Automatic Classification of Eye Blink Types Using a Frame-Splitting Method

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Abstract. Human eye blinks include voluntary (conscious) blinks and involuntary (unconscious) blinks. If voluntary blinks can be detected automatically, then input decisions can be made when voluntary blinks occur. Previously, we proposed a novel eye blink detection method using a Hi-Vision video camera. This method utilizes split interlaced images of the eye, which are generated from 1080i Hi-Vision format images. The proposed method yields a time resolution that is twice as high as that of the 1080i Hi-Vision format. We refer to this approach as the frame-splitting method. In this paper, we propose a new method for automatically classifying eye blink types on the basis of specific characteristics using the frame-splitting method.

Keywords: Eye blink, Voluntary blink, Interlaced image, Natural light, Input interface.

1 Introduction

Recently, input interfaces that use information derived from a user's eye blinks have been reported [1-5]. Users can input text or commands into PC systems via these interfaces. The systems only require user eye blinks as inputs. These systems were used to develop communication aids for people with severe physical disability such as amyotrophic lateral sclerosis (ALS). In general, eye blinks are detected by performing image analysis on moving images of the area surrounding the eye [1-5]. The moving images are recorded by a video camera. However, it is difficult for standard video cameras (such as NTSC and 1080i Hi-Vision) to measure the detailed temporal changes that occur during the eye blink process because eye blinks are relatively rapid (a few hundred milliseconds).

Therefore, a high-speed camera is required for detailed eye blink measurements [2]. Previously, we developed an eye blink detection method that utilizes split interlaced images [6]. These split images are odd- and even-numbered field images in the 1080i Hi-Vision format, which are generated from interlaced images. We refer to this approach as the frame-splitting method. The detailed temporal changes that occur during the eye blinking process can be detected using this method.

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Human eye blinks can be classified into three types: involuntary blinks, voluntary blinks, and reflex blinks. Involuntary blinks occur unconsciously, whereas voluntary blinks are generated consciously by a cue. Reflex blinks are induced by stimuli such as loud sounds or bright lights. If voluntary blinks could be detected automatically, then it would be possible to develop a more user-friendly interface. We have confirmed the feature parameters of involuntary and voluntary eye blinks, which can be used to distinguish these two types of blinks from each other. In this paper, we present the frame-splitting method and the feature parameters of voluntary and involuntary eye blinks.

2 Eye Blink Measurement by Frame-Splitting Method

If the entire process of an eye blink is captured, the wave pattern of the eye blink can be generated. 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 or LED lights, and it can measure the wave pattern automatically [6]. The experiments described below are conducted using this method. In this method, eye blinks are detected by measuring the pixels of the open-eye area [6]. The open-eye area is extracted from the eye images using the color information imbedded in their pixels.

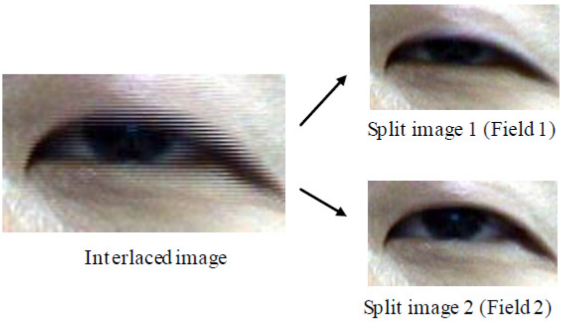

Fig. 1. Overview of frame splitting method

1080i Hi-Vision video cameras output interlaced images. If one interlaced image is split by scanning even- and odd-numbered lines separately, two field images are generated. These field images are captured at 60 fields/s, and the 1080i interlaced moving images are captured at 30 frames/s; therefore, this method yields a time resolution that is twice as high as that of the 1080i Hi-Vision format. By using the frame-split images, the entire process of an eye blink can be captured. The overview of the frame-splitting method is shown in Fig. 1; the left-hand side shows the blinking eye image (interlaced), and the right-hand side shows the two field images split by the scan line. To describe this phenomenon clearly, the image on the left has been captured at a low resolution (145 × 80 pixels).

3 Classification of Eye Blink Types by Its Wave Pattern

3.1 Automatic Extraction for Wave Pattern of Eye Blink

Moving images of the eye include images of the blinking eye and those of the open eye. Thus, the contiguous data of the estimated open-eye area include the samples with these mixed situations. If we want to classify the eye blink types, we need to extract the data only for the blinking eye. Then, the parameters of eye blinks are estimated in order to classify the different types of eye blinks. To estimate the threshold for the extraction of the wave pattern of eye blinks, we utilize the difference wave pattern of eye blinks. A sample of the wave pattern of an eye blink and its difference wave pattern are shown in Fig. 2 and Fig. 3, respectively. In these figures, the x-axis indicates the sampling point (interval = 1/60 s), and the y-axis indicates the open-eye area pixels and its difference value, respectively.

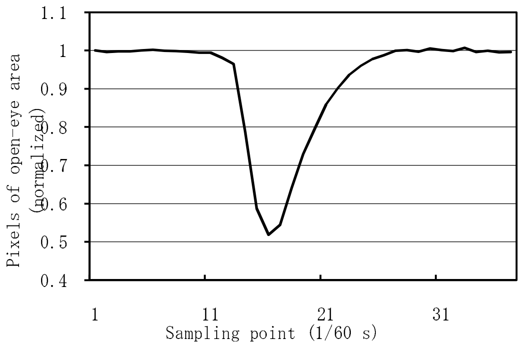

Fig. 2. Wave pattern of an eye blink

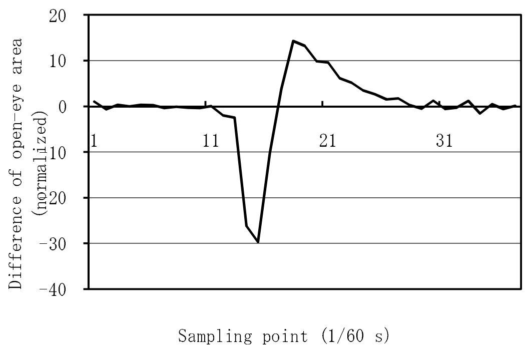

Fig. 3. Difference wave pattern of an eye blink

These plots were normalized relative to the pixels in the open-eye area in the first field image. From Fig. 3, it is evident that the difference value for the blinking eye is greater than that for the open eye. In other words, the fluctuation in the difference value for the open eye is smaller than that for the blinking eye. Thus, we can use statistical information to distinguish between data for the open eye and that for the blinking eye. In particular, we estimate the average and standard deviation of the difference value of the open-eye area when the eye is open. By using these values, the threshold is estimated automatically. The thresholds for the discrimination of data when the eye is open, Th_1 and Th_2, are determined by the formulae

$$\mathrm{Th}_1 = \mathrm{E}_{\mathrm{avg}} + 2\sigma \quad (1)$$

$$\mathrm{Th}_2 = \mathrm{E}_{\mathrm{avg}} - 2\sigma\,, \quad (2)$$

where E_{avg} is the average difference value of the open-eye area when the eye is open, and sigma is its standard deviation. If the sample of the open-eye area is greater than Th_1, it indicates that the eye is opening. Similarly, if the sample of the open-eye area is smaller than Th_2, it indicates that the eye is closing. The part between these two results is the wave pattern for the blinking eye.

3.2 Feature Parameters for Classification of Eye Blink Types

If voluntary blinks could be detected automatically, then it would be possible to develop a more user-friendly interface. Thus, users could employ this interface to input commands to their PC consciously [3-5]. Many input interfaces that utilize the information of voluntary blinks have been developed. Users can input text to PCs by using these interfaces. However, these interfaces utilize specific patterns of eye blinks. For example, they use the method for classifying voluntary blinks on the basis of duration [4], [5] or the occurrence of multiple blinks [3].

To relax these conditions, we are developing a new interface. If users close their eyes firmly, the new interface captures an input command. In other words, the constraint when users utilize the interface by means of an eye blink is alleviated. To classify the eye blink types, we need to scrutinize the feature parameters of an eye blink. Eye blink patterns can be extracted automatically from the detection results using the method described in section 3.1. The feature parameters are estimated from the eye blink pattern. It is reported that there is a large difference in the duration of voluntary and involuntary blinks [4], [5]. We conduct metering experiments to confirm the parameters. The outline of an eye blink pattern is shown in Fig.4; we define the feature parameters on the basis of duration (T_d) and maximum amplitude (A_m) of an eye blink.

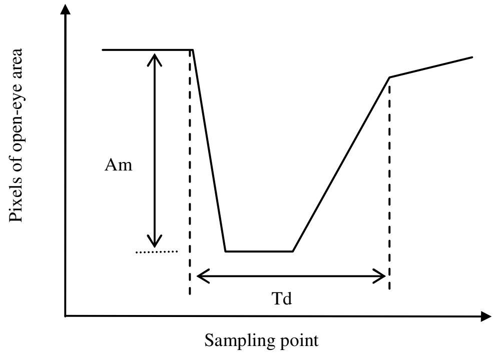

Fig. 4. Feature parameters of an eye blink

4 Metering Experiments

We confirmed the feature parameters of the eye blink types by conducting two experiments, both of which involved five subjects. In experiment 1, the subjects blinked unconsciously without any instructions from the researcher, i.e., involuntary blinks were measured. In experiment 2, the subjects blinked consciously, i.e., the subjects closed their eyes firmly when they heard a beep sound emitted by a PC. The beep sound generated at random, these intervals are 5 to 7 seconds. These experiments were conducted using the methods described in sections 2 and 3.

In these experiments, the thresholds for the extraction of the wave pattern of eye blinks were calculated using the contiguous data of the open-eye area. In particular, the subjects kept their eyes open for 3 s at the beginning of these experiments, and the thresholds were estimated using images captured when the eye was open. The experimental setup includes a 1080i Hi-Vision video camera (Sony HDR-HC9, for home use), and a PC (OS: Microsoft Windows 7; CPU: Intel® Core™ i7, 2.8-GHz clock frequency). The PC analyzes sequenced eye images captured by the video cameras.

4.1 Measurement of Feature Parameters of Eye Blink

We measured the feature parameters of the eye blink types using the method described in sections 2 and 3. The durations and the maximum amplitudes of the eye blinks are shown in Fig. 4. We also estimated the occurrence interval of involuntary blinks. These parameters were calculated from the successful results of automatic extraction of wave patterns of eye blinks.

Table 1 lists the parameters of involuntary blinks that are measured in experiment 1. Table 2 and Table 3 list the parameters of involuntary blinks and voluntary blinks that are measured in experiment 2, respectively. Tables 1–3 also list the average values of the durations, the maximum amplitudes, and the occurrence intervals. In addition, the standard deviations are listed in parentheses. The open-eye area varies widely among individuals. Therefore, the maximum amplitudes of eye blinks are normalized relative to the pixels in the open-eye area in the initial sample.

Table 1. Feature parameters of involuntary blinks (experiment 1)

Subject	Counts	Numbers of extraction	Duration (ms)	Maximum Amplitude	Occurrence interval(ms)
A	6	6	363.9(141.2)	0.394(0.130)	2783.3(965.8)
B	10	10	381.7(50.0)	0.355(0.029)	1170.4(731.6)
C	11	10	300.0(69.8)	0.329(0.048)	1142.9(453.2)
D	7	7	281.0(45.6)	0.329(0.049)	2322.2(1246.2)
E	4	4	237.5(16.0)	0.463(0.043)	3794.4(2508.9)
Average	-	-	312.8	0.374	2242.6

Table 2. Feature parameters of involuntary blinks (experiment 2)

Subject	Counts	Numbers of extraction	Duration (ms)	Maximum Amplitude	Occurrence interval(ms)
A	8	8	250.0(247.6)	0.410(0.047)	1490.9(1031.9)
B	6	6	258.3(20.4)	0.237(0.023)	1944.4(1236.8)
C	9	9	238.9(45.6)	0.274(0.037)	1216.7(422.1)
D	5	5	303.3(41.5)	0.281(0.039)	2336.1(1943.8)
E	3	2	216.7(0.0)	0.211(0.006)	2755.6(2348.4)
Average	-	-	253.4	0.283	1948.7

Table 3. Feature parameters of voluntary blinks (experiment 2)

Subject	Counts	Numbers of extraction	Duration (ms)	Maximum Amplitude
A	4	4	716.7(102.7)	0.575(0.015)
B	4	4	508.3(141.7)	0.354(0.022)
C	4	3	1038.9(265.8)	0.418(0.020)
D	4	3	794.4(34.7)	0.399(0.005)
E	4	3	516.7(44.1)	0.264(0.007)
Average	-	-	715.0	0.402

Table 1 indicates that the average duration and maximum amplitude of involuntary blinks are 312.8 ms and 0.374, respectively. We confirmed that the duration and maximum amplitude of involuntary blinks depend on the subject. Table 2 and Table 3 show that the average duration of involuntary blinks and voluntary blinks are 253.4 ms and 715.0 ms, respectively. In addition, these tables show that the average of the maximum amplitudes of involuntary blinks and voluntary blinks are 0.283 and 0.402, respectively. From the results of experiment 2, it is evident that the duration and the maximum amplitude of an involuntary blink are smaller than those of a voluntary blink. In addition, these values vary among individuals.

