A Method for Analyzing Improper Driving Using Passenger's Danger Perceptions

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***Abstract*—One of the main causes of traffic accidents is "improper driving", such as driver's carelessness and operation mistakes. To prevent traffic accidents, it is necessary to detect the occurrence of improper driving, point it out to the driver, and advise improvement. However, the driving behavior analysis method, which analyzes the driving itself from several sensor data, cannot accurately and comprehensively detect improper driving because it cannot consider the traffic situation related to the road, the other vehicles and so on. This paper proposes a method that combines the driving behavior analysis method and the danger perception by passengers. This method enables us to detect improper driving comprehensively and correctly because passengers objectively see both the driving and traffic situation. We conducted experiments of applying this method and confirmed its usefulness.**

Keywords-Drive Analysis; Heart Rate; Passenger.

I. INTRODUCTION

Traffic accidents caused by automobiles are one of the many serious problems in the modern society. One of the major causes of traffic accidents is the driver's improper driving [1], including driver's operational errors and carelessness.

To prevent traffic accidents caused by such improper driving, a support system that points out its occurrence and provides advice for improvement will be useful for the driver. Driving behavior analysis uses sensors to measure the behavior of a car caused by driving to detect abnormal driving patterns, such as rapid acceleration and meandering as improper driving. However, the driving behavior analysis does not have a high degree of accuracy because only a few driving patterns can be analyzed without traffic conditions in which the driving takes places. Therefore, it is often the case where the driving behavior analysis wrongly determines improper driving or even misses improper driving altogether. This problem can be a major drawback for the support system to give appropriate advice to the drivers.

To solve this problem, we propose a method that utilizes the passenger's danger perception on the traffic situation in addition to the driving behavior analysis. The proposed method analyzes the variation of the passenger's heart rate to detect the passenger's danger perception. Next, the detected danger perceptions are compared to the abnormal driving patterns detected by the driving behavior analysis. If they are matched, the detected patterns are considered improper driving. In addition, there are many cases of improper driving that cannot be detected by driving behavior analysis because they are strongly dependent on the traffic conditions. The method analyzes the passenger's danger perceptions that do not match the abnormal driving patterns to extract such cases. This makes it possible to detect improper driving comprehensively and correctly.

To implement the proposed method, we firstly devise a way to detect passenger's danger perceptions by analyzing his/her heart rate variability based on some experiments. The experiments consist of a measurement method and judging criteria for heart rate abnormalities.

We secondly conduct an experiment to show that our method works as expected. The results of the experiment show that the passenger's danger perceptions are useful to improve the accuracy of detecting the improper driving, and the passenger's danger perceptions that do not match the abnormal driving patterns, called danger-perception-only data, include many cases of improper driving. However, some of the abnormalities detected in the passenger's heart rate are not related to improper driving, and so it is necessary to exclude them from the danger-perception-only data to utilize them.

Section Ⅱ of this paper describes the existing methods for detecting improper driving and its problems; Section Ⅲ proposes our method in detail; Section Ⅳ describes an experiment and its results, and Section Ⅴ discusses them, to show the validity and remaining issues of the proposed method; Section Ⅵ concludes this paper.

II. EXISTING METHODS FOR DETECTING IMPROPER DRIVING

A. Driving behavior analysis

Driving behavior analysis is an analysis method that detects dangerous driving patterns by collecting and analyzing sensor data on the motion state of a vehicle while driving [2][3]. The sensor data includes speed, acceleration, and angular velocity. These data are used to detect dangerous driving patterns, such as sudden braking, sudden steering, sudden acceleration, and unsteady handing. This method has been already used in many cars to analyze the driver's

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driving to provide cautions and advices to the driver on the occurrence of improper driving. However, this method has a problem that it cannot detect improper driving accurately due to the following reasons:

- The information that can be obtained from existing sensors is too little to cover all the abnormal driving patterns to analyze.
- Because of no consideration of traffic conditions, the analysis often results in incorrect judgment of improper driving.

Concerning the latter, this is because the criteria for judging whether a certain driving is improper or not vary depending on the traffic conditions in which it is taken place. That is, the improper driving can be correctly determined by the combination of driving operations and traffic conditions.

