Validity of Detection of Driver’s Surprised State Based on Systolic Blood Pressure

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Abstract: It is said that one-third of deaths from traffic accidents is due to improper state of driver, such as unfocused or inattentive driving, thus the development of systems that can detect state of drivers is very important in order to reduce the number of deaths more. In order to develop the system which can detect driver’s state, we attempt to detect driver’s surprised state based on blood pressure. From the experiment using driving simulator, it is found that systolic blood pressure get to be high after driver feels surprised. In addition, compared to the time-series data of LF/HF, the detection by systolic blood pressure is more adequate method than that by LF/HF when we refer the driver’s introspective reports.

Keywords: Driver’s state, Surprised state, Blood pressure, Systolic blood pressure, Driving simulator

1. Introduction

In this study, we propose a method of estimating driver state during driving based on blood pressure. The number of deaths from traffic accidents in Japan has decreased for 14 consecutive years from 2000 to 2014[1]. One of the reasons for this decrease is the development of collision prevention systems for vehicles and their deployment in many vehicles. These devices are categorized into two types: one is for detecting the circumstances around own vehicle and the other is for detecting driver state. Detecting driver state is especially necessary for preventing accidents caused by poor driver state such as excessive tension[2-4] or inattention. One-third of the deaths in traffic accidents are caused by improper driver state[5] such as unfocused or inattentive driving. Thus, it is important to develop systems that can detect driver state to reduce the number of such deaths.

There are two types of systems for detecting driver state. One is the camera system that monitors the driver’s face and expressions and provides a sound or visual warning if the driver is not in a state to drive, for instance, if the driver is sleepy or tired (Fig. 1(A))[6]. The other is the bioinstrumentation system, which monitors the driver’s pulse wave and R-R interval and provides a sound or visual warning if the driver is found to be unfit to drive (Fig. 1(B))[7].

These systems seem to be suitable for estimating driver state; however they have major demerits. The camera system which monitors the driver’s face and expressions can detect many driver expressions such as anger, depression, and sleepiness[8]; moreover, the system is expensive. In addition, a high-spec CPU is needed to execute the algorithm[9], which means that the system cannot be run using the in-vehicle microcomputer. On the contrary, the bioinstrumentation systems that monitor driver pulse wave are inexpensive and easy to install in vehicles. Calculation of the R-R interval is very easy; therefore, a high-spec CPU is not needed. However, the system can detect only a few types of states. The camera system can detect when a driver is angry but the bioinstrumentation system cannot. In addition, pulse wave tends to be affected by body motion, and it is very difficult to design and develop a filter to reduce the effect of body motion.

Thus, there is a need to develop an alternative detection system, and we conceived the idea of a system that can detect driver state based on blood pressure. Although only a few driver states can be estimated using blood pressure, the number of states that can be estimated using blood pressure may be more than that estimated using pulse wave. In addition, the effect of body motion on the proposed system is less severe than that on the pulse wave system. From the above discussion, the proposed in-vehicle blood pres-
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Figure 2: Block diagram of experimental system. Computer for vehicle motion, scenario of driving simulator, vehicle control calculation and displaying scene are connected via LAN and each computers are synchronously controlled.

sure system seems to be adequate for estimating driver state. We are developing a prototype of the proposed bioinstrumentation system based on blood pressure, and we show the efficacy of the proposed system. To this end, based on blood pressure, we attempted to detect driver state as it transitioned from calm to surprising, which is a typical driver-state transition.

Our previous study showed the probability of estimating driver state based on blood pressure[10]. However, one of the common approaches to estimating driver state is based on LF/HF[11]. Thus, in this study, we compare the result based on systolic blood pressure to that based on LF/HF.

2. Experiment

Eight males (all aged 22 years, participants A - H) participated in the experiment. To acquire the blood pressure data of subjects during driving, the subjects were instructed to operate a driving simulator (D3sim, by Mitsubishi Precision CO., LTD.), and the measured RRI (R-R interval) and blood pressure were measured using a measurement system (Radia Press RBP-100, by KANDS Inc.). This driving simulator can acquire data such as velocity, steering angle, and braking pressure, which would help us analyze participants’ driving behaviors. The driving scene is projected onto three front screens to give the participants the feeling that they are operating a real car.

All participants were not used to operating the driving simulator. Thus, for acclimatization, they navigated through a simple course for approximately 7 min. Thereafter, they were indicated to drive a vehicle on a simulated test course. They drove on the test course for approximately 7 min. Their blood pressure and driving behaviors such as velocity, steering angle, and braking pressure were measured in this time. Approximately 5 min and 6 min after the start of driving, a child and a cycle, respectively, were abruptly projected in front of the participants’ cars. This was to check for any deviation in drivers’ states from calm to surprise. Each driver reported introspective while driving after experiment was completed. The times at which the child and the bicycle were projected were provisionally determined.

Figure 2 shows a block diagram of the experimental system, and Fig.3 shows an image of the experiment.

It should be noted that the description of this chapter is the same as that of previous study[10] because the experimental method used herein is the same as that in the previous study.

3. Results

3.1 Result of introspective reports Table 1 shows that the result of each participant’s introspective reports. From table 1, participants C, E, and H reported being surprised by the child rushing out. Especially, participant E was so upset that he crashed his vehicle onto a wall after being surprised. On the contrary, participants D and G reported anticipation of someone or something rushing out from hiding and they drove slowly. Thus, participants D and G seemed to drive carefully.