From Tables 1–3, we confirmed that the parameters of eye blinks depend on the experimental conditions. Therefore, if these parameters are utilized for an input interface that uses the classification of eye blink types, this system needs to be calibrated.

In addition, in experiments 1 and 2, the average intervals of involuntary blink occurrence are 2.2 s and 2.0 s, respectively. Considering the standard deviation of each subject, an involuntary blink occurs, at most, approximately every 6 s. From this result, if several involuntary and voluntary blinks are used for the calibration, then the calibration will take approximately 30 s.

4.2 Classification of Eye Blink Types

The feature parameters of eye blink were described in section 4.1. We confirmed that there is large difference in the duration of voluntary and involuntary blinks. Therefore, we classify the eye blink types by using the duration of the eye blinks as a feature parameter. Methods for classifying voluntary blinks on the basis of duration have been proposed [4], [5]. These methods use a fixed threshold. However, we confirmed that the threshold duration varies significantly and that it depends on the subject and the experimental conditions. These points are evident from the data in Tables 2 and 3. To classify the eye blink types with certainty, we focused on these points and developed a new method for estimating the threshold automatically. The threshold is calculated using the formula

$$\mathrm{Th_c} = \frac{\mathrm{Tdv_{avg}} - \mathrm{Tdiv_{avg}}}{2} + \mathrm{Tdiv_{avg}}\,, \tag{3}$$

where $\mathrm{Tdv_{avg}}$ and $\mathrm{Tdiv_{avg}}$ are the average duration of voluntary and involuntary blinks, respectively. If the duration of an eye blink is greater than the threshold $\mathrm{Th_c}$, this eye blink is classified as a voluntary blink. Otherwise, the eye blink is classified as an involuntary blink. The classification rates of eye blink types are listed in Table 4.

Table 4. Classification rates of eye blink types (experiment 2)

Subject	Counts		Passed Classifications		Classification rates (%)		
	Voluntary	Involuntary	Voluntary	Involuntary	Voluntary	Involuntary	Total
A	4	8	0	0	100	100	100
B	4	6	1	0	75	100	90
C	3	9	0	0	100	100	100
D	3	5	0	0	100	100	100
E	3	2	0	0	100	100	100
Average	-	-	-	-	95	100	98

The $\mathrm{Th_c}$ value utilized in Table 4 is calculated using the average durations of voluntary blinks and involuntary blinks listed in Table 2. In addition, the classification rates of eye blink types are estimated using the same experimental data.

Using our proposed method, the average rate of successful classification of voluntary eye blinks is approximately 95% for the experimental sample of five subjects (see Table 4). In addition, one passed classification occurs for a voluntary blink with subject B. However, we believe that this passed classification of a voluntary blink is not a major problem. If these passed classifications occur, the input can be attempted again through an intentional repetition of the voluntary blink.

5 Conclusions

We proposed a frame-splitting method that detects eye blinks using split interlaced images. These split images are odd- and even-numbered field images in the 1080i Hi-Vision format. This method also yields a time resolution that is twice as high as that of the 1080i Hi-Vision format. Using this method, the feature parameters of eye blinks can be detected automatically. We conducted experiments to measure the feature parameters that can be used to classify eye blink types. From the results, we confirmed that there is large difference in the duration of voluntary and involuntary blinks. We also confirmed that the threshold duration varies significantly and that it depends on the subject and the experimental conditions.

We developed a new method for classifying eye blink types, which utilizes the duration of the eye blinks. Using this method, voluntary blinks can be extracted from eye images that include involuntary blinks. This method also yields a high degree of accuracy. In our experiments with five different subjects, the average accuracy was 95%.

In the future, we plan to conduct additional experiments in order to confirm the accuracy of our calibration method. We also plan to develop a more user-friendly interface for using the information from voluntary eye blinks.

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