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Driver Blink Measurement by the Motion Picture Processing and its Application to Drowsiness Detection

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***Abstract*– There is a requirement for driver assistance systems in ITS to be made driver-friendly. Therefore, unusual driver states (drowsiness, inattentive driving, excessive concentration, etc.) must be detected. A method for measuring the blinking of a driver in real time by motion picture processing has been developed. Moreover, a method for presuming consciousness degradation from the change in blink duration has been developed. The waveform of blinking differs for individual people and differs over time for the same person. The method developed for processing blink waveforms is robust against the influence of differences among individuals. The blink extraction rate obtained with ten subjects has considerably improved from 76% to 95%, and we have the prospect of presuming degree of consciousness degradation from these results.**

***Index Terms*-- Blink measurement, Drowsiness detection, Human interface, Motion picture processing**

I. INTRODUCTION

FROM the late 1980s, research and development of ITS (Intelligent Transportation Systems) has been energetically pursued in the United States, Europe and Japan, and some systems have been developed and put into practical use [1]. Driving support systems to assist drivers play a central role in ITS. Examples of such systems include forward/side obstacle detection systems to detect vehicles driving in front of, or in front of and to the side of, the vehicle equipped with the system; distance detection systems for vehicles ahead; and lane departure prevention support systems [2], [3].

These systems give warning information or other information in the event of an emergency. But the current systems are not always driver-friendly because they give warnings independently of the state of the driver. To realize driving support systems that are friendly to drivers, it is essential to give information that depends on the seriousness or urgency level of the information after the driver's state has been detected [4], [5].

Examples of driver states to be detected include consciousness degradation through drowsiness, inattentive driving and physical or mental fatigue [6]. Recently, detection of concentration due to cellular phone use has also been pointed out[7]. Consciousness degradation through drowsiness is the most important state to be detected because of its potential for causing vehicular accidents.

For detection of drowsiness or detection of driver states for a human interface, presumptions based on blink measurement are being given most attention. For this purpose, changes in blinking over time in real time must be measured and drowsiness detected from the change in blinking.

The problems to be solved in measuring the blinking of a driver during driving by image processing are the following:

1) to develop a capturing method robust against changes in the surrounding illumination; 2) to measure blinking in real time; 3) to deal with the differences in the shapes of faces or the shapes around the eyes of individual people; 4) to deal with the differences in blink waveforms that differ from individual to individual.

We have examined a method for processing a driver's blinking in real time by using motion picture processing and have developed a technique to measure, in real time, blinking that differs from individual to individual. Furthermore, we have applied this method to detect drowsiness and have proved its potential.

II. BLINKING DETECTION METHOD

A. The whole processing method

Figure 1 shows the whole flow chart for blink measurement by motion picture processing developed in this study.

The eye areas are extracted and tracked from the obtained facial images. After pre-processing involving gray level changes to compensate for differences in the shapes around

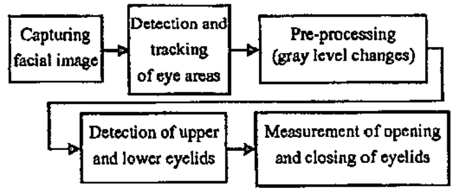

Fig. 1 Whole flow chart for blink measurement• by motion picture processing

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the eyes of individual people, the upper and lower eyelids are detected. Then, blinking is measured by processing the waveform of opening and closing of the upper and lower eyelids. A detailed explanation of each part involved follows.

B. Capturing the facial image

Figure 2 shows the composition of the image capture part. The pulsed infrared light projection method is used here. In this method an infrared light with a wavelength of 850 nm is projected in a pulsed form, and the CCD camera captures images in synchronization with this pulse. Therefore, it is able to capture facial images stably independent of the change in surrounding illumination conditions. To deal with positive reflection from the surface of glasses, polarizing filters with a polarization angle of 90 deg. are set in front of the pulsed light source and the CCD camera in order to eliminate positive reflected light.

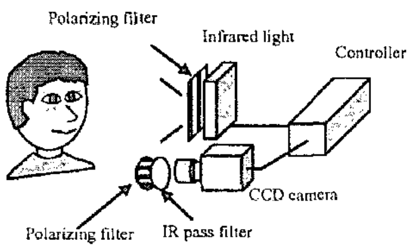
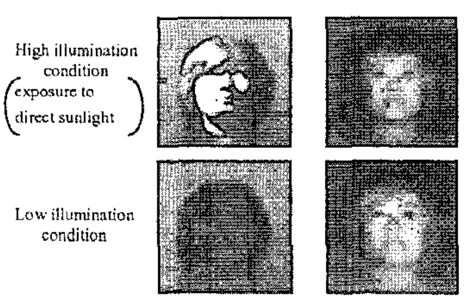


Fig.2 Composition of image capture part

Figure 3 shows examples of facial images captured by this method and ones captured by conventional method (capture by CCD camera without infrared light projection). It can be seen from this figure that with the conventional method halation and sharp shadows are partly generated in high illumination surroundings caused by direct sunlight, while a stable image is obtained with this method. Also, the image obtained with the conventional method is dark on the whole and lacking in information in low illumination surroundings at night, whereas, a stable image is obtained by using this method. This method enabled stable facial images to be obtained experimentally despite illumination changes ranging from 3×10^{-1} cd/m^2 at night to 1.5×10^4cd/m^2 in direct sunlight.



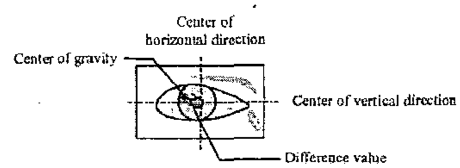
(a) Conventional method (b) Pulsed infrared light projection method

Fig.3 Examples of captured images

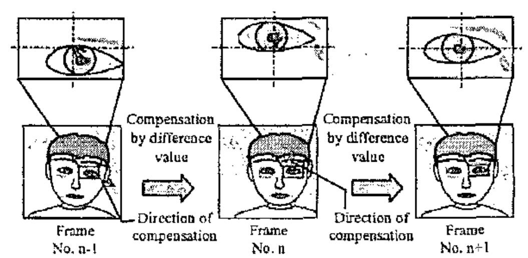
C. Extracting and tracking of eye area

First, to detect the eye area, the candidate for the eye area is extracted from the captured whole facial image using separability filter. Then Euclidean distance between the extracted candidate for the eye area and standard pattern of the eye area on subspace made in advance is compared, and the one that has the smallest distance is determined as the eye area.

Furthermore, tracking the eye area is essential to measure the upper and lower eyelids stably because the face of a driver during driving moves always. Figure 4 shows the method for extracting and tracking the eye area. The difference value between the center of gravity of both eyelids and the center of the eye area is calculated for the previous frame (Fig.4(a)), then the eye area is adjusted in accordance with this difference value in the next frame to decide the new eye area (Fig.4(b)). The eye area is tracked by repeating this procedure. Moreover, the centers of gravity of the past five frames are used to weight the present frame for smooth and stable tracking. This is based on a thing that although the facial image is a time-varying image that changes with time, there is no abrupt change between the frames obtained every 1/30th of a second. Therefore, even if there is a detection error in the previous frame, this method enables stable and smooth tracking by taking account of the past four frame results.



(a) Calculation of difference value



(b) Extraction of eye area by tracking processing

Fig. 4 Method for extracting and tracking the eye area

D. Detection of upper and lower eyelids

Figure 5 shows the method for detecting the upper and lower eyelids within the eye area. In this method, after the captured two-dimensional image has been sliced into vertical sections, candidate points of the upper and lower eyelids are detected in each section. The candidate points A and B for the upper and lower eyelids shown in Fig.5 (a) are decided as follows: First, derivatives of the gray level distribution at section L are calculated, and then a search for the maximum and minimum point pair in the derivatives is conducted, working from the center point, C (the darkest point at section L as shown in Fig.5 (b)), toward outside, and the outermost point pair (the pair P1 and M1 in Fig.5(c)) is assumed to be A and B.

