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Portable Driver Drowsiness Prediction Device and Method

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***Abstract*—Nowadays, apparatus and corresponding methods for estimating driver's fatigue level are prevailing in the vehicle market. However, the data captured from visual images of a drowsy driver, such as observation of the driver's behavior and the reflectivity of the eyelid may risk existence of assessment error because it's not easy to compel the driver to refrain from his/her habits. Therefore, evaluating method of physiological signals has been proposed greatly. Consequently, we developed an advanced drowsiness prediction method and apparatus acquiring and analyzing heartbeat frequency during a plurality of time intervals. In our experiments, no other information than heartbeat frequency will ever be needed for driver drowsiness assessment. This achievement is easy to be used during driving and extended to prevent drowsiness in any other activity instead of commercial facilities.**

I. Introduction

A report from National Sleep Foundation (NFS) showed that 100,000 police-reported crashes, 71,000 injuries, and 1,550 deaths occurred due to drowsy driving each year in the United States [1]. Accidents caused by driver's fatigue had become a big issue in recent years. Researchers indicated that lateral position tracking and speed tracking are useful criteria to evaluate driver's fatigue [2]. In 1994, Wierwille *et al.* developed the method, PERCLOS, which distinguished the driver's status by observing eye-closure rate [3]. It worked robustly during day and night, but not for the driver who wears glasses [4] or who has problem with eye blinking. Therefore, detection of driver inattention by using overhead capacitive sensor array as well as PERCLOS is proposed [5]. Although nodding is one of the most obvious characteristic for discriminating driver fatigue, it's difficult to ask the driver not to move his/her head arbitrarily. Hiroshi Ueno *et al.* published several techniques for detecting drowsiness [6]. It is believed that the accuracy of detection by sensing human physiological phenomena is much better than observing driving operations or driver's behaviors. In other words, it's worth paying attention to driver's physiological signals, like heart rate, skin electric potential, physical reactions, sagging posture, and frequency at eyes close, *etc.* With electrocardiography (ECG), electroencephalography (EEG), electrooculography (EOG), and electromyography (EMG) signals from the driver, drowsiness is able to be detected [7], [8]. In fact, the status of the driver's fatigue is accessible by observing the frequency domain of the heart rate variability (HRV), very low frequency power (VLF, 0.008 to 0.04 Hz), low frequency power (LF, 0.04 to 0.15 Hz), high frequency power (HF, 0.15 to 0.5 Hz) and the LF/HF ratio. [9] However, neither physiologic sensors are practicable while driving because a lot of cables and the sensor pads are required to be set up around that will distract the driver and probably result in accidents. To improve this, some research worked on integrated physiological sensor systems [10]-[12]. By utilizing HRV data captured from electrodes on both sides of a steering wheel, drowsiness could be predicted. The experiment resulted from calculating HF of HRV and detecting decreases in heart rates, the accuracy is 70.7% [11].

In spite of the fact that ECG electrodes were able to be integrated into the steering wheel by car manufactures, both hands operating were required. As a result of, people who always drive by one hand were not suitable for this even if interpolation was adopted.

Fig. 1. Installation of NPNS between safety belt and driver's chest.

However, more attention has been given to the Doppler radar as a remote monitoring technique [12]. In this paper, we present a solution to predict driver's drowsiness with non-invasive sensor, Nano-second Pulse Near-field Sensor (NPNS), which is fixed between safety belt and driver's chest (Fig. 1.) and a heart rate (HR) computing method that is able to predict drowsiness by minutes. The method is designed for any existing and novel HR sensors including ECG electrodes and NPNS. Moreover, based on this study, one-hand driving,

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head shaking and eye blinking symptoms during driving were also acceptable. This paper aims to propose a practicable method to predict drowsiness by minutes and a novel HR sensor which will not distract the driver and will be easy to be installed in vehicles.

