Automatic Method for Measuring Eye Blinks Using Split-Interlaced Images

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Abstract. We propose a new eye blink detection method that uses NTSC video cameras. This method utilizes split-interlaced images of the eye. These split images are odd- and even-field images in the NTSC format and are generated from NTSC frames (interlaced images). The proposed method yields a time resolution that is double that in the NTSC format; that is, the detailed temporal change that occurs during the process of eye blinking can be measured. To verify the accuracy of the proposed method, experiments are performed using a high-speed digital video camera. Furthermore, results obtained using the NTSC camera were compared with those obtained using the high-speed digital video camera. We also report experimental results for comparing measurements made by the NTSC camera and the high-speed digital video camera.

Keywords: Eye Blink, Interlaced Image, Natural Light, Image Analysis, High-Speed Camera.

1 Introduction

The blinking of the eye is related to factors such as human cognition, fatigue, and depressed consciousness; many studies have investigated eye blinking in relation to these factors. Most conventional methods for the measurement of the eye blink analyze eye images (images of the eye and its surrounding skin) captured by a video camera [1], [2], [3]. The NTSC video cameras that are commonly used are capable of detecting eye blinks; however, it is difficult for these cameras to measure the detailed temporal change occurring during the process of eye blinking, because eye blinks occur relatively fast (within a few hundred milliseconds). Therefore, a high-speed camera is required for an accurate measurement of the eye blink [3].

NTSC video cameras capture moving images at 60 fields/s and these field images are mixed with images that have a frame rate of 30 frames/s (fps) to field interlaced images. In this paper, we propose a new method for measuring the eye blink that uses

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NTSC video cameras. This method utilizes split-interlaced images of the eye captured by an NTSC video camera. These split images are odd- and even-field images in the NTSC format and are generated from NTSC frames (interlaced images). The proposed method yields a time resolution that is twice that in the NTSC format. Therefore, the detailed temporal change that occurs during the process of eye blinking can be measured.

To verify the accuracy of the proposed method, we performed experiments using a high-speed digital video camera. Thereafter, we compared results obtained using the NTSC cameras with those obtained using the high-speed digital video camera. This paper also presents experiments that evaluate the proposed automatic method for measuring eye blinks.

2 Open-Eye Area Extraction Method by Image Analysis

In general, eye blinks are estimated by measuring the open-eye area [2] or on basis of characteristics of specific moving points between the upper and lower eyelids [3]. Many of these methods utilize image analysis. It is possible to measure the wave pattern of eye blinks if the entire process of an eye blink is captured [3]. Furthermore, the type of eye blink and/or its velocity can be estimated on the basis of this wave pattern. However, it is difficult to measure the wave patterns of eye blinks by using video cameras that are commonly used for measuring eye blinks because the resulting eye images include high noise content owing to the change in light conditions.

We have developed a new method for measuring the wave pattern of an eye blink. This method can be used with common indoor lighting sources such as fluorescent lights, and it can measure the wave pattern automatically. Hence, our proposed measurement method can be used under a variety of experimental conditions. In this method, the wave pattern is obtained by counting the number of pixels in the open-eye area of the image as captured by a video camera. This image is enlarged for capturing the detailed eye image.

We have proposed an algorithm for extracting the open-eye area in a previous study [4]. It utilizes color information of eye images. We have adapted the algorithm to our proposed method for elucidating the wave pattern of eye blink measurement. This algorithm has been developed for our eye-gaze input system, in which it compensates and traces head-movement [5]. Furthermore, the algorithm has been used under common indoor sources of light for a prolonged period.

Hereafter, we describe in detail our image-processing algorithm for extracting the open-eye area.

2.1 Binarization Using Color Information on Image

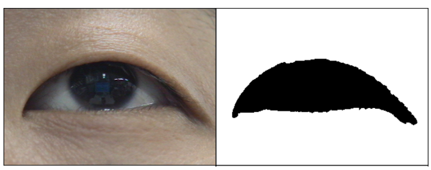
Many methods have been developed for the purpose of skin-color extraction; these methods are primarily focused on facial image processing, including those that utilize color information on a facial image. They mostly determine threshold skin-color values statistically or empirically [6]. We have developed an automatic algorithm for estimating thresholds of skin-color. Our algorithm can extract the open-eye area from the eye image on the basis of the skin-color.

Using our algorithm, skin-color threshold is determined by the histogram of the color-difference signal ratio of each pixel—Cr/Cb—that is calculated from the YCbCr image transformed from the RGB image. The histogram of the Cr/Cb value has 2 peaks indicating skin area and open-eye area. The Cr/Cb value indicated by the minimum value between the 2 peaks is designated as the threshold for open-eye area extraction.

2.2 Binarization by Pattern Matching Method

The method described in Subsection 2.1 can extract the open-eye area almost completely. However, the results of this extraction sometimes leave deficits around the corner of eye, because the Cr/Cb value around the corner of eye is similar to the value on skin in certain subjects. To resolve this problem, we have developed a method for open-eye extraction without deficits by combining 2 extraction results. One of them is a binarized image using color information, as described in Section 2.1. The other extraction result is a binarized image using light intensity information, which includes in the extraction result the area around the corner of the eye.

Binarization using light intensity information utilizes the threshold estimated by a pattern matching method, which determines the matching point by using the color information of the binarized image as reference data. Hence, the threshold level is estimated automatically. The original image and the extracted open-eye area image are shown in Fig. 1(a) and Fig. 1(b).



(a) (b)

Fig. 1. Original eye image (a) and extracted open-eye area (b)

3 Measurement Method of Wave Patterns of Eye Blinks Using Split-Interlaced Images

Commonly used NTSC video cameras output interlaced images. One interlaced image has 2 field images, which are designated as odd or even fields. If an NTSC camera captures a fast movement such as an eye blink, there is a great divergence between the captured odd- and even-field images. Therefore, the area around eyelids on the captured image has comb-like noise. This phenomenon occurs because of mixing of 2 field images of the fast movement of eyelids. An example of interlaced images during eye blinking is shown in Fig. 2. To describe this phenomenon most clearly, Fig. 2 has been captured at low resolution (145 × 80 pixels).

If one interlaced image is split by scanning even- and odd-numbered lines separately, 2 field images are generated. Thus, the time resolution of the motion images doubles, but the amount of information in the vertical direction decreases by half. These field images are captured at 60 fields/sec, and the NTSC interlaced moving images are captured at 30 fps; therefore, this method yields a time resolution that is double that available in the NTSC format. The duration of a conscious blink is a few hundred milliseconds; therefore, it is difficult to measure accurately the wave pattern of an eye blink by using NTSC cameras. However, the detailed wave pattern of an eye blink can be measured by using our proposed method. The split-interlaced images are shown in Fig. 3. The 2 eye images shown in Fig. 3 are enlarged in a vertical direction and were generated from the interlaced image shown in Fig. 2. Our proposed method measures the wave patterns of eye blinks from these images.

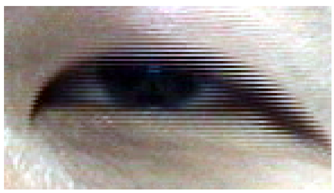


Fig. 2. Blinking eye image (interlaced)

Fig. 3. Split-interlaced image generated from Fig. 2

4 Evaluation Experiment for Proposed Method

Either 4 or 5 subjects participated in experiments to evaluate our proposed method, as described in Subsections 4.1 and 4.2, respectively. The experimental setup includes an NTSC DV camera (for home use), a high-speed digital video camera, and a personal computer (PC). The PC analyzes sequenced eye images captured by the video cameras. The DV camera captures interlaced images at 30 fps, and the high-speed digital video camera captures non-interlaced images at 300 fps. In the experiments performed using these video cameras, the wave pattern of eye blinks is measured from sequenced eye images. The experimental setup is shown in Fig. 4.

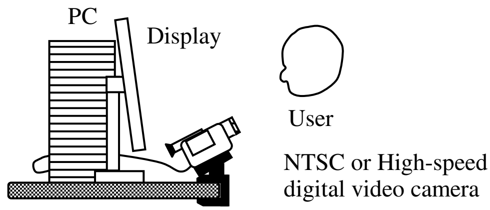


Fig. 4. Hardware configuration of experimental system

4.1 Experiment for Eye Blink Measurement Using NTSC Camera

In this experiment, sequenced eye images were captured using the DV camera at 30 fps in NTSC format. In addition, split-interlaced images are generated from these interlaced NTSC images. These split-interlaced images have a time resolution of 60 fields/s. The wave pattern of eye blinks is measured by the interlaced NTSC images and split-interlaced images. The binarization threshold for open-eye area extraction is determined automatically from the first field image of the experimental moving images. This threshold is estimated by the method described in Section 2. A typical result from this experiment is shown in Fig. 5.

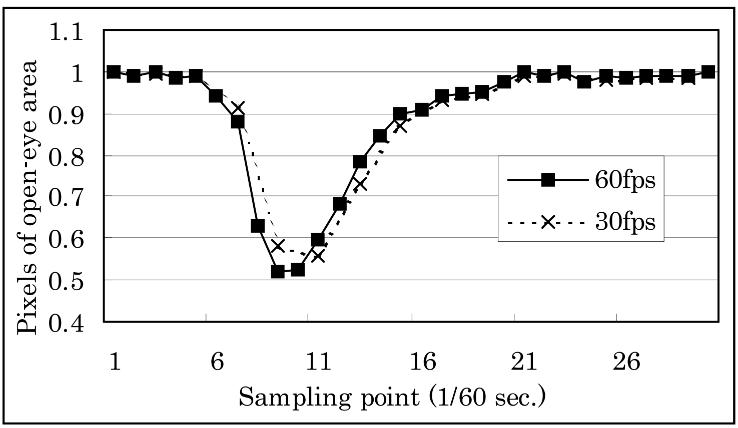


Fig. 5. Wave patterns of eye blinks measured by DV (30 fps and 60 fps)

In Fig. 5, the longitudinal axis and the abscissa axis indicate pixels of open-eye area and sampling point (interval: 1/60 sec), respectively. To compare the 2 wave patterns of eye blinks, these plots are normalized using the pixels of open-eye area at the first field image. The bottoms of the plots indicate the eye-closed condition. Our proposed algorithm classifies the area of eyelid outline and cilia into the open-eye area; therefore, the pixels at the bottom of the plots are not reduced to zero. From Fig. 5, it is evident that sequenced images at 60 fields/s can be used to estimate the detailed wave pattern of an eye blink. During the eye blink, there is a great difference in the 2 plots of pixels of the open-eye area; however, this difference is not dependent on individual subjects.

Results of the wave pattern of eye blink measurements for 5 subjects are shown in Fig. 6, where the longitudinal axis and the abscissa axis show pixels of open-eye area and sampling point, respectively. These plots also are normalized in a manner similar to those in Fig. 5. From Fig. 6, it is evident that there are great differences in the results for each subject.

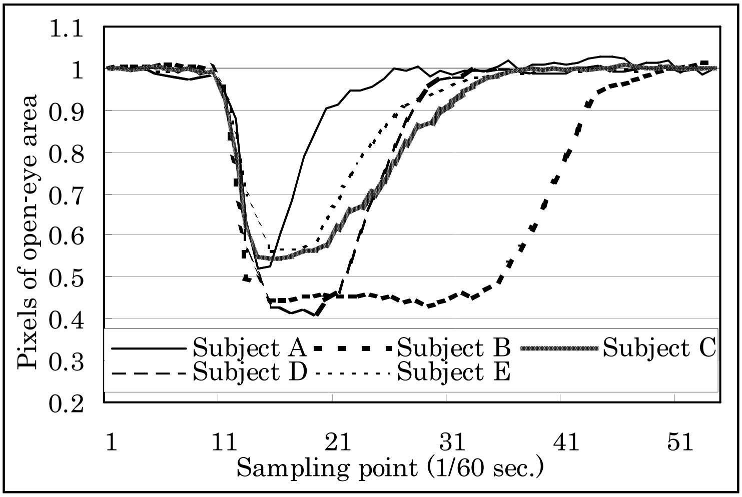


Fig. 6. Wave patterns of eye blinks of 5 subjects measured by DV (60 fps)