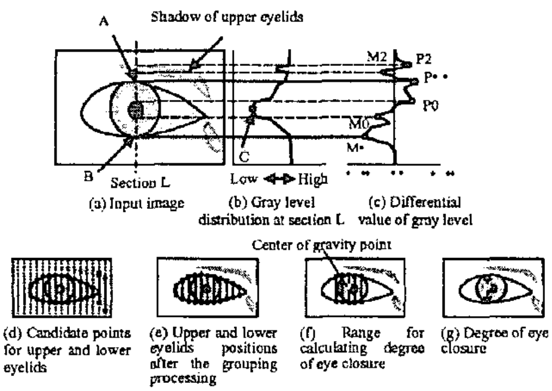


Fig.5 Method for detecting upper and lower eyelids

Next, the candidate points of the upper and lower eyelids are grouped (five sections are grouped in this method), and then the upper and lower groups are judged as the upper and lower eyelids respectively. For the measurement of degree of eye closure, the average values of the distance between the upper and lower eyelid points at the five sections are used. In this method, the upper and lower eyelids can be detected reliably largely irrespective of the differences in the shapes around the eyes of individual people. Blinking corresponds to the opening and closing movement of the upper and lower eyelids defined in this way.

E. Blink measurement

Figure 6 shows a general example of the waveform of a blink. This figure shows that when the eyes are open, the space between the upper and lower eyelids (hereafter, "degree of closure") is large, and when a blink starts, the degree of closure decreases. After the eyes have shut completely, the degree of closure increases gradually when the eyes begin to open. The downward pulse in this waveform is called the blink

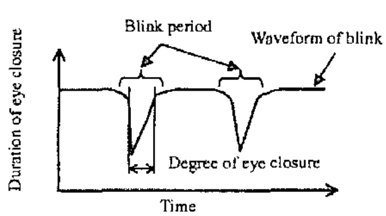


Fig.6 A general example of waveform of blink

period, and the width of this pulse is calculated to give the duration of eye closure. Here, the image of the eye areas is 80x40 pixels, and the space between the upper and lower eyelids in this image is about 15-18 pixels. The difference between eye opening and eye closure is about 5-8 pixels.

III. Method for Detecting Blinking Free from the Influence of Individual Differences

A. Problems in blink measurement

To measure the frequency of blinking and the duration of eye closure from the waveform described above, it is necessary to search for the starting point and ending point of a blink: the blink is then detected from these points.

When blinking is detected using a fixed threshold value, it cannot be detected correctly (the blink is missed) in some cases depending on the blink waveform. This happens because blinking changes from time to time. Also, blinking differs from individual to individual. Therefore, a method to detect blinking stably is necessary.

B. Proposed method for detecting blinking

It has been pointed out that the change over time of the starting and ending of blinking is stable for all individuals. Working from this point, we have devised a detection method that uses the time differential value of blinking to detect the blink starting and ending points, and to check the main part of the waveform. Figure 7 shows the proposed blink detection method.

The processing procedure is as follows:
(1) Define the point where the differential value of a blink exceeds the threshold value (th_start) as the blink starting point. (2)Confirm the crossover point (minus->plus)of the differential value. (3)Confirm that the degree of eyelid closure exceeds the middle value between the degree of closure at the starting point and the degree of closure at the pulse bottom.
(4) Set the point where the differential value goes below the threshold value (th_end) as the blink ending point.

The threshold value Vth of the differential value used here is calculated as follows.

Vth= (Fixed deviation value-50) / 10
x Variance of the differential value of the degree of eyelid closure + average of the differential value of the degree of eyelid closure (1)

Here, the fixed deviation value in expression (1) at the starting point differs from that at the ending point. Note also that the variance or average value is calculated from the past degree of eyelid closure and is renewed at constant intervals (one-minute intervals in this method).

Blinking that differs from individual to individual can be detected correctly by using the deviation value as described above.

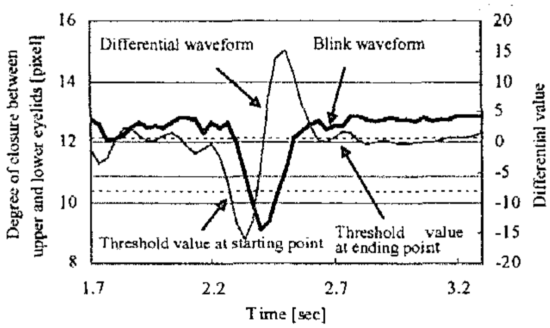


Fig.7 Blink detection method

Figure 8 shows an example of blink detection results obtained by this method. In the figure, the blink waveform is the degree of closure determined by the processing in this method and the eye closure judgement indicates the judgement whether the eye is closed or not. In the figure, small falls in the degree of closure at around 2 seconds or 16 seconds are not judged to be blinks: only large falls are detected as blinks. This result shows that blinking can be detected stably by using this processing method.

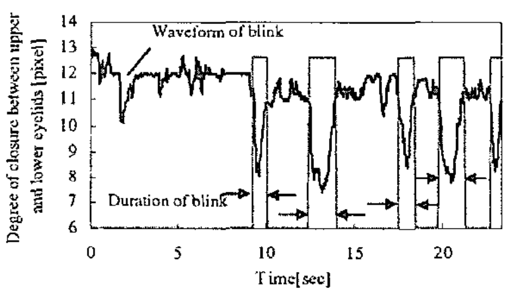


Fig.8 An example of blink detection results

C. *Verification experiment*

1) *Experimental condition*

A verification experiment has been conducted to confirm the effectiveness of this method. The experiment was carried out in a laboratory using the experimental set-up shown in Fig.9. The subjects were ten men in their twenties who were not wearing glasses. The subjects were requested to watch the projected scenery image (real image) in front of a car driving on a monotonous road. The laboratory was darkened and the room temperature was controlled by an air conditioner, so the surroundings were made conducive to dozing. The CCD camera was positioned in front of the subject and the infrared light was set beside the camera. The CCD camera was set 90 cm above floor level and 80 cm (distance in a straight line) from the subject's face. The infrared light was positioned 15 cm to the left of the CCD camera as viewed from the subject. This set up was decided assuming that the CCD camera would be set on the dash-board of a car and images of the driver would be taken from a space in the steering wheel.

In the experiment, the subjects were requested to blink as naturally as possible for a given period of time (about thirty minutes) following the instructions of the experimenter. The images captured by the CCD camera were stored temporarily in a memory, and the blink measurement processing was performed by the processing unit after the measurement was finished. After that, the measurement results were compared with the visually analyzed results.

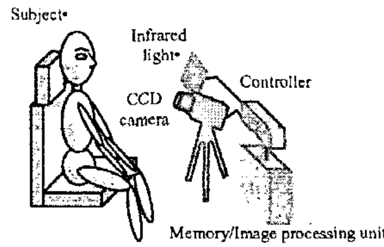


Fig.9 Experimental set-up for measuring blinking

2) *Experimental results*

The experimental results are summarized in Table 1. In this table, the "number of extractions" indicates the value measured by this method, and the number counted visually (indicated as the "true value") is the value measured visually from the captured images.

Extraction rate=[1-(Missing extractions + Excess extractions)/Number counted visually] x 100 • • (2)

Here, the "missing extractions" are the blinks that the system cannot detect even though the subject blinks, and "excess extractions" are the blinks that the system detects even though the subject does not blink.

TABLE 1
Blink extraction rates

Subject	Number counted visually (true value)	Blink measurement by this method			
		Number of extractions	Missing extractions	Excess extractions	Extraction rate[%]
A	1607	1550•1498•	64•252•	7•443•	95.6•75.4•
B	1423	1417•1487•	16•51•	10•95•	98.2•91.1•
C	1204	1206•1425•	17•96•	19•317•	97.0•65.7•
D	1162	1163•1135•	12•44•	13•17•	97.8•94.8•
E	550	509•629•	45•12•	4•91•	91.1•81.3•
F	1645	1600•1610•	47•168•	2•133•	97.0•81.7•
G	1480	1434•1414•	57•161•	11•95•	95.4•82.7•
H	1028	1028•1021•	6•11•	6•4•	98.8•98.5•
I	1202	1194•1151•	11•94•	3•43•	98.8•88.6•
J	766	696•1145•	93•163•	23•542•	84.9•8.0•

•• ••Fixed threshold value method

In this table, the average extraction rate of this method is over 85 % for the ten subjects, and the extraction rates for most subjects are over 95%: the exception is one subject whose rate was 91%. These results prove that this proposed method is effective for detecting blinking that differs from individual to individual.

As mentioned above, the shape around the eyes and the blinking waveform of the driver differs from individual to individual. It has been shown that blink measurement that accommodates individual differences has been realized by using the proposed blink measurement method.

IV. APPLICATION TO THE DROWSINESS DETECTION

Blinking is receiving attention as one of the effective methods for detecting drowsiness. Although there are differences between individuals, it has been pointed out that there is a strong relationship between the change in the duration of eye closure during blinking and the degree of consciousness degradation [8].

