Method of Drowsy State Detection for Driver Monitoring Function

Masahiro Miyaji

***Abstract*—Driver's psychosomatic state adaptive driving support safety system is highly expected to reduce the number of traffic accidents. Drowsiness is thought as crucial risk factor which may result in severer traffic accidents. When a driver is fallen in a drowsy state, it influence may appear in fluctuating of heart beat and eye movement. Heart rate was acquired from Electrocardiogram (ECG). Then heart rate variability (HRV) was calculated from ECG waveform using the maximum entropy method. CCD camera with infrared ray was introduced to capture gaze direction and eyelid closure. This study took a hypothesis that simultaneous measurement of both heart rate variability (HRV) and blinking duration may be useful means to detect onset of drowsiness in real time. The method to estimate onset of drowsiness was proposed, which function may be incorporated into driver's psychosomatic state adoptive driving support safety system for the reduction of traffic accidents.**

***Index Terms*—Psychosomatic state, driver monitoring, onset of drowsiness, blinking duration, heart rate variability.**

I. Introduction

The number of traffic fatalities in Japan as of 2012 has fallen below 4,500, however, the number of traffic injuries has still exceeded 0.8 million as shown in Fig. 1 [1]. Japanese govrnment has set the challenge to reduce the number of traffic fatalities lower than 3,000 level by the end of 2015 fiscal year. To create the sustainable mobility society, establishing technologies which may prevent traffic accidents remains one of the highest ranked issues. From the reason preventive safety technologies may play more important role as well as passive safety technologies. Recently pre-crash safety system with function that detects eye closure of a driver has been introduced into production vehicle [2], [3] to reduce inattention related accidents. Driver's psychosomatic state adaptive driving support function may have potential ability to enhance safety performance of the preventive safety systems. Among driver's psychosomatic state, drowsiness is one of crucial risk factors being involved in the traffic accident [1], [4]. Therefore a method to detect driver's drowsiness is highly expected for driver monitoring safety function. Lots of studies have been executed to detect drowsiness of a driver by using heart rate [5]-[7] and eye blinking [8]-[10] respectively. Autonomic activity can be evaluated by analysis of heart rate variability (HRV). HRV changes during different sleep stages, showing a predominant parasympathetic activity to the heart during non-rapid eye movement sleep and an increased sympathetic activity during rapid eye movement sleep [11]. However time response of HRV is not feasible for real-time use in detecting onset of sleep. Because time response of blinking is said to be approximately 1 to 5 sec, measuring time duration of blinking may bring good prediction of drowsiness of a driver invasively. Recently an infrared ray based CCD camera unit has been developed for in-vehicle applications to obtain driver's psychosomatic state by capturing movement of head, face and eye of a driver.

This study aimed at establishing a method to predict onset of drowsiness by simultaneous measuring of heart rate related physiological signals (HRV) and blinking of eye on a non-invasive basis, which should be applied for the constituent technology of driving support safety function in the area of vehicle preventive safety.

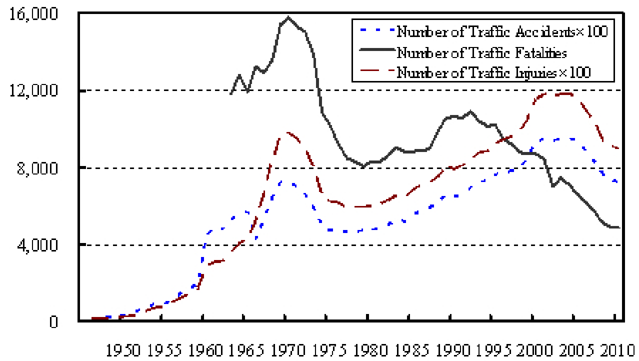

Fig. 1. Transition of road traffic accidents, fatalities, and injuries in Japan as of 2012.

