}\}$.

Our detection method does not require a face detector or an eye detector because it is fast and sufficiently accurate. The differences calculated over the image examples in Figure 2(c) and 2(d) in channel a^* are shown in Figure 2(e). The corresponding R_c and R_e are shown in Figure 2(f) and 2(g) respectively.

4. Red-eye Removal

Previous red-eye correction methods of changing redness to some pre-set color and desaturating the redness can also be used here to correct red-eye. But neither of these two methods considered the iris color, which could be different for every individual.

Here, we can use the chroma information in the non-flashed image to restore the original iris color. The first step is chroma compensation: The color cast in the non-flash image should be adjusted to match that in the flash image; the second step is chroma replacement: replace a_f^* , b_f^* of red-eye region in flash image with the a_{nf}^* and b_{nf}^* of

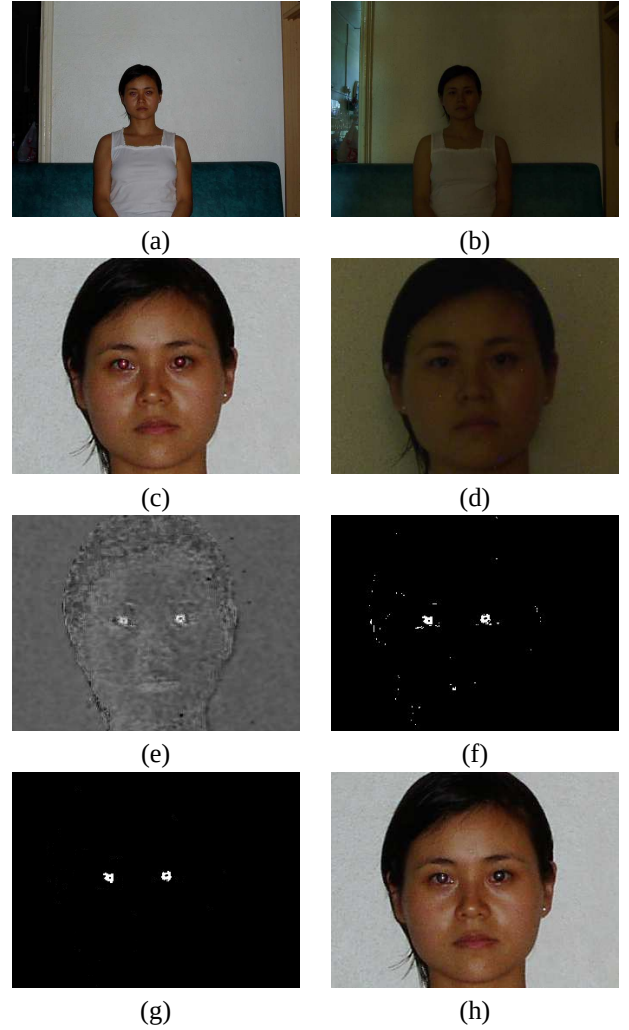


Figure 2: An example of red-eye detection and correction: (a) is the flash image with red-eye defect (f/2.8, 1/60 sec, ISO-200); (b) is corresponding non-flash image (f/2.8, 1/30 sec, ISO-1600); (c) and (d) are the close-up view of (a) and (b) respectively; (e) is their difference in channel a^* ; (f) shows the R_c region and (g) shows the R_e region with isolated red pixels removed; finally (h) shows our correction result.

corresponding region in non-flash image. Let $S = \{(x, y) | (x, y) \notin R_c\}$ denote the locations where the pixels have no color aberrations.

$$a_f^*(x, y)_{correct} = a_{nf}^*(x, y) + \frac{1}{|S|} \sum_{(u, v) \in S} \Delta\tilde{a}(u, v),$$

$$b_f^*(x, y)_{correct} = b_{nf}^*(x, y) + \frac{1}{|S|} \sum_{(u, v) \in S} \Delta\tilde{b}(u, v),$$

$$\forall (x, y) \in R_e.$$

The second term in these equations is the mean color cast, which we add back to the non-flash image. The correction result of the example in Figure 2(a)/(c) is shown in Figure 2(h).

5. Results and Conclusion

In this paper, we presented a simple and fast technique to detect and correct red-eye defects automatically by combining flash and non-flash digital images. The use of two images enable us to recover the true eye color, overcoming the limitations of previous techniques. We aim to implement our method onto most existing digital cameras that support continuous shooting by modifying only the camera control software to capture a flash image together with a non-flash image in quick succession.

We tested our red-eye detection and removal technique on a variety of flash and non-flash image pairs. The results show that our method works well. Examples are shown in Figures 2 and 3.

We currently require that the ambient light in the non-flash image not be too low. This minimum light intensity depends on the ISO setting, the aperture size, shutter speed and the camera-specific SNR. We have yet to quantify the precise relationship between these factors. Doing so will enable us to determine when our technique may not be applicable. We leave this as future work.

As digital cameras continue to improve, we anticipate that more sophisticated algorithms be incorporated into the camera itself, so that better pictures may be produced without post-processing. The use of multiple flash and non-flash images is a promising direction. In the near future, we intend to explore such techniques to correct other flash-caused artifacts, such as uneven exposure, unpleasant shadows and reflection of the flash from a shiny surface.

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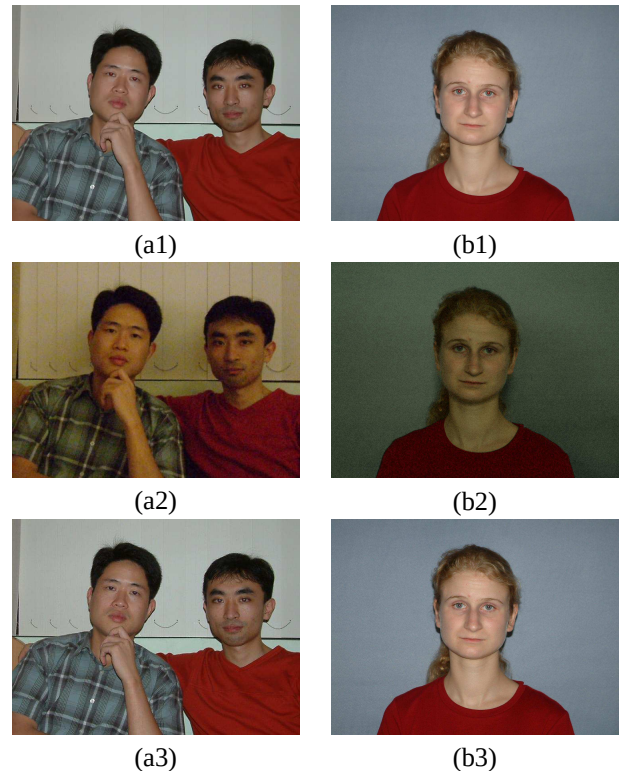


Figure 3: Experiment results. (a1), (a2) and (b1), (b2) are the flash and non-flash image pairs with red-eye defects (flash image: f/2.8, 1/60 sec, ISO-200; non flash image: f/2.8, 1/30 sec, ISO-1600). (a3) and (b3) are the correction results of (a1) and (b1) respectively.