Automatic Discrimination of Voluntary and Spontaneous Eyeblinks.

The use of the blink as a switch interface

Shogo Matsuno, Minoru Ohyama, Shoichi Ohi
Graduate School of Information Environment
Tokyo Denki University
Tokyo, Japan
e-mail:12jkm25@ms.dendai.ac.jp

Kiyohiko Abe, Hironobu Sato
Department of Network and Multi-Media Engineering
Kanto Gakuin University
Kanagawa, Japan
e-mail:abe@kanto-gakuin.ac.jp

***Abstract*— This paper proposes a method to analyze the automatic detection and discrimination of eyeblinks for use with a human-computer interface. When eyeblinks are detected, the eyeblink waveform is also acquired from a change in the eye aperture area of the subject by giving a sound signal. We compared voluntary and spontaneous blink parameters obtained by experiments, and we found that the trends of the subjects for important feature parameters could be sorted into three types. As a result, the realization of automatic discrimination of voluntary and spontaneous eye blinking can be expected.**

Keywords— computer interface; automatic discrimination; voluntary eye blink; spontaneous eye blink

I. INTRODUCTION

The relation between eyeblinks and cognitive states has been pointed out by psychological experiments [1][2]. Realization of automatic discrimination of spontaneous and voluntary eyeblinks is desired. However, it is difficult to automate the detection of eyeblinks or the discrimination of kinds of eyeblinks, because the generation of eyeblinks has large variations between individuals. Therefore, until now, the detection or discrimination of eyeblinks has been carried out manually in most cases. Now, researchers are advancing their studies by aiming at automation of the detection and discrimination of eyeblinks while bearing a computer interface in mind.

A technique using the electro-oculogram (EOG) has been proposed as an automatic detection method for voluntary eyeblinks [3][4]. The EOG method consists of sticking an electrode on the skin near the eyeball and detecting changes in cornea-retina potential. However, adopting the EOG method as a common interface is accompanied with the difficulty of directly equipping the skin with an electrode and exclusively using a special machine.

In this research, the videotape recording (VTR) method is adopted, whereby eyeblinks are measured from a video image. Until recently, automatic blink detection using the VTR method was difficult, because the accuracy was lowered by a shortage of sampling points. Then, a technique for using an interlaced picture was incorporated, which divided the field that others had proposed. Hence, even if we use an ordinary NTSC video camera, we can obtain twice as much time resolution as with natural NTSC video. In this research, we tried to detect a blink waveform by analyzing interlaced pictures taken with an ordinary NTSC video camera and then conducting a discrimination experiment on spontaneous eyeblinks and voluntary eyeblinks. In this experiment, we performed an estimation experiment on automatic detection of eyeblinks and extraction experiments on the shape feature parameters of eyeblink waveforms (two-pattern condition). The results are reported herein.

II. AUTOMATIC DETECTION OF EYEBLINK WAVEFORM BY VTR METHOD

If the time evolution of the eyeblink process is correctly measurable, it is possible to express an eyeblink as a waveform (a so-called eyeblink waveform). In order to identify the kind of eyeblink that has occurred, sampling the eyeblink waveform is first necessary. The typical techniques for sampling eyeblink waveforms are the EOG method and the VTR method. The former technique involves sticking an electrode on the skin near the eyeball, and it acquires the eyeblink waveform by recording the changes in cornea-retina potential. Until now, this has been the technique proposed for automatic methods to detect voluntary eyeblinks. However, the EOG method needs an exclusive apparatus, and the skin must be directly equipped with an electrode. For that reason, it is unsuitable for a simple interface. Moreover, there exists the disadvantage of easily mixing in noise from a living body.

