Feature Analysis of Eyeblink Waveform for Automatically Classifying Conscious Blinks

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ABSTRACT

In this paper, we propose and evaluate a new feature parameter of eyeblink for automatically classifying between conscious (voluntary) and unconscious (spontaneous) blinks. We focused on integral values of an eyeblink waveform, which is defined as a measurement record of a progression of eyeblinks, as the feature parameter. Previous researchers have used duration time and waveform amplitude as the feature parameter, whereas the integral values have both feature parameter characteristics. We obtained these parameters using an NTSC video camera by splitting a single interlaced image into two fields. We used flame-splitting methods to obtain and analyze the integral value of the eyeblink waveform, and we experimentally compared the feature parameters to automatically classify the conscious and unconscious eyeblink. Duration and amplitude did not show a significant difference in some subject cases, but we confirmed a significant difference when using the integral value. Our results suggest that integral values of eyeblink waveform are effective for classifying the two eyeblink types.

KEYWORDS

Eye-Blink, Voluntary Blink, Spontaneous Blink, Input Interface.

1 INTRODUCTION

Eyeblinks are classified as voluntary, reflex, or spontaneous. A voluntary eyeblink arises by its own will; a reflex one arises by external factors, like sound or light stimuli; and a spontaneous one arises by other primary factors or unconsciously [1], [2]. An eyeblink can be applied to a contactless input interface if automatic classifying were possible. The input interface could be utilized in a smart device or a wearable device. However, we may cause an automatic mental condition, such as fatigue, strain, and unease, if we automatically classified the type of eyeblink.
This paper presents and discusses the results of experiments for obtaining the feature parameter of an eyeblink waveform.

2 PREVIOUS WORKS

The results of psychology experiment have shown that the occurrence of eyeblinks is associated with cognitive status. Using this knowledge, a system that measures the state of exhaustion of drivers has been developed [3]. Further, studies have been conducted in an effort to determine whether it can be used as a communication support sclerosis (ALS) patients [4][5][6][7][8]. Systems using eye-blink as an input switch and otherwise combining it with eye gaze in an input interface to operate equipment have also been proposed [9][10][11][12][13]. Conventional eye-blink input systems are classified into two basic types. The first type uses input based on pre-established time values. For example, when the user closes eyes for more than 200ms [4][14][15]. In this case, a dynamic threshold value is used for each type of eye-blink because eye-blinks show wide individual differences. A false input may occur if the threshold is fixed because the input time is user-dependent; a user might unconsciously produce considerably short or long eye movements. The second type of input system examines special eye movements, such as double eye-blinks and winks [9][16][17]. However these system require the user to perform conscious, and occasionally complex, actions; therefore, users have to practice in order to be proficient at using these systems. In addition, the unusual eye-blinks required can cause user stress, especially when the systems are used over a long period [1][10].

Previously, the operation by the eye-blink has been the most important point is possible inputs. For this reason, it has not realized that automatic classification of eye-blink types, in consideration about individual difference of each user. What we are concerned here is the problem that eye-blink is a very fast action. Until now, NTSC video camera cannot capture the highly detailed of eye-blink waveforms because the time resolution of conventional video cameras is low. However we previously reported that the method of captured highly detailed of eye-blink waveforms by using frame splitting [11]. This method improves the time resolution by splitting a single interlaced image into even and odd fields. Instead, this method halves spatial resolution. But, we have already evaluated effects about to improve time resolution and to decrease spatial resolution [18]. We obtained feature parameter of eye-blink waveform by analyzing moving image captured using this method.

3 MESUREMENT METHOD

When image analysis is used, the first step is to analyze video images of the area surrounding the eye in order to assess changes in eye aperture using binarization based on flesh color. Figure 1 shows an example of changes that eye-opening area. Change data shown in Fug.2 include changes in the eye-blink waveform. The next step applies smoothing differentiation between the split field area and the next split field. Coordinates that reveal the maximum area difference value and the minimum area difference value are determined using a second differentiation.

However, this step in the analysis involves excessive noise. This noise means small movement in the vicinity of the eye, such as from an eyelid. Therefore, we remove noise value using k-means method. Those noise values are almost small maximum/minimum because its happened based on small movement. After then, we obtained a pair of maximum and minimum in the nearest field. An eye-blink is composed closing phase and opening phase. In other word, the maximum corresponding the closing phase, and the minimum corresponding the opening phase. We obtained one eye-blink waveform based on those one pair coordinates. Figure 2 shows an example of the detected eye-blink waveform.

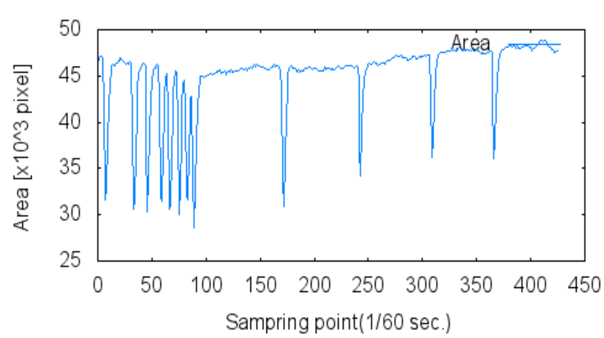

Figure 1. Change in eye-opening area.

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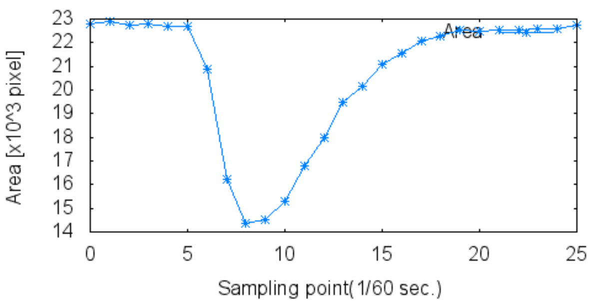

Figure 2. Example of eye-blink waveform.

4 CHARACTERISTICS OF EYEBLINK WAVEFORM

Figure 3 shows a model of an eyeblink waveform. Previous papers by our group have examined duration and amplitude of the eyeblink waveform in reference to related work [] in which the closing phase amplitude Acl is defined as the height of the closing phase starting point Ps to the minimum point Pmin. Pmin is defined as the average of the eye-opening field areas that are less than the threshold Th_1 in one eyeblink waveform; this refers to where an eye-opening area is smallest (from the closing-phase end point Psb to the opening-phase starting point Peb). The threshold Th_1 is determined by the following equation:

$$Th_1 = \frac{Amax-Amin}{10} - Amin \qquad (1)$$

where Amax and Amin are the maximum and minimum, respectively, of the eye-opening area of the eyeblink waveform. The opening phase amplitude Aop is defined as the height of the minimum point Pmin to the opening-phase end point Pe. The eyeblink duration Dur is defined as the field counts from Ps to Pe. The eyeblink amplitude is defined as the average of the closing-phase amplitude and the opening-phase amplitude. Because of the difference between the two, this is not a unique feature in each user; the ratio of the two amplitude values differs for each measurement, even in the same user. This factor has been previously confirmed [19].

However, to classify the types of eyeblink using either amplitude or duration was shown to be difficult [18]. Therefore, we focused on the integral value of the eyeblink waveform. The integral value area is defined as the sum of the amplitude values of the fields that exist between Ps and Pe and can be determined from the following equation:

$$\text{Area} = \sum_{k=1}^{Dur}\left(\frac{Ps+Pe}{2} - Pk\right) \qquad (2)$$

where Dur is the duration (sample number), Ps and Pe are eye-opening areas at the closing-phase starting point and opening-phase end point, respectively, and Pk is the eye-opening area at the point of the k field. This makes it possible to use the instantaneous integral value of the eyeblink waveform as a feature parameter that inherits the characteristics of duration and amplitude. Ps and Pe are shown in Fig. 3 corresponding to each point in the model.

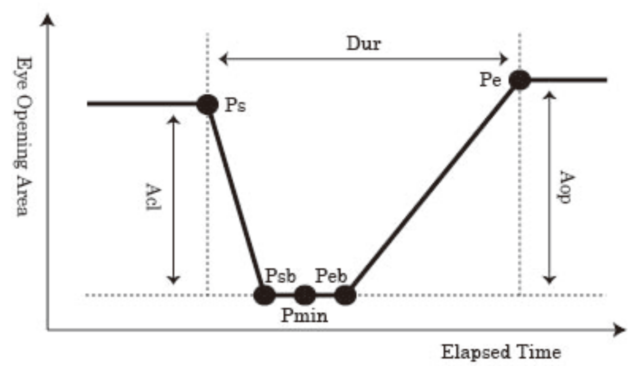

Figure 3. Model of the eyeblink waveform.