II. APPARATUS AND METHODS

A. APPARATUS

A person's chest has a quasi-periodic movement caused by heartbeat and respiration. Based on the Doppler theory, the phase difference value $\Delta(t)$ between reflected and reference RF pulse signals is proportional to the chest displacement $R(t)$. Whereas f is the frequency of oscillations filling the transmitted RF pulse and c is velocity of light as in (1).

$$\Delta(t) = 4\pi R(t) f / c \quad (1)$$

We can calculate the chest displacement $R(t)$ by obtaining the phase difference value $\Delta(t)$. The apparatus which monitors $\Delta(t)$ is so-called NPNS. It is comprised of an antenna board including a transmission antenna which radiates electromagnetic waves to the driver's chest and a reception antenna which receives the waves scattered form the chest, an analog board with amplifiers and filters circuits for acquiring analog signals which represents the physical movement of driver's chest, a digital board which digitalizes the analog signal and then signal processing is also done here by a 8051 chip, and a beeper is able to remind the driver to be aware of drowsiness.

The operating frequency of antenna is below 1 GHz and the total power meets FCC requirements, which will not do harm the human body. A lithium battery is installed as power supply and 60 hours continuous working is achieved by a 1050mA type battery designed for general mobile phone. The measure of the area of this device is 50 mm × 40 mm that is smaller than a regular business card. All we need to do is put it in front of the driver's chest, for example, attach it to the safety belt or put it into shirt pocket directly or just wear it like fashion necklace.

B. METHOD

We predict the driver's drowsiness just from his/her heart rate. The state of consciousness are quantified as the drowsiness index by Drowsiness Algorithm. In this algorithm, the concept of Fuzzy is applied to transferring the physiological parameters to the drowsiness index. This index tells us the level of the driver's tiredness. We can give a warning to the user according to this drowsiness index.

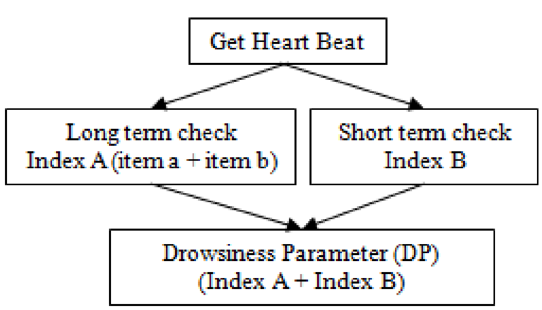

Fig. 2. Flow chart of method.

The Drowsiness Algorithm is shown in Fig. 2. We divided this algorithm into two parts. One is Index A for long term monitoring and the other is Index B for short term monitoring. At the beginning, the heart rate (HR) is fetched per second. We calculate the average HR every 5 minutes and noted as HR_5 for long term monitoring and average HR for every 1 minute, which is noted as HR_1 for short term monitoring.

In the long term monitoring, the linear regression of HR_5 for five minutes, which is noted as $HR_{5Reg,}$ is checked at first. If HR_{5Reg} is less than -0.02, the length of time is recorded as T1 (HR_{5Reg}). The weight of the item a is larger as long as the duration of the T1 is larger. We also calculate the five minutes linear regression of ten seconds difference of HR_5 and noted as $HR_{5DiffReg}$. If $HR_{5DiffReg}$ is less than -0.01, the length of time is recorded as T2($HR_{5DiffReg}$). Similarly, the weight of the item b is larger as a result of lager T2. Finally, the Index A for long term monitoring is sum of the weights of the item a and item b. However, the thresholds -0.02 for HR_{5Reg} and -0.01 for $HR_{5DiffReg}$ are based on the empirical method. These thresholds may be optimized by results of the huge amounts of experiments, but they are related to the false alarm rate. If the thresholds are too high, the false alarm rate will be raised. On the contrary, the accuracy will be decreased if the thresholds are too low.

In the short term monitoring, 1 minute linear regression of HR_1 (HR_{1Reg}) is calculated. The 256 points Fast Fourier Transform of HR_1 is also derived. We integrated the difference of low frequency intensity and the Index B is proportional to the slope of linear regression.

Eventually, the drowsiness parameter (DP) is obtained by the sum of Index A and Index B. We then set a threshold for DP by our experience after several experiments. The alarm is issued as a sign of drowsiness by minutes if the DP is larger than this threshold.

III. EXPERIMENT

A laboratory-based driving simulator [13] is applied in our experiments to measure on-road driving performance. 15 subjects were assessed with this driving simulator. Because drowsiness occurs easily after lunch in daylight, the experiments with drowsiness prediction were held after lunch. Every subject has 5 to 10 minutes to be familiar with the driving simulator in order to avoid any accident caused by unacquainted control. The subject had to drive for 90 minutes in a small, dark, and isolated room. If any crash occurred, the subject was asked to push the re-drive bottom to finish the remainder of the driving time. Every subject also had to be equipped both with NPNS and Philips MP20, a traditional ECG monitor with electrode pads attached to the subject's skin as a comparison, to measure heart rate every second. The tracking of the lateral position, speed and crash issued with time were recorded within the final report, which was generated from the simulator. We analyzed this report and heart rate to validate the Drowsiness Algorithm.

(b)

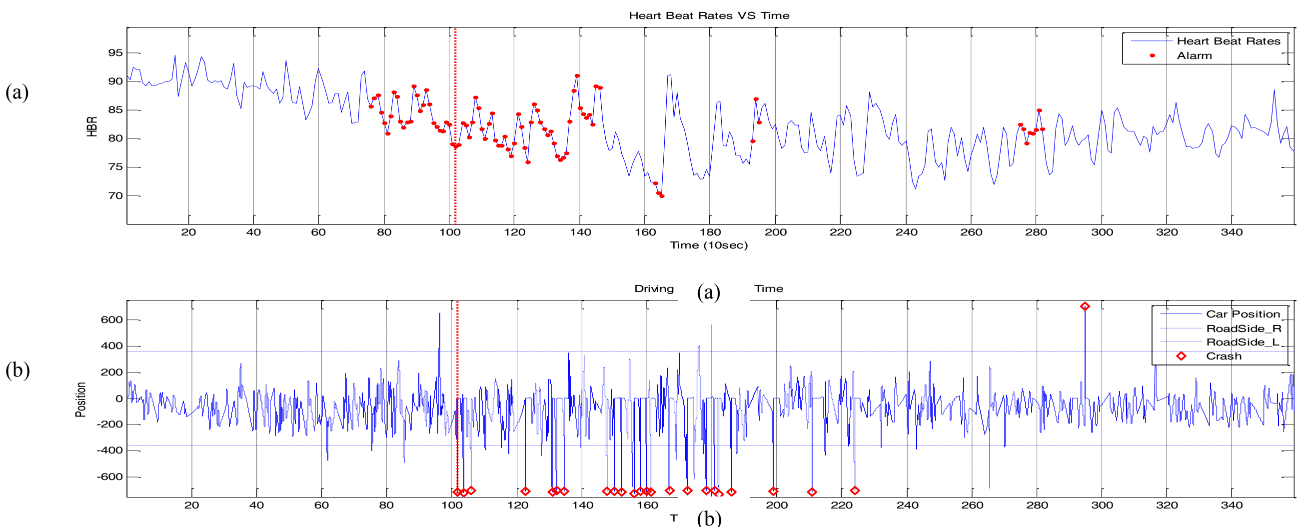

Fig. 3. Experiment result of subject X: (a) Heart rate versus time and (b) driving position which 0 stands for center lane and the position approached boundary will be regards as guardrail accident

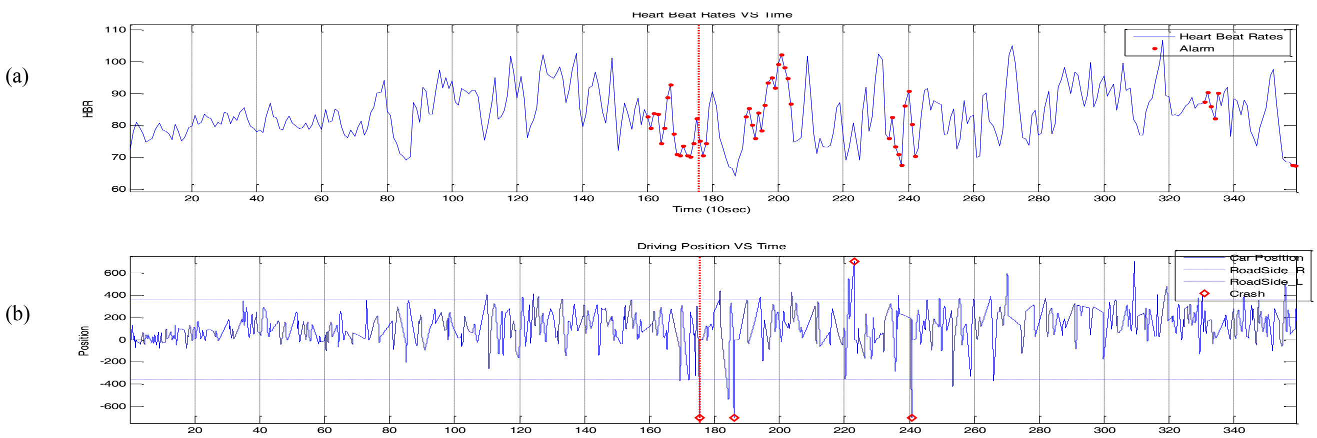

Fig. 4. Experiment result of subject Y: (a) Heart rate versus time and (b) driving position which 0 stands for center lane and the position approached boundary will be regards as guardrail accident

IV. RESULTS

The heart rate and driving position tracking of subject X and subject Y are shown in Fig. 3 and Fig. 4 respectively. Alarm points results from Drowsiness Algorithm are also marked as dark dots in Fig. 3(a) and Fig. 4(a). The tracking of driving positions is shown in Fig. 3(b) and Fig. 4(b). Crash points generally come from guardrail accidents and absences of breaking caused by drowsiness are also marked as a diamond at the same curve. The dotted line generated originally from (b) presents when the first crash occurred. Therefore, if we focus on Fig. 3(a) and Fig. 4 (a), alarms are always triggered before 150 seconds which validate the Drowsiness Algorithm capability to predict when drowsiness happens, and probably avoid accidents several minutes before, which is enough time to allow drivers to refresh themselves. The average time interval between alarm and crash is 366.7 seconds in Table I. We also calculated false alarm rate by summing up false alarm duration divided by total driving duration. The performance of Drowsiness Algorithm is shown in Table I. The accuracy is up to 85% and the false alarm rate is 0.78%.

V. CONCLUSION

A simple non-invasive detection technique and method of predicting drowsiness by several minutes using Doppler radar and Drowsiness Algorithm has been proposed and demonstrated. The method was presented and verified by the experiments. Unlike prior art, our method not only detects the fatigue level of drivers, but also predict the occurrence of drowsiness by sequentially obtaining the average heart rate of the driver, and the power spectrum of heart rate value curve as well. For some subjects, they only felt a little bit sleepy when the alarm occurred while others were almost unconscious. The timing of the alarm occurrence varies from person to person. By all accounts, however, the alarm always triggered before the subjects dozed off. The most important innovation and breakthrough of our method is, to achieve satisfactory results, it only needs heart rate values to predict the occurrence of drowsiness. Maybe combined with additional physiological information, like brain waves, number of blinking, tilt angle of head, or eyeball motion, it can increase the accuracy of our method, but it will also increase the cost of the whole system because of the additional sensor required. Moreover, the improvement is less than 15%.

In addition, NPNS can detect not only heart beat, but also other physiological movements, like respiration, body movements, and distinguish if the driver is on the seat or not. All of the above information were obtained at the same time by the Doppler radar and data processing. Up to now, we only analyzed the heart rate information in our experiment data. We will progressively put other physiological information into our method if it is able to increase the accuracy of the drowsiness prediction without any additional hardware expense. Since parameters used in the algorithm are simple enough, extension to other applications is also practicable. People who deal with public transportation like tourist bus, high-speed rail, and airplane are also suitable. Sleeping condition and emotion evaluations are available to be estimated by physiological signals, too. Further researches are proceeding continuously as well. The technology promises to greatly improve the cost and convenience of predicting drowsiness of the driver by analyzing heartbeat using Doppler radar and potentially be a practicable on-road test.

Table I
Summary of experiments

No. of subject	**Existence of crash**	**Alarmed before the first crash and the time interval between alarm and crash**		**False alarm rate %**
1	No	No Crash		0
2	Yes	Yes	300 s	0
3	No	No Crash		5.6
4	No	No Crash		0.18
5	Yes	No		0
6	Yes	Yes	150 s	0
7	Yes	Yes	150 s	0
8	Yes	Yes	300 s	0
9	No	No Crash		0.55
10	No	No Crash		0.18
11	Yes	Yes	800 s	0
12	No	No Crash		5.18
13	No	No Crash		0
14	No	No Crash		0
15	Yes	Yes	500 s	0
Summary		Accuracy **85.7%**	Average **366.7 s**	**0.78**

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