On the other hand, the VTR method is suitable for a computer interface because it is a non-contact technique and has great flexibility. However, the process of change is difficult for a typical NTSC video camera to capture, because an eyeblink is a high-speed operation. Therefore, analysis using a high-speed camera has been attempted [5]. Computer interfaces using eyeblinks have been proposed in several papers [6][7][8]. Eyeblink switches were devised by using two different types of hard instructions in these techniques. For example, in [7], a subject closed an eye for a blink time of over 200 ms but, in [8], double-blinking was used for a mouth clicking switch. We aimed for a method to lower the stress of the subject. Eyeblink waveforms exhibit large individual variations, so automatic detection with multiple persons as the target is difficult. However, we have developed an algorithm such as that described below.

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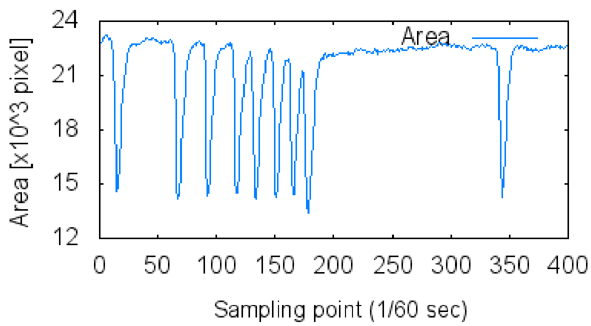

Figure 1. Changes of opening eye aperture area.

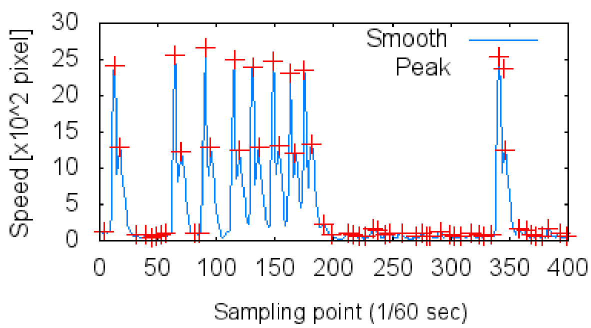

Figure 2. Coordinates of speed maximums.

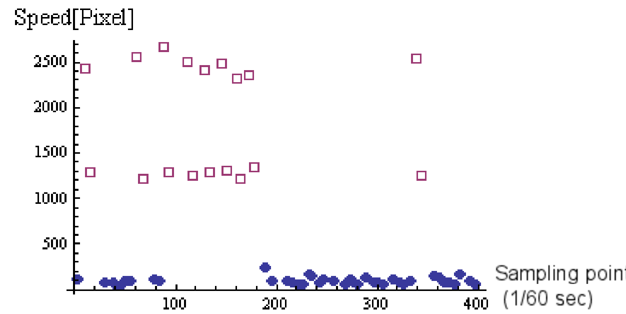

Figure 3. Result of clustering.

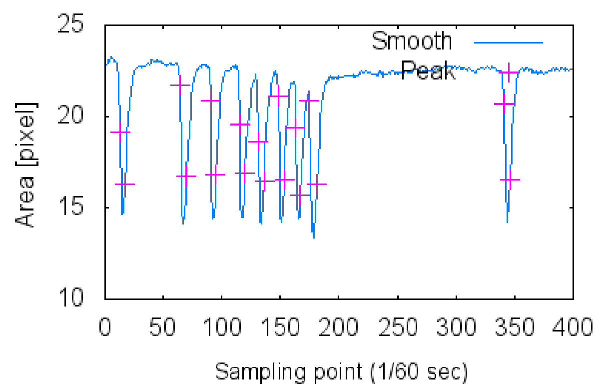

Figure 4. Coordinates of retrieved speed maximums an diagram that records.

The first step is to analyze video images of the near-eye area to obtain the changes in eye aperture area (Fig. 1). The data include the eyeblink waveform. This step incorporates an algorithm used in previous research [9]. This technique shows that we can detect a change in eye aperture area while sampling at 1/60 s by using interlaced NTSC video images divided into field images.

