Brief Report

Drowsy Driving Detection Based on Steering Maneuvers

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Report received on Jul. 24, 2014

KEYWORDS Drowsy Driving Detection, Active Safety, Steering Maneuver, Kullback-Leibler Divergence, Auto-truck

1. Introduction

Driver drowsiness is a major factor in a number of traffic accidents.(1) The National Highway Traffic Safety Administration reported that drowsy driving was the cause of approximately 24% of all crashes and near-crashes and increased the risk of crashes and near-crashes by fourfold.(2)

Moreover, McCartt et al. reported that 47% of long-distance truck drivers had fallen asleep while driving.(3) Therefore, technologies to prevent drowsy driving are expected to reduce the number of crashes and near-crashes. We have developed a method of detecting driver drowsiness based on a filter with weighted discriminative frequency response (WDFR) between steering maneuvers in the drowsy and wakeful states.(4) In the present report, we briefly introduce the proposed method.

2. Drowsy Driving Detection Algorithm Based on the WDFR

During drowsy driving, characteristic steering maneuvers (e.g., sloppy steering and few small steering corrections) are observable. The proposed method warns a driver of drowsy driving by detecting the repeated occurrence of such maneuvers by means of the WDFR filter, which is constructed based on a frequency analysis of the maneuvers in drowsy and wakeful states and selectively passes such maneuvers. We explain the detection of drowsy driving with the WDFR filter and describe the construction of the filter in the following paragraphs.

The proposed method consists of three stages to detect drowsy driving. In the first stage, we apply an elliptical band-pass filter with a cutoff frequency of 0.3 to 2.5 Hz to the steering velocity signal in order to suppress some environmental effects (e.g., road environment and mechanical noise). The second stage is to calculate the signal-emphasized frequency elements related to drowsy driving by filtering the steering velocity signal with the WDFR filter. Finally, the driver is warned of drowsy driving when the absolute value of the filtered signal for 90 s exceeds a predefined threshold. We discussed how to decide this threshold in a previous paper.(4)

Next, we explain how to construct the WDFR filter. The basic concept of the WDFR filter is to emphasize the frequency elements that have better discrimination between normal driving and drowsy driving. The weight for each frequency bin is proportional to the symmetric Kullback-Leibler divergence (referred to hereinafter as the KL divergence), which is measured between the probability distributions of power spectral density (PSD) for two states of driving. When each distribution of the PSD can be assumed to be a Gaussian distribution at each frequency bin, the KL divergence can be calculated as follows:

$$KL(n)=\frac{\sigma_{aw}^{2}(n)}{\sigma_{dr}^{2}(n)}+\frac{\sigma_{dr}^{2}(n)}{\sigma_{aw}^{2}(n)}+ \\ (\mu_{aw}(n)-\mu_{dr}(n))^{2}\left(\frac{1}{\sigma_{aw}^{2}(n)}+\frac{1}{\sigma_{dr}^{2}(n)}\right),$$

where n, μ, and σ^2 are the nth frequency bin, and the mean and variance of the Gaussian distributions, respectively. Moreover, suffixes aw and dr represent normal driving and drowsy driving, respectively. The WDFR is the normalized value of the KL divergence and is given as follows:

$$WDFR(n)=\frac{KL(n)}{\sum_{i=1}^{N}KL(n)}\ .$$

3. Experimental Setup

We recorded the CAN (Controller Area Network) bus signals of trucks (e.g., steering angle, yaw rate, and vehicle velocity) as well as the driver's face at 10 Hz for up to two hours on a test course until each subject decided to terminate the experiment or a supervisor judged that the driver could no longer drive safely. The number of subjects was 31, all of whom have more than three years of truck driving experience. Twenty-five-ton cargo trucks were used in the experiments. We defined a Drowsiness Level (D-Level) as a subjective index based on driver facial expression. The D-Level ranged from 1 (awake) to 5 (asleep) to evaluate driver drowsiness. The subjective criteria for the facial characteristic behavior for each D-Level are shown in **Table 1**.

We evaluated the performance of the proposed method via the equal error rate (EER), which is the balanced ratio between the false alarm rate (FAR) and the false rejection rate (FRR). False alarms and false rejections were defined as having occurred when the system alerted a driver despite the D-Level being less than 3 and when the system failed to alert a driver despite the D-Level being greater than or equal to 3, respectively. These values were computed every 3 s.

4. Experimental Result

The results of the WDFR calculated using the data of 16 subjects whose D-Levels exceeded 4 are shown in **Fig. 1**. Drowsy driving was found to have two characteristic steering behaviors. The first characteristic steering behavior was that around 0.4 to 0.9 Hz, corresponding to sloppy steering behavior without small steering correction. This low-range-frequency signal has been demonstrated to be useful in detecting drowsy driving in previous studies.(5) The second characteristic steering behavior was that around 1.5 to 2.4 Hz, corresponding to small steering behaviors to correct the vehicle position after preventing a lane departure.

Table 1 Drowsiness Level (D-Level).

D-Level		Examples of Facial Characteristic Behavior
Awake	1	・Fast and frequent eye movement ・Constant eye blink rhythm
	2	・Slow eye movement
Drowsy	3	・Slow and frequent eye blink ・Yaw
	4	・Conscious eye blink ・Useless body movement (e.g. shoulder bobbing)
	5	・Long-time eye closure ・Swaying head

We compared the driver drowsiness detection performances of the proposed algorithm and the conventional algorithm (baseline), which was calculated as the 90 s moving average of the 0.3 to 0.5 Hz steering power spectrum based on a previous study.(5) **Figure 2** shows the drowsiness detection performance. The proposed method achieved an EER of 29 whereas the EER of the baseline was 37%. Thus, the proposed method could detect drowsy driving with a higher accuracy with a fixed false alarm rate than the conventional method.

5. Conclusion

In the present report, we introduced a drowsy driving detection algorithm based on a filter with a weighted discriminative frequency response between steering maneuvers in the drowsy driving state and the

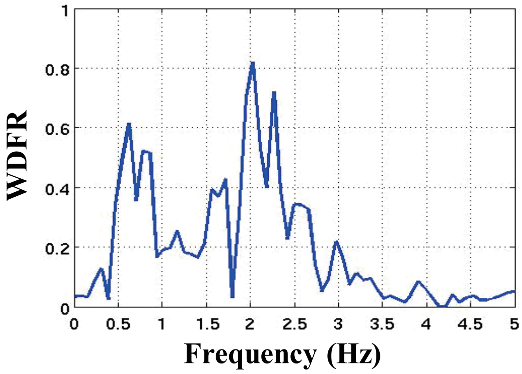

Fig. 1 WDFR for each frequency bin.

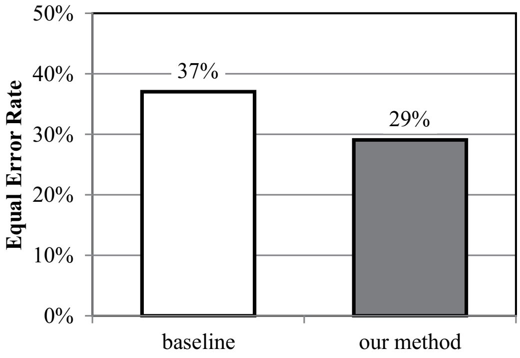

Fig. 2 Performance of drowsiness detection.

normal driving state. Although the steering signal has been reported to be useful in detecting drowsy driving in previous studies, in these studies, the frequency filters were designed based on heuristics. In contrast, the WDFR filter of the present study was consistently constructed based on the KL divergence between the probability distributions of power spectral density for two states of driving. Therefore, the filter could capture the features of drowsy driving more precisely, and we demonstrated experimentally that the proposed method could detect drowsy driving with an 8% greater accuracy than the conventional method. Since the proposed approach requires only an additional steering angle sensor, we expect the proposed method to contribute to a reduction in the number of drowsy driving accidents as a part of future accident prevention systems.

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Fig. 1
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