II. Psychosomatic States in the Traffic Incident

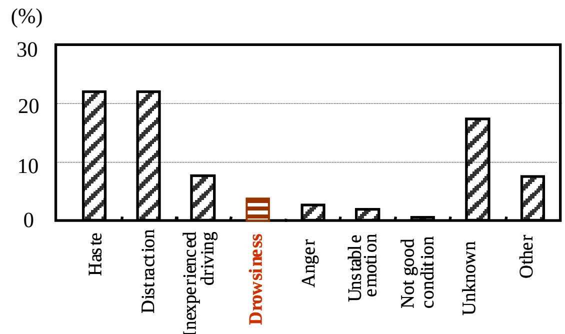

Fig. 2. Driver's psychosomatic state.

In the previous study using by the Internet survey with regard to the traffic incident experiences [12], [13], the psychosomatic states immediately before traffic incident was identified as *haste* (22%), *distraction* (21.9%), inexperienced driving (7.6%) and *drowsy* (3.8%) as shown in Fig. 2. From the analysis it is said that drowsiness of a driver is one of key

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factors that hold potential risks to be involved in severe accidents.

III. Physiological Information in Drowsy State

When a driver is in drowsy state, its influence may appear in heart rate by acceleration of the sympathetic nerve, and leads eye blinking. Accordingly it may increase potential risk of being involved in a traffic accident. Therefore the change of both the autonomic nerve activity and blinking may be expected as indicators of onset of drowsiness. Detection of the autonomic nerve activity is quite difficult. For that reason this study focused to capture the change of heart rate variability (HRV) as a substitute of the autonomic nerve activity. The blinking duration is captured from the movement of eyes by three-dimensional analysis of the recorded image of the CCD camera. Therefore simultaneous measurement of heart rate and blinking of eye were executed in this study [14].

IV. Experimental Environment

A. Physiological Signal for Sleepiness Detection

Sleep latency on the maintenance of wakefulness test was introduced to detect sleepiness of a subject by using daytime polysomnography (PSG) in an anechoic room as well as measuring of heart rate and eye-blinking as shown in Fig. 3. The subjects were instructed to sit on relax posture. Eyelid of the subject was instructed to be open with no tasks with dark illumination of the room. The PSG is a method to estimate an onset of sleepiness by using the physiological signals in the electroencephalogram (ECG) by using the ten-twenty electrode system, electrooculogram (EOG), and electromyogram (EMG). The analysis of PSG was manually executed on an expert judgment basis.

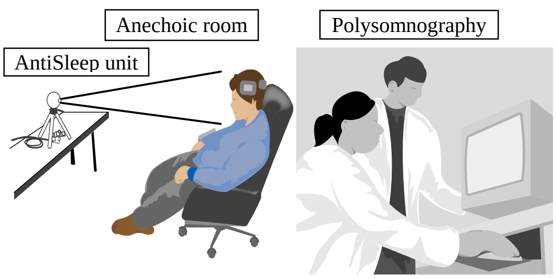

Fig. 3. Sleep latency test environment.

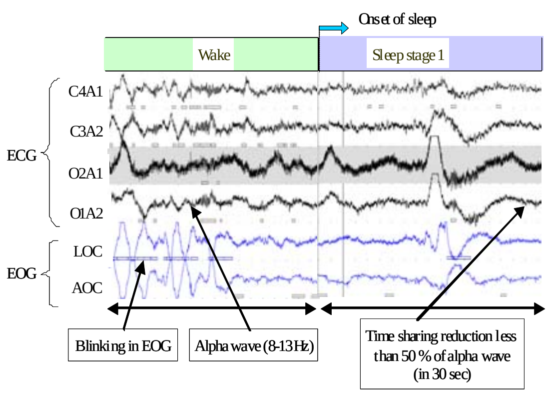

Fig. 4. Waveform in PSG in 30 sec time duration.

An example of typical waveform in PSG in 30 sec time duration is shown in Fig. 4, where stage 1 of sleepiness was defined as drowsy level.

B. Measurement of Autonomic Activity on Drowsy State

The RRI in the electrocardiogram waveform used by NASA lead method was obtained from ECG waveform as shown in Fig. 5. It is said that the NASA lead method is not mostly affected by the EMG noise.

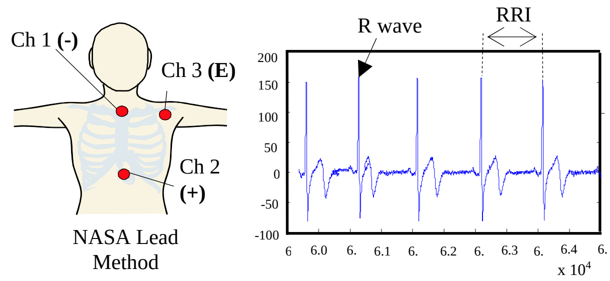

Fig. 5. Heart rate RRI in ECG.

The RRI was recorded to calculate HRV by means of using the software of Memcalc/Win (GMS Co. Tokyo, Japan). The Memcalc is one of calculation methods to analyze power spectrum density of a time serial data set based on the maximum entropy method. The method is said as suitable for expressing the basic change of a certain time serial data set, which can obtain the high-frequency (HF) and the ratio low-frequency /high-frequency (LF/HF). HRV is often used as an index to measure autonomic nerve activity. The power spectra were quantified at 0.04-0.15Hz (low frequency power; LF) and 0.15-0.40Hz (high frequency power; HF). The HF component and the ratio of LF/HF were used as indices of autonomic nerve activities.

C. Measurement of Eyelid Movement

By using tracking unit (Smart Eye's Anti Sleep) composed of an infrared CCD camera, face information of head position, gaze direction and eyelid distance was measured as shown in Fig. 6. The unit needs one time calibration on check board at the beginning of measurement.

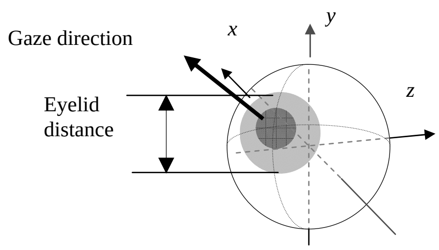

Fig. 6. Eyelid distance.

An example of a typical wave form of eyelid distance and eye ball position in combination with vigilance state and sleep stage is shown in Fig. 7.

The following algorithm was adopted for detection of blinking, which used median filter of 70 mm second time window with 60 Hz sampling rate. Raw data of d_{eyelid} for eyelid distance follows equation (1), where units was in meter.

$$dm_{eyelid} = MEDLAN\,(dm_{eyelid}) \quad (1)$$

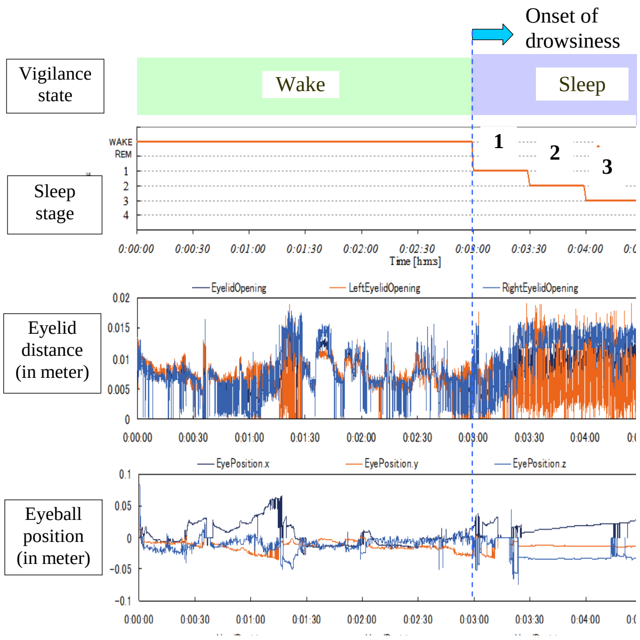

Fig. 7. A typical waveform.

MEDIAN(*) denotes the median filter. dm_{eyelid} in meter designates filtered value of eyelid aperture. Then eyelid state is expressed followed by equation (2) on threshold-based determination basis.

$$EyelidStatus = \begin{cases} ElelidOpen, & dm_{eyelid} < 0.003 \\ EyelidClose, & dm_{eyelid} \geq 0.003 \end{cases} \quad (2)$$

EyelidStatus denotes a status of eyelid in binary state of *EyelidOpen* or *EyelidClose*. The blinking duration was calculated by measuring time duration of *EyelidClose*.