4.2 Experiment for Eye Blink Measurement Using High-Speed Video Camera

To verify the accuracy of the proposed method that utilizes split-interlaced images, experiments were conducted with 4 subjects; this experiment and the one described in Subsection 4.1 were conducted separately. Subjects A and E (listed in Fig. 6) were enrolled in this experiment continuously, in which sequenced images at 3 different frame rates (30, 60, and 150 fps) were generated from moving images captured by the high-speed digital video camera. These sequenced images were then analyzed to measure the wave pattern of eye blinks. The results of eye blink measurements performed using the sequenced images at 3 different frame rates and those taken at 300 fps are compared. Typical examples of measurement results are shown in Fig. 7, Fig. 8, and Fig. 9, which display results at 30, 60, and 150 fps, respectively.

From Fig. 7 and Fig. 8, it is evident that the degree of accuracy of measurement at 60 fps is higher than that at 30 fps. The minimum of the wave pattern (bottom of the curve) is quite characteristic of when an eye blink occurs. Results at 60 fps show that the bottom of the plot is measured with a high degree of accuracy. Therefore, sequenced images at this frame rate are suitable for measurement of eyelid movement velocity.

Moreover, our proposed method using split-interlaced images (described in Section 3) utilizes 2 field images generated from one interlaced image; that is, the spatial information of these field images is decreased by half. We have confirmed that this decrease in spatial information does not affect measurement accuracy via an experiment using sequenced images at 60 fps. The sequenced images at 60 fps were generated from moving images captured by a high-speed digital video camera. In this experiment, we generated half-sized eye images by extracting scanned odd-numbered lines from sequenced images at 60 fps. We estimated wave patterns of eye blinks using these half-sized images. Our results show that the measured open-eye area decreases by half, which is in agreement with the results shown in Fig.8.

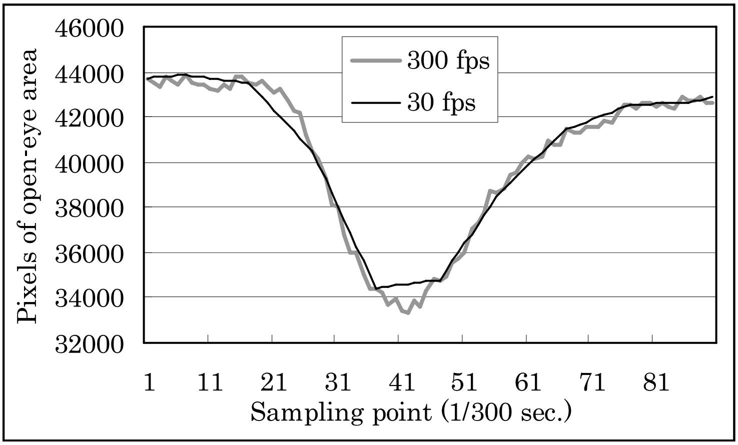


Fig. 7. Wave pattern of eye blinks measured by high-speed video camera (30 fps)