The next step is to differentiate the area data obtained. We smooth the derivative of the aperture area, and then we take the absolute value. The coordinates of the maximums are determined by using a second differentiation. Fig. 2 shows the coordinates of these maximums. Here, the eyeblink operation (namely, the closing and opening phases) corresponds to maximums with large values. However, the result of this step contains much noise. In other words, the maximums due to small changes in the coordinates are from noise. Therefore, we needed to remove the noise by using the *k*-means method for optimal partition clustering. We set the number of clusters to two, because the purpose was separation of the required data part from the noise part. We applied the evaluation function

$$J_b = \sum_{i=1}^{k} \sum_{x \in C_i} \| x - c_i \|^2 . \qquad (1)$$

where J_b represents the objective function, C is the dataset, x is a data value, and c is the cluster centroid. The *k*-means process is repeated until J_b is minimized, and then we terminate the clustering process. Fig. 3 shows the clustering result. Of the clusters obtained, the lower cluster is the noise cluster, and the upper cluster is the required data cluster. We then plotted the coordinates of the retrieved maximums on the diagram that records the changes of eye aperture area (Fig. 4).

There are times when a strange movement of the eyes is noted in the middle of a blink and maximums are recorded in more than three places. Then, if a clustering process is performed, it will not be able to remove superfluous points and will not be able to pick up the eyeblink waveform normally. Hence, we need to remove the superfluous points. We solve this problem by removing as noise the points that were recorded later, if the recording was continuous over a short period of time.

As a result of these processes, we obtain maximums in the middle of the eyeblink waveform. We can distinguish closing and opening by evaluating the derivative of the eye aperture area at that point. In other words, if the derivative at the point is negative, the point exists in the closing phase. Conversely, if the derivative is positive, the point exists in the opening phase. We can determine the eyeblink starting point and the eye closing point based on this. Moreover, we can determine the duration of a single eyeblink waveform.

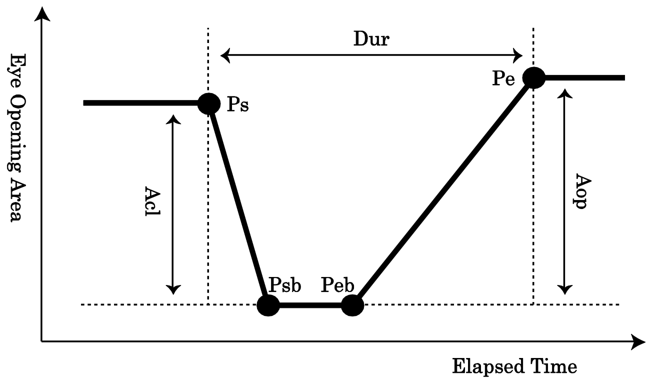

Figure 5. Shape feature parameters of eyeblink.

III. Shape Feature Parameters of Voluntary Eyeblink

Blinking can be categorized as voluntary, reflex, or spontaneous [10]. A voluntary eyeblink occurs consciously and is performed at the order of the experimenter. A reflex eyeblink occurs due to external stimulation such as photic stimulation or auditory stimulation. A blink that occurs unconsciously is called a spontaneous eyeblink. In this paper, we intend to discriminate between voluntary and spontaneous blinks. Spontaneous eyeblink waveforms have various amplitude patterns and greater individual unevenness than other kinds of eyeblink waveforms. Nevertheless, a voluntary eyeblink causes the eyelids to close almost completely. Moreover, there is relatively little variation in the recorded eyeblink waveforms of the same person. Thus, based on the literature [11], we focused on the parameters of two types of eye blinking. The parameters are the amplitudes in the closing and opening phases as well as the duration. Fig. 5 models a single blink. In this figure, the amplitude of the closing phase (Acl) is measured from the blink start point (Ps) to the eye aperture area minimum (Pmin) between the closing phase end point (Psb) and the opening phase start point (Peb). The eyeblink duration (Dur) is the number of samples from the blink start point (Ps) to the blink end point (Pe).