Eventually physiological signal used for estimation of drowsiness is shown in Table I.

TABLE I: PHYSIOLOGICAL SIGNAL FOR DROWSINESS ESTIMATION

Sleep Index	Analytical equipment	Physiological signals
Sleep Stage	Daytime Polysomnography (Alice 3, Healthdyne Technologies, Pa., USA)	Electroencephalograph (C3-A2, C4-A1, O1-A2, O2-A1)
		Electrooculogram
		Electromyogram
Heart rate variability	Memcalc/Win (GMC, Tokyo, Japan)	Electrocardiogram

V. EXPERIMENTAL RESULTS

A. HRV (Heat Rate Variability)

By using the Memcalc, autonomic nerve activity of HF (index of activity of parasympathetic nerve) and LH/HF (index of activity of sympathetic nerve) for the state of wake and drowsiness were obtained as shown in Fig. 8 and Fig. 9. An amount of LF of drowsy state increased significantly at the moment of drowsiness onset by 57.1 % and HF of drowsy state increased by 49.2 %. Furthermore LF/HF during wake time increased by 105%. From the results heart rate variability may be suitable to estimate a state of drowsiness.

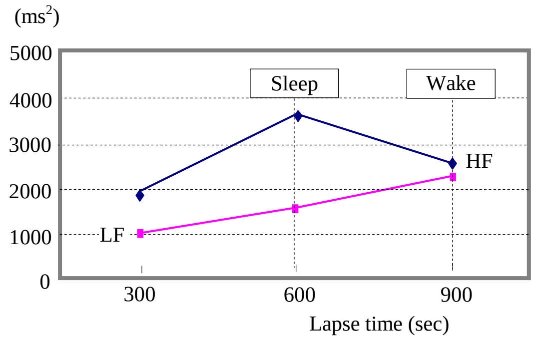

Fig. 8. Heart rate variability (LF, HF).

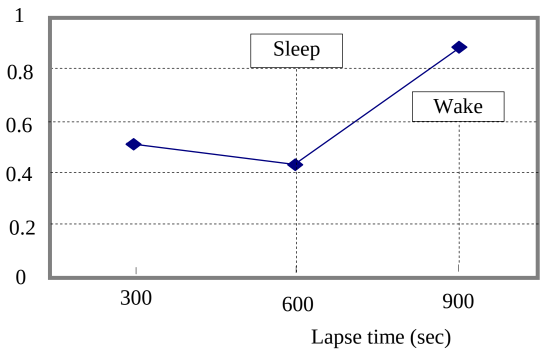

Fig. 9. Heart rate variability (LF/ HF).

B. Eyelid Movement

By using tracking unit, eyelid blinking was captured. Eyelid distance was decreased by 64.9% just after an onset of drowsiness as shown in Fig. 10. From the results analysis of eyelid movement may be suitable to distinguish states of a subject such as wake or drowsiness.

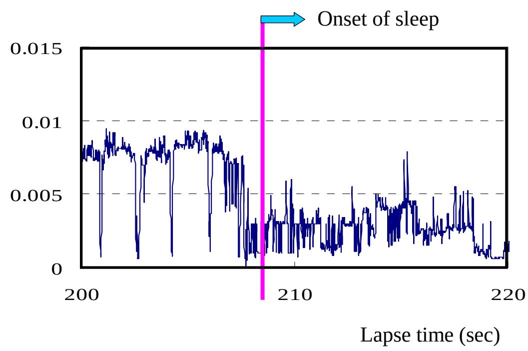

Fig. 10. Example of eyelid distance (Unit; meter).

C. Simultaneous Measurement of HRV and Blinking Duration

Following equation (2), eyelid status was obtained from the information of eyelid distance which enabled calculation of blinking duration. Then blinking duration of wake state was compared with the moment at 10 minutes before onset of sleep, where state of subjects was determined by the PSG. The blinking duration of 10 minutes before onset of sleep was extended by 25 % during wake to sleep transition period as shown in Fig. 11. From the results blinking duration may be suitable to estimate onset of sleep as well as drowsiness.

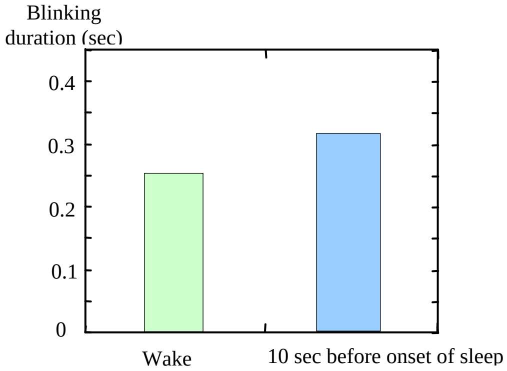

Fig. 11. Change of blinking duration.

Maximum blinking duration of 5 minutes was compared with HF as shown in Fig. 12, where white circle indicates maximum blinking time and dark rhombus indicates HF. Extension of blinking time was antecedent to an onset of drowsiness at the lapse time of 390 second. After that moment an amount of HF increased, and at the lapse time of 1590 both shortening of blinking duration and reduction of HF were obtained. Although HRV may indicate the activity of autonomic nerve, it needs more than a minute to measure heart rate RRI to obtain better reliability. However index of blinking duration responds within 5-10 second to detect onset of drowsiness for an in-vehicle application. For the reason simultaneous measurement of HRV and blinking duration may have ability to detect onset of drowsiness in real time for the establishment of driver's psychosomatic state adaptive driving support safety function in the area of vehicle preventive safety [14].

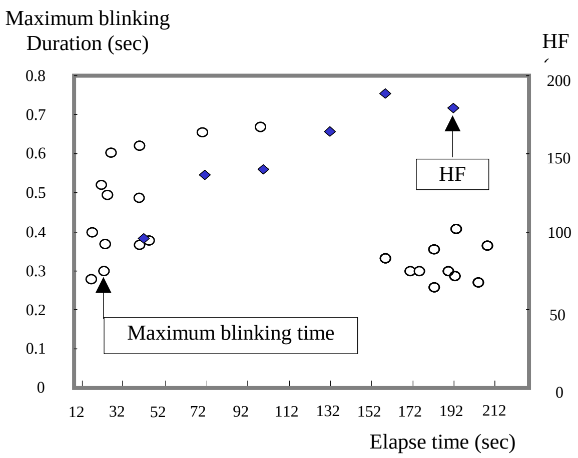

Fig. 12. Maximum blinking duration and HF.

VI. Method of Drowsy State Detection for the Driving Support Safety Function

The flowchart as shown in Fig. 13 indicates architecture to decide onset of drowsiness. The function is comprised of two tasks. Task a measures movement of eye by tracking unit and calculates blinking duration (BD). Then Task A calculates drowsiness index based on blinking (BID), Task B measures HRV and analyzes HF, and LF/HF. Then Task B calculates drowsiness index based on HRV (HRD). In the next stage the probability of drowsiness is calculated by comparing amount of BID and HRD. When the function decides that drowsiness may be imminent, it alerts the risk level to a driver or intervenes into a function of vehicle driving control system to avoid traffic accident. The function of drowsiness detection is shown in the center part in yellow of Fig. 14 on bloc diagram basis. The function should be incorporated into driver's psychosomatic state monitor, which is a part of driving support safety function.

From the previous study [13], the relationship in a particular combination among driver's behavior, driver's psychosomatic states for the potential driving support safety system was identified. For example, when a driver's psychosomatic state monitoring system could detect a state of drowsiness as well as improper recognition of a traffic environment of a driver, the function could provide proper information to the driver, to give alert, or to intervene in the driver's operation in order to help lower the risk of being involved in the traffic accident.

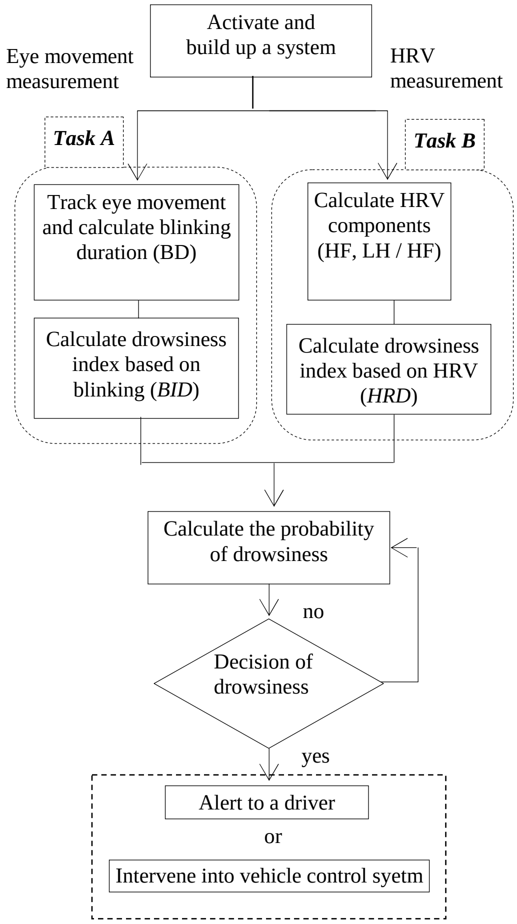

Fig. 13. Function of drowsiness detection.

VII. Summary

From the analysis of the Internet survey on the traffic incident experiences, driver's drowsy state was identified as one of key risk factors of psychosomatic state which may results severer traffic accidents in the real world. By means of introducing the analytical tool for HRV (Memcalc and PSG) and the tracking unit for eye movement (Smart Eye's AntiSleep), this study clarified that simultaneous measurement of HRV and eye blinking duration may be feasible to detect a state of drowsy of a driver on real time basis.

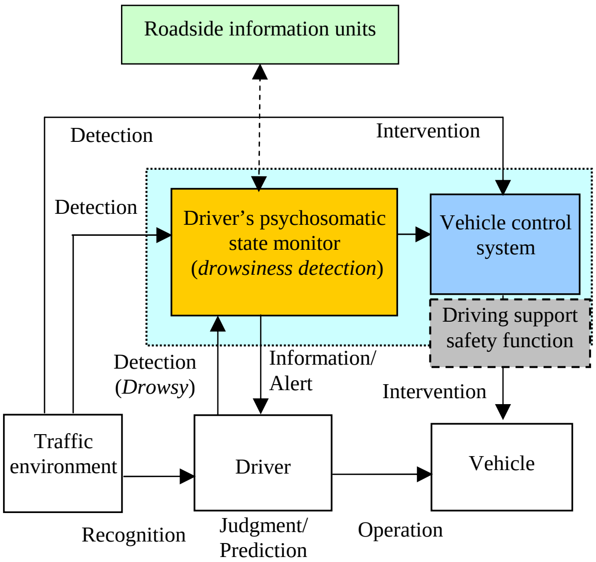

Fig. 14. Potential driving support safety function.

Then the architecture was proposed for the estimation of onset of drowsiness, which should be incorporated into essential constituent function of driver's psychosomatic state adaptive driving support safety system. The system may have potential ability to reduce the number of the traffic accident.

The conclusions are as follows:

1) Drowsy state is one of key risk factors which cause severe traffic accident.
2) HRV and eye blinking is available indicator to estimate the onset of drowsy state.
3) The proposed method of the drowsiness detection may be applicable for the driver's psychosomatic state monitoring function.
4) Proposed driving support safety system may have ability to enhance the performance of safety for the lowering of the risk of being involved in the traffic accident.

VIII. Future Issues

This study is first stage of validating possibility of simultaneous measurement of HRV and blinking duration for comprising the function to prevent driver from falling into drowsy state on laboratory basis.

In order to replicate drowsy state in the real world traffic environment, a driving simulator should be introduced.

Blinking habit varies from person to person, and as there is instability in the capturing blinking due to head movements before onset of drowsy, in-vehicle device may be required further improvement of observing better image of eye movement.

As a next step, our challenge should be focused to realize in-vehicle devices on a practical basis for the reduction of the number of the traffic accident.

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