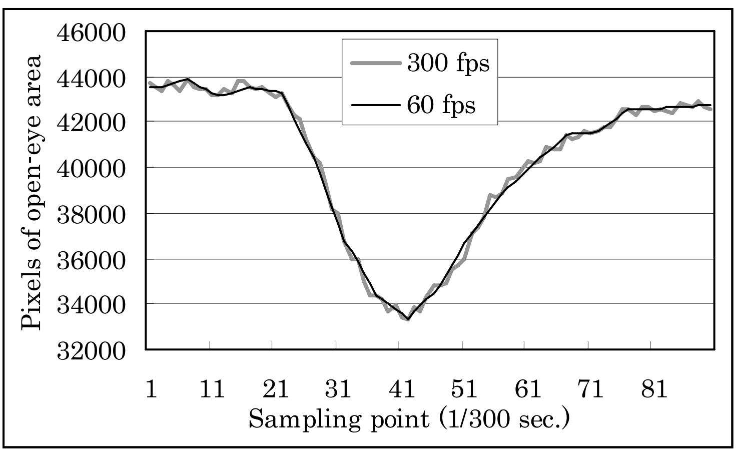


Fig. 8. Wave pattern of eye blinks measured by high-speed video camera (60 fps)

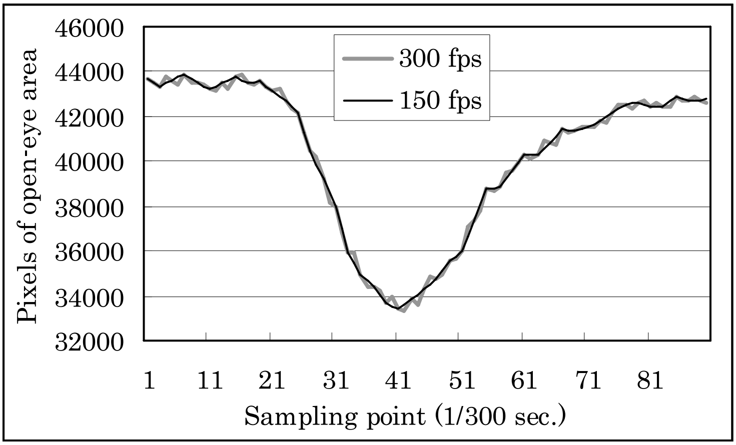


Fig. 9. Wave pattern of eye blinks measured by high-speed video camera (150 fps)

4.3 Discussion

On the basis of Fig.5, it is evident that by using split-interlaced images, the time resolution of measurement is doubled than that of the results obtained in previous studies. These split images are odd- and even-numbered field images in the NTSC format that are generated from NTSC frames. This method can also be utilized for any subject under common indoor lighting sources, such as fluorescent lights. We have shown the wave patterns of eye blinks for 5 subjects in Fig. 6. From results shown in Fig. 7, Fig. 8, and Fig. 9, it is evident that the degree of accuracy of measurement increases with increasing frame rate. A closer estimate of eye blinking velocity can be achieved if the wave pattern of an eye blink were to be measured with higher accuracy. In other words, the type of eye blink can be classified with a high degree of accuracy. In addition, our proposed method can measure the wave patterns of eye blinks efficiently even by using half-sized eye images.

As shown by our experimental results presented earlier, we have verified the reliability of our proposed method described in Section 3. Thus, detailed wave patterns of eye blinks can be measured by using our proposed method.

5 Conclusions

We present a new automatic method for measuring eye blinks. Our method utilizes split-interlaced images of the eye captured by an NTSC video camera. These split images are odd- and even-numbered field images in the NTSC format and are generated from NTSC moving images. By using this method, the time resolution for measurement increases to 60 fps, which is double that of conventional methods. Besides the function of automatic measurement of eye blinks, our method can be used under common indoor lighting sources, such as fluorescent lights. In evaluation experiments, we measured eye blinks of all subjects without problems.

To verify the accuracy of our proposed method, we performed experiments using a high-speed digital video camera. On comparison of the results obtained using NTSC cameras with those obtained using a high-speed digital video camera, it is evident that the degree of accuracy of measurement increases with increased resolution time. Additionally, a decrease in area of the split-interlaced image has no adverse effect on the results of eye blink measurements. We confirmed that our proposed method is capable of measuring the wave pattern of eye blinks with high accuracy by using an NTSC video camera.

In the future, we plan to develop a new method for classifying types of eye blinks using our proposed measurement method reported above. That new method will be capable of profiling eye blinks according to velocity of open-eye area changes. We also plan to apply this new method to more general ergonomic measurements.

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