An experiment on detection of drowsiness was carried out using the above-mentioned method for measuring blinking.

The experimental set-up is shown in Fig.10. The experiment was performed using a driving simulator with four subjects (A,B,C,D)in their thirties or forties who had driving careers of more than ten years. The duration of the experiment was about one hour for each subject. The driving simulator is equipment that simulates the driving of a real car by projecting images of a road surface on the screen in front of a driver's seat using an LCD projector and the images change in response to the subject's driving operations. In the experiment, the subjects were instructed to drive at a constant speed, using only steering operation. The change in duration of eye closure during blinking, the change of operation character, and the self-declared degree of drowsiness (degree of consciousness degradation) were measured. The self-declared degree of drowsiness was classified into four levels: normal, somewhat drowsy, drowsy, and considerably drowsy. The subjects were requested to self-declare by operating a switch by hand.

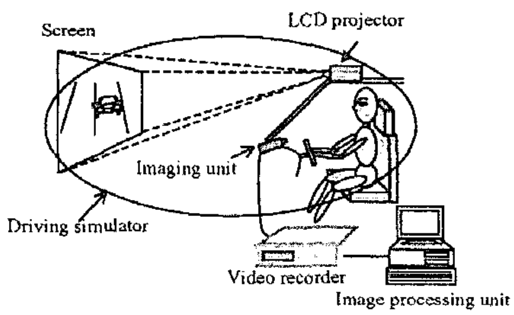


Fig.10 Experimental set-up for detecting drowsiness

Figure 11 shows the change over time of the duration of eye closure and the side displacement of steering operation for subject B. In this figure, the duration of eye closure means the average duration of eye closure in a one-minute period, and the side displacement also means the average side displacement.

This figure shows that the average side displacement begins to increase with consciousness degradation after 27 minutes, and the average duration of eye closure also increases after

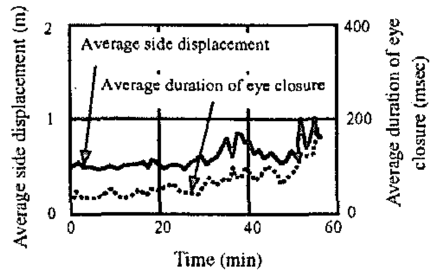


Fig.11 Duration of eye closure and side displacement of steering operation

that time. This tendency is confirmed in the self-declared degree of drowsiness.

Figure.12 shows the relationship between the average duration of eye closure and the declared degree of consciousness degradation for the four subjects. Although there are differences in the value of the duration of eye closure in relation to the consciousness degradation between the subjects, it is shown that the degree of consciousness degradation can be detected by measuring the duration of eye closure.

The past five frames (150 ms) are used to achieve stable tracking of the eye area in this method. Although this delays the processing by 150 ms, it does not greatly influence the judgement of the consciousness degradation level. There is an increase in the average duration of eye closure for each degree of consciousness degradation, but it is not very great for any of the subject. In order to reliably assume the degree of consciousness degradation from the change over time of the duration of eye closure based on blink measurement, it is essential to measure this change over time with both high precision and high reliability.

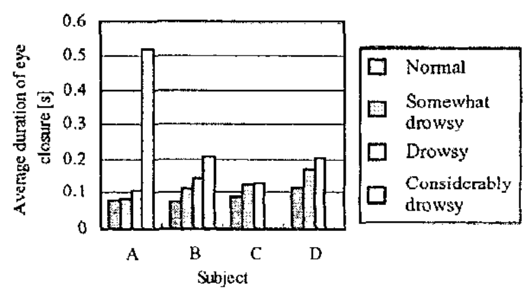


Fig.12 Average duration of eye closure at each level of consciousness degradation for each subject

V. CONCLUSIONS

In order to realize a driver-friendly on-vehicle system, it is essential to detect the driver's state during driving. Among the driver's states to be detected, drowsiness is the most important.

This paper has described the development of a technique to process the blinking of a driver in real time by motion picture processing and to measure, in real time, blinking that differs from individual to individual. Furthermore, it shows that drowsiness can be detected from the change in the duration of eye closure during blinking.

The subject for the future is to measure the duration of eye closure during blinking with both high precision and high reliability, and also to develop assumption algorithms for drowsiness detection that are applicable to many people.

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