As in the previous study, we examined the changes in systolic blood pressure before and after the child rushed out[10]. In the following, we use “change in systolic blood pressure,” which is defined as follows:

\[
\text{(change in systolic blood pressure)} = \text{(systolic blood pressure)} - \text{(systolic blood pressure at the start of experiment)}
\]

We defined “relative systolic blood pressure” because the blood pressure of each participant is different; therefore, the absolute value of systolic blood pressure is inadequate, and relative value of systolic blood pressure is suitable for analysis[10].
Figure 4 shows the average and the standard deviation of the relative systolic blood pressure before the child rushed and that in the time after the child rushed out but before the bicycle rushed out.

From Fig. 4, the systolic blood pressure after the child rushed out is higher than that before the child rushed out. Especially, the systolic blood pressures of drivers A, C, E, F, and H are comparatively high and have statistical significance.

Next, we show the average and the standard deviation of relative systolic blood pressure of each 5 min from 10 s before the child rushed out to 15 s after the child rushed out. The result is shown in Fig. 5. From Fig. 5, relative systolic blood pressure does not increase immediately after the child rushed out; it increases gradually. Thus, in terms of their blood pressures, drivers did not feel surprised immediately after the child rushed out but a little later, specifically 15 s later, according to Fig. 5. This result confirms the result of the previous study[10]. The systolic blood pressures of participants A, B, C, D, E, F, and H during 10-15 s after the child rushed out were significantly higher than that during 0-5 s after the child rushed out. In addition, in the cases of participants A, B, E, F, and H, the systolic blood pressures during 5-10 s after the child rushed out were significantly higher than those during 0-5 s after the child rushed out.

3.2 Participant's heart-rate variability  
Heart-rate variability, which is used for evaluation of stress or surprise, was measured as well for the sake of comparison with the result of systolic blood pressure. In this study, as written in chapter 1, we measured participants’ RRI during driving.

We analyzed LF/HF, which can be obtained from the power spectrum using Fast-Fourier-Transformed (FFT) RRs. Here LF is the intermediate-frequency component of the power spectrum, and HF is the high-frequency component of the power spectrum. In this study, LF is defined as 0.05-0.15 Hz in the power spectrum, and HF is defined as 0.15-0.40 Hz in the power spectrum. The ratio of LF to HF (LF/HF) is a useful indicator of tension or fatigue[11].

Frequency is usually analyzed using the autoregressive (AR) model, which is efficient for the analysis of short-time data because of its high spatial resolution. However, in this study, we analyzed long-term data, and the frequency analysis results obtained using the AR model and FFT showed similar tendencies[12]. Thus, we analyzed the RRI data and LF/HF data by using FFT, as in our previous study[11]. LF/HF was z-transformed because its value was different across the participants.

Figure 6 shows the LF/HF data of each participant. In this figure, the gray horizontal lines denote the moment at which the child rushed out.
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4. Discussion

4.1 Relation between introspective reports and systolic blood pressure

We consider the relation between the introspective reports and systolic blood pressure from Table 1 and Fig. 4. Participants C, E, and H were very surprised at the child rushing out, and there was a corresponding increase in the LF/HF ratio, whereas participant G was not surprised at the child rushing out because he felt someone or something would rush out from hiding and drove slowly. His LF/HF after the child rushed out was not high, and this corresponds to his introspective report. However, participants C, D, and E show a different trend. According to the introspective report of participant D, his LF/HF just after the child rushed out should have decreased or only slightly increased. However, his LF/HF just after the child rushed out increased significantly. In contrast, according to introspective reports of participants C and E, their LF/HF just after the child rushed out should have increased significantly, but in fact, it decreased or increased only slightly.

4.2 Relation between introspective reports and LF/HF

We consider the relation between the introspective reports and the LF/HF data from Table 1 and Fig. 5. Participants A and H were very surprised at the child rushing out, and there was a corresponding increase in the LF/HF ratio, whereas participant G was not surprised at the child rushing out because he felt someone or something would rush out from hiding and drove slowly. His LF/HF after the child rushed out was significantly higher than that before the child rushed out. From this result, there is a probability that he did not notice the child at the moment of rushing out, but he felt surprised after a short while, and his report did not reflect this. Thus, it seems that these reflect the increase in systolic blood pressure.

4.3 Which is better evaluation method for driver’s surprised state, systolic blood pressure or LF/HF?

This inconsistency is due to the characteristics of LF/HF. LF/HF is an evaluation method in which breath is controlled under the premise that breathing frequency is in the HF band. Thus, a prerequisite is not fulfilled if the breathing frequency is outside the HF frequency band or the depth of respiration is changed[13]. Especially, it is impossible to evaluate driver state based on LF/HF exactly when the driver feels surprised during driving. Based on these considerations, evaluation based on blood pressure is better than that based on LF/HF for determining when the driver is surprised.

5. Conclusions

In this study, we evaluated driver state, especially the surprised state, based on blood pressure. In addition, the blood pressure-based result was compared to that obtained using LF/HF, which is commonly used for evaluation of stress or surprised state. Consequently, the detection of driver’s sur-
prised state based on blood pressure proved to be better than that based on LF/HF.

Considering results of this experiment, we are developing a driver state estimation system that can estimate a greater number of driver states. We will report on this development in the future.

Conflict of interest
The author declares no conflict of interest.

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References


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