IV. Experiments

A. System Outline

The hardware for our experimental system includes one digital camcorder, which acquires pictures near the eye, and a personal computer, which conducts image analysis and eyeblink waveform analysis. Although the camera can also take high-definition (HD) pictures, the standard-definition (SD) picture was used for the experiment. In addition to ordinary indoor lighting (incandescent lighting), the experiment used LED lighting (LPL: LED VL-300C L26811).

TABLE I. Results of Automatic Detection of Eyeblinks.

	Eyeblinks [number]	Error [number]		Agreement rate [%]
		oversight	*misdetection*	
Subject 1	12	0	0	100.0
Subject 2	4	0	0	100.0
Subject 3	4	2	0	50.0
Subject 4	2	0	0	100.0
Subject 5	4	0	0	100.0
Total	26	2	0	92.3

Incandescent lighting was set when taking the moving images. Then, LED lighting was installed at a distance of about 60 cm from the front of the subject's face. Subjects would sit on a chair at a distance of about 20 cm from the video camcorder, and the back of the head was lightly supported with a device to prevent the head from shaking. The video camera was placed in front of and below the subject`s head. Then, the camera magnified and took pictures around the subject's left eye. The image format is SD video, so the resolution is 720 pixels by 480 lines with 16:9 aspect ratio and the refresh rate is 30 frames per second (NTSC). These experiments were performed on the naked eye, so eye glasses were not allowed during the filming in the experiments.

B. Automatic Detection of Eyeblink Waveform

We conducted an evaluative experiment for the automatic detection of the eyeblink waveform by using the algorithm described in Section II. This experiment was used for preprocessing purposes and to extract the shape feature parameters of the eyeblink waveform. Five people were included in this experiment: four men in their twenties and one man in his thirties.

1) Method: Before the experiment, the subjects were first instructed to "pay attention to the mark that was installed on the upper part of the camcorder" and told "you do not have to resist the unconscious urge to blink." Rest time was provided for about 1 min prior to beginning the experiment. Once the experiment began, moving images were taken for 10 s. Changes in the eye aperture area were obtained from this moving picture by image analysis, and automatic detection of eyeblink waveforms was achieved by using the proposed algorithm.

In this experiment, the obtained waveforms mixed some voluntary eyeblinks with many spontaneous eyeblinks, because the subjects were not instructed to blink. In addition, the instances of automatic detection were validated by comparing the data with those of real blinks observed visually.

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TABLE 2. RESULTS OF SHAPE FEATURE PARAMETER EXTRACTION 1 (SPONTANEOUS EYEBLINKS).

	Blinks [number]	Amplitude (Closing) [pixels]	Amplitude (Opening) [pixels]	Duration [ms]
Subject A	19	14589	14964	335.83
Subject B	25	13024	12076	490.67
Subject C	27	15830	15190	356.67
Subject D	3	15562	12635	422.17
Subject E	30	5043	2962	197.67
Subject F	15	10138	10453	556.67
Subject G	3	9397	9352	394.3
Subject H	2	11006	10720	358.3
Subject I	21	11799	10474	506.3
Subject J	16	10039	10318	534.3

TABLE 3. RESULTS OF SHAPE FEATURE PARAMETER EXTRACTION 1 (VOLUNTARY EYEBLINKS).

	Blinks [number]	Amplitude (Closing) [pixels]	Amplitude (Opening) [pixels]	Duration [ms]
Subject A	8	19249	23379	545.8
Subject B	9	14016	13281	1238
Subject C	9	16354	15908	396.1
Subject D	9	16581	15155	762.8
Subject E	9	8712	5320	214.6
Subject F	9	12482	11434	737.0
Subject G	9	12370	12688	474.0
Subject H	9	10459	11045	785.2
Subject I	9	19724	17667	588.8
Subject J	9	13581	12741	498.2

TABLE 4. RESULTS OF SHAPE FEATURE PARAMETER EXTRACTION 2 (SPONTANEOUS EYEBLINKS).

	Blinks [number]	Amplitude (Closing) [pixels]	Amplitude (Opening) [pixels]	Duration [ms]
Subject K	16	12276	12353	346.9
Subject L	13	10077	9909	371.8
Subject M	10	7503	6506	370.0
Subject N	13	7366	5859	421.8
Subject O	19	11775	8085	384.2

TABLE 5. RESULTS OF SHAPE FEATURE PARAMETER EXTRACTION 2 (VOLUNTARY EYEBLINKS).

	Blinks [number]	Amplitude (Closing) [pixels]	Amplitude (Opening) [pixels]	Duration [ms]
Subject K	9	14196	14388	353.7
Subject L	9	12227	12070	381.6
Subject M	9	13044	12396	787.0
Subject N	9	19737	19397	653.7
Subject O	9	12316	11288	807.4

2) Result: Table 1 shows the number of automatic detections and the number of confirmed eyeblinks for each of the subjects. The overall agreement rate of these blink numbers is 92.3%. This result was satisfactory enough for preprocessing. Subject 3 produced a low detection rate; however, a factor in this result is the number of oversights in detection. This factor makes little difference, because the problem can be solved by promoting re-input if the algorithm is implemented as the interface.

C. Shape Feature Parameter Extraction 1 (Experiment 1)

Based on the results of the evaluative experiment of Section IV-B, we performed an experiment to extract the shape feature parameters described in Section III for eyeblink waveforms. Ten people were included in this experiment: nine men and one woman in their twenties. These subjects were all different persons from those in the abovementioned preprocessing experiment.

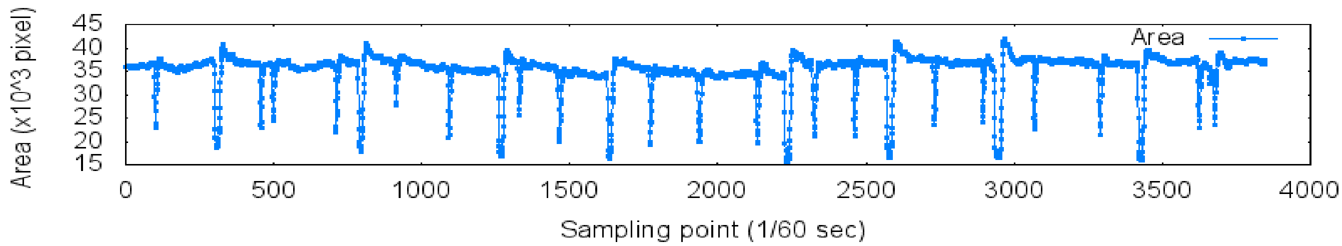

Figure 6. Example of eyeblink waveform.

1) Method: As in the experiment described above, the subjects were instructed before the experiment to “pay attention to the mark that was installed on the upper part of the camcorder” and told “you do not have to resist the unconscious urge to blink.” In addition, the subjects in this experiment were told, “you must always blink when you hear the signal.” This instruction makes it possible to distinguish voluntary eyeblinks from spontaneous eyeblinks. The signal was sounded randomly at intervals of from 4 s to 8 s by using a digital timer. A rest time of about 1 min was provided prior to the task. Once the experiment began, moving images were taken for approximately 1 min.

2) Result: Fig. 6 shows an example of the acquired waveforms (changes in eye aperture area). Moreover, Tables 2 and 3 list the shape feature parameters that were obtained in this experiment. Those for spontaneous eyeblinks are listed in Table 2, and those for voluntary eyeblinks are listed in Table 3. The value of each parameter is the mean for the detected blinks.

D. Shape Feature Parameter Extraction 2 (Experiment 2)

In addition to the experiment described in Section IV-C, an experiment was carried out in another room. Five of the subjects who generated the data presented in this section differed from those who participated in the experiments of Sections IV-B and IV-C (four men and one woman in their twenties).

1) Method: Basically, the experimental method was the same as that described in Section IV-C-1. However, there were two differences. The light of the sun was not evident in the room, and the camcorder was moved to a position directly in front of the subject’s face.

2) Result: Tables 4 and 5 list the shape feature parameters that were obtained in this experiment. Like Tables 2 and 3, these tables each list statistics for spontaneous or voluntary eyeblinks, respectively. The value of each parameter is the mean for detected blinks.

V. DISCUSSION

First, we were able to obtain waveform data regardless of the influence of sunlight, because we compared the data of Experiment 1 with that of Experiment 2 and there was no great difference between the two sets of data.

We discuss the results on the basis of the assumption mentioned above. Fig. 6 shows an example of the acquired waveforms (changes in eye aperture area). In addition, Figs. 7–9 show the patterns of waveform pairs for three types of subject. To enable comparisons between a pair of eyeblink waveform patterns, these plots were normalized using the pixels of the eye aperture area at the first sampling point of the first field image. When we reviewed the average values in Tables 2–5, the shape feature parameters of the voluntary eyeblinks recorded were nearly all greater than those of the spontaneous ones. This was a common trait found with all subjects. Admittedly, the recorded amplitude of the closing phase for Subject H in Experiment 1 was an exception, because so few spontaneous eyeblinks were found during the experiment. However, this voluntary parameter is greater than the spontaneous one if the length of time taken for the experiment is added. Hence, it is difficult for discrimination methods to use the rate of amplitude change because there is an absence of variety in the patterns.

A significant difference existed in the blink durations of the majority of subjects. In particular, Subjects B and H of Experiment 1 had values recorded for voluntary blinks that were twice those recorded for spontaneous blinks. Subject E had a small difference in duration but large differences in the amplitudes of the opening and closing phases. Subject J had a duration for spontaneous blinks that was longer than that for voluntary ones. The reasons are as follows: Subject J was observed to produce many blinks with larger ocular movements than the other subjects. When we accumulated the numbers of blinks, a voluntary eyeblink was counted whenever the subject responded to the signal heard. Consequently, it is thought that among the spontaneous eyeblinks were included some voluntary eyeblinks. Moreover, the change of eye aperture area by ocular movement is a factor that extends the duration.

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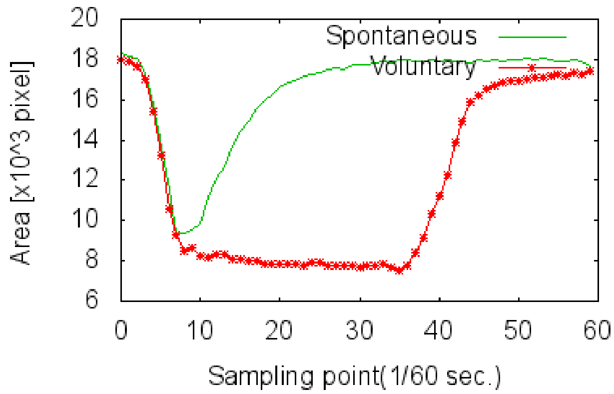

Figure 7. Waveforms recorded for the type of subject with a large difference in duration between voluntary and spontaneous blinks.

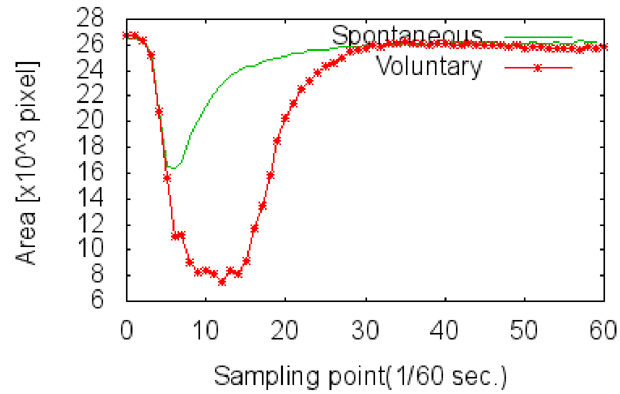

Figure 8. Waveforms recorded for the type of subject with a large difference in amplitude between voluntary and spontaneous blinks.

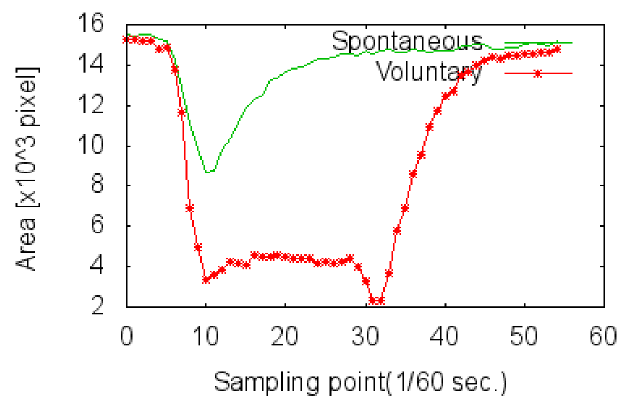

Figure 9. Waveforms recorded for the type of subject with both characteristics mentioned above.

Next, we classified the subjects on the basis of three patterns in the shape feature parameters (Figs. 7–9): 1) subjects with a large difference in duration between voluntary and spontaneous blinks (e.g., Subjects B and D), 2) subjects with a large difference in amplitude between voluntary and spontaneous blinks (e.g., Subjects A and I), and 3) subjects with both characteristics mentioned above (e.g., Subject M). There are meaningful differences between these patterns in parameters that reveal each large difference.

Hence, we expect that automatic discrimination of voluntary eyeblinks can be realized by using a machine that has learned to weight the parameters that exhibit large differences. In addition, we think that classifying patterns would become more accurate if the velocities of the eye opening and closing phases were included among the parameters.

VI. CONCLUSION

We examined automatic discrimination of voluntary and spontaneous eyeblinks, which is a problem that has been awaiting solutions in various kinds of blink research. So far, eyeblink detections have needed to use the EOG method or a high-speed camera. However, this paper has proposed a detection algorithm by using ordinary interlaced NTSC video images divided into field images. This algorithm can automatically pick up every eyeblink waveform from the changes in the eye aperture area, which were obtained from an SD moving image by means of image analysis. In our experiments to evaluate this algorithm, the average rate of detection was 92.3%.

Further, we conducted experiments on shape feature parameter extraction using an audio signal and our proposed algorithm. In this experiment, we instructed the subjects to blink voluntarily in order to yield an eyeblink waveform of both voluntary and spontaneous blinks. We instructed the subjects by saying, “you must always blink when you hear a signal.”

After that, we analyzed the tendencies of the shape feature parameters, and three facts became known. First, the parameters of voluntary eyeblinks are greater than those of spontaneous ones. Second, a large difference in the blink duration is usually observed, even apart from these parameters. Third, a different tendency for large feature parameters is observed with every subject. However, we knew that the rate of amplitude change would be difficult to use as a shape feature parameter.

In particular, we newly observed subjects who exhibited both of the different patterns found in Experiment 2. In other words, we understood that we could classify subjects using three types; namely, 1) subjects with a large difference in duration between voluntary and spontaneous blinks, 2) subjects with a large difference in amplitude between voluntary and spontaneous blinks, and 3) subjects with both characteristics mentioned above.

From the above results, we showed the possibility of discriminating voluntary eyeblinks from spontaneous eyeblinks by using shape feature parameters such as the eyeblink duration and the amplitudes of the opening and closing phases. Moreover, we confirmed the ability to process these parameters in a uniform manner, because we could obtain some tendencies from the parameters even

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when the environmental conditions, such as the lighting or the subjects, were changed.

We now wish not only to classify more accurately using other parameters such as velocity but also to classify subjects automatically using the three patterns. We are aiming for real-time discrimination of voluntary eyeblinks and spontaneous eyeblinks.

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