5 EXPERIMENT

In this chapter, we try experiment of examined possibility of classifying of eye-blink types based on each feature parameter (Duration, Amplitude, Integral value). This experiment detects eye-blink waveform by using method of chapter 3, and obtains feature parameter by using method of chapter 4.

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It is difficult for experimenter to confirm that the eye-blink has been observed whether the true voluntary eye-blink, because voluntary blinks are arisen due to the internal factor of the subject. So, in the experiment, it is defined voluntary blinks that an eye-blink who subject occurred according to the signal of sound. The experimenter gives previous instruction for the subject to perform tightly blink when heard signal of sound. Herewith, the experimenter can check the voluntary eye-blink externally later clearly.
This experiment measures the eye-blink waveform of 12 subjects (10 men and 2 women ranging in age from 20 to 29, subject F and G is women) to analyze the periodicity of feature parameters of eye-blinks. We have been described about this experiment about methods and purpose to the subject. Also, we got consent for publication of the experimental data in a state that is not able to identify the subject of the experiment.

5.1 System Outline

The hardware for the study's experimental system includes a Sony HDR-HC7 NTSC digital camcorder that is used to obtain eye images, and a personal computer (Windows 7, Intel Xeon E31245, 3.30GHz, NVIDIA Quadro 600) used for image and eye-blink waveform analysis. Although the camera can capture high-definition (HD) pictures, standard-definition (SD) pictures are used in the experiments.
In the measurement, Subjects were instructed to focus on a video camera installed at a distance of about 40cm front in a state of sitting on a chair. In addition, we were respectively installed two LED lightings on each side of the video camera, however, its are prevented from entering directly into the field of view of the subject. And, instruct removed in subjects wearing glasses regularly, and performs photographing with the naked. Captured image is the SD image of horizontal 720 x 480 vertical pixels, the frame rate is recorded at 30 fps. Captured image is record real time on the PC hard disk via the i.Link cable, then performs image processing off-line, have acquired eye-blink waveform and feature parameters.
Analysis of moving images is divided into the odd and even field because it is used frame-splitting method. Therefore, acquired eye-blink waveforms are obtained as 60 fps time resolution, and 720 x 240 pixels image size.

5.2 Experimental Procedure

In the experiment, the experimenter was instructed to stare at the screen of the video camera to the subject. In addition, experimenter is instructed to perform a firm eye-blink when the signal sound is heard from the computer, in order to get conscious eye-blinks. signal sound is set a timer to occur at random intervals of about 4-8 seconds. And it was reported that there is no need to stand with eye-blink even when there is no indicator sound. Thus, it is possible to measure spontaneous eye-blink simultaneously with the conscious eye-blink. The experimenter is doing the distinction of conscious eye-blinks and spontaneous eye-blinks by checking the video visually based on signals. Under this condition, subjects perform imaging of about 90 seconds after a rest time of about 30 seconds. This video is detected eye-blink waveform from images using the method described in section 2, and acquires the feature parameters described in chapter 3.

5.3 Results

Table 1 shows the summary of the result of experiments. Row of table 1 shows an average of eye-blink amplitude, duration, and integral value. Cell shows the average value of the conscious eye-blinks and spontaneous eye-blinks from the left side. In addition, asterisk means significant difference in the result of performing t-test at 1% level for each feature parameter amount of the conscious eye-blinks and spontaneous eye-blink for each subject.

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Table 1. The results of the experiment

Parameter	A	B	C	D	E	F
Amplitude	5689, 3763, *	10155, 6882, *	11715, 11139	11189, 10025	14535, 8572, *	8240, 6856, *
Duration	718.8, 437.8, *	715.5, 320.2, *	534.4, 455.7	544.4, 358.3 *	459.5, 400.0	600.0, 324.8 *
Integral value	126631, 28450, *	197729, 41320, *	171187,122395,*	157675, 67862, *	118319, 44781, *	124716, 43843, *
Parameter	G	H	I	J	K	L
Amplitude	12757, 9866, *	12217, 8007, *	7200, 6813	8674, 8034	11126, 9925, *	16402, 15034
Duration	546.6, 353.5 *	690.4, 261.1, *	436.1, 265.4, *	780.0, 487.5, *	360, 354	600, 387, *
Integral value	132036, 72464, *	240933, 41574, *	75327, 37954, *	183373, 95056, *	96767, 66156, *	151260,108546,*

$* \ p < 0.01$

Table 2. Results from previous work [10]

Parameter	a	b	c	d	e
Closing Amplitude	129, 105, *	150, 110, *	162, 130, *	164, 133, *	73, 44, *
Opening Amplitude	121, 92, *	144, 100, *	153, 118, *	156, 117, *	60, 31, *
Duration	199, 206	336, 278, *	279, 278	568, 382, *	648, 255, *
Integral value	1108, 886, *	2742, 1378, *	1977, 1617, *	6424, 2420, *	3288, 571, *

$* \ p < 0.01$

6 DISCUSSION

6.1 About the Experiment Results

When interviewing the subjects after the experiment, we found that some subjects did not consciously eyeblink if the signal sound was heard soon after a subject had had a spontaneous eyeblink; in the experiment, however, this was recorded as a conscious eyeblink. Therefore, there is the possibility that a spontaneous eyeblink was entered as a conscious eyeblink in the experimental results.
With respect to the subjects, subjects A, B, F, G, and H were significantly different in all feature parameters. Subjects D, I, J, and L were significantly difference with regards to duration and integral value. Subjects E and K were significantly different for amplitude and integral value. Only subject C showed a significant difference for the integral value.
This result shows that the integral value is significantly different even if there is no significant difference in the feature parameters used by previous studies (amplitude and duration). Therefore, we confirmed that the integral value is an effective parameter for classifying eyeblink types.

6.2 Related Study Comparison

Table 2 shows the difference between the voluntary eyeblink and spontaneous eyeblink of the feature parameter from Tanabe [10] who did a preliminary examination to automatically classify eyeblink types. Tanabe also measured eyeblink using a video camera in the same way as we did and used an experimental procedure similar to ours. The differences in the two experiments are the following:

1. use of a high-speed camera (120 fps);
2. amplitude was defined between an upper eyelid and a lower eyelid (eye column width);
3. used a mouse click by the subject in order to confirm the voluntary eyeblink.

The amplitude measurement points were different in [10] from our method; however, the value for the number of pixels was taken from pixels in the image. Therefore, it is a parameter having the same properties as the amplitude value of our method.

There were also differences in the results between our study and those of [10]. First, Tanabe observed a significant difference in the amplitude value among all subjects, but this was not seen in our experiment, nor was it seen in our previous work [18]. The reason for this is that individual differences related to eyeblinks are diverse, and different tendencies exist even among a few people. On the other hand, both Tanabe's and our results showed a significant difference in amplitude. However, despite the experimental methods being similar, duration differed. We attribute this difference to changes in the feature parameter due to the instructions given for measuring the conscious eyeblink. That is, the feature parameter amount of the conscious eyeblink is largely dependent on the psychological state of the subject. It may therefore be possible to estimate psychological changes, such as tension, from the change in the feature parameter. A similar trend can be seen between this experiment and [10] with respect to the integral value. Integral value is a parameter that combines both amplitude and duration. Thus, the tendency of an eyeblink for the feature parameter of all subjects is similar because it is the same trend in the integral value.

7 CONCLUSION

This paper discussed the difference between voluntary and spontaneous eyeblinks with a focus on the integral value as the feature parameter. We compared our results with previous studies to evaluate what factors affect the eyeblink feature parameter.

From experiments on 12 individuals, a significant difference was obtained for duration in nine subjects and for amplitude in seven subjects. We confirmed a significant difference in integral values in all subjects. Of note is that one person did not have a difference in duration and amplitude but did have a significant difference in integral value. This suggests that automatic classification by the unique feature parameter is possible by using the integral value for classifying voluntary and involuntary movement. By comparing our results with a previous study, we found that there is a possibility of estimating a person's psychological state from the change to feature parameters.

In future work, we will develop a possible classification algorithm corresponding to the feature parameter of change over time and will investigate the feature parameter of change with time to elucidate the emotion and eyeblink relationship.

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