B. *Driver's danger perception*

Another approach to analyzing improper driving is to estimate the danger perception while driving from the driver's own physiological data. There exist several methods to adopt this approach:

- Detection of the occurrence of danger by using heart rate variability while driving [4]
- Monitoring some visual behaviors that characterize a driver's level of vigilance [5]
- Estimation of the driver's emotions [6]

These methods can detect the driver's danger perception when capturing external dangers, such as unexpected events or unsafe situations.

Since the driver's perception of danger comprehensively captures all the driving situation including driving behavior and traffic conditions, it is expected to get more comprehensive information the driving behavior analysis cannot obtain, such as pedestrians' sudden crossing or the other vehicles' improper driving.

On the other hand, this method has the following problems:

- There are individual differences in the human heart rate and its changes, and these individual differences affect the accuracy of hazard detection.
- Since the change in heart rate is not an event that occurs only when a danger is recognized, events other than danger recognition while driving may be detected.
- Because drivers recognize the situation subjectively, i.e., they tend not to think their driving has problems, the driver's perception of danger is not suitable to use for judging improper driving.

III. PROPOSED METHOD

A. *Approaches*

To solve the problems of the existing methods in the previous section, we adopt an approach to use the passenger's danger perception. Because the passenger's perception of danger is more objective that the driver's one, its combination with the driving behavior analysis is expected to work well.

B. *How to determine improper driving*

The proposed method for detecting improper driving using the passenger's perception of danger is shown in Figure 1.

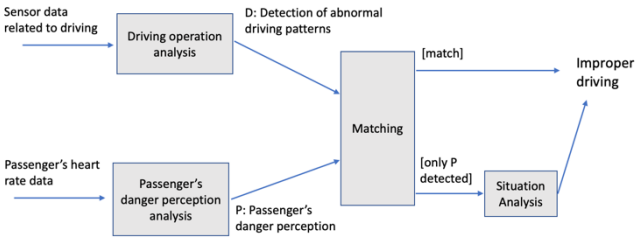

Figure 1. Proposed method for detecting improper driving using passenger's perception of danger

The method first does the driving behavior analysis using sensor data, such as Global Positioning System (GPS) speed and angular velocity to detect abnormal driving patterns. Next, it analyzes the variation of the passenger's heart rate to detect the passenger's danger perception. After that, the detected danger perceptions are compared to the abnormal driving patterns detected by the driving behavior analysis. If they are matched, the detected patterns are considered improper driving. In addition, there are many cases of improper driving that cannot be detected by driving behavior analysis because they are strongly dependent on the traffic conditions. The method analyzes the passenger's danger perceptions that do not match the abnormal driving patterns to extract such cases. This makes it possible to detect improper driving comprehensively and correctly.

C. *Passennger's danger perception analysis*

The proposed method uses the danger perception analysis, which detects human danger perception by analyzing the variation of the heart rate to find out the occurrence of its abnormalities. Through an experiment, we defined the following two types of abnormal heart rate patterns.

- Rapid increase in heart rate: As shown in Figure 2, when the amount of change in heart rate increases above the specified threshold within a certain period of time, it is determined that there is a rapid increase in heart rate. The heart rate is measured every second, and the threshold of the amount of change is 10 beats.

Figure 2. Heart rate variability during rapid heart rate increase

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- High heart rate state: As shown in Figure 3, when the heart rate value stays high for a certain period, it is judged to be in a high heart rate state. The heart rate is judge as high when it is over the threshold of the average heart rate plus 10.

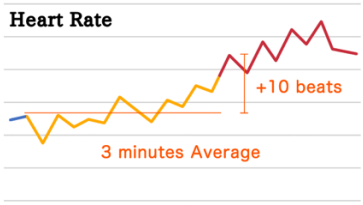

Figure 3. Heart rate variability during high heart rate state

The average heart rate is determined based on the measurement in the last three minutes. This makes it possible to compensate individual differences in the passenger's heart rate.

IV. EXPERIMENTAL EVALUATION

A. *Purpose of the experiment*

The following two hypotheses, which support the theoretical basis of the proposed method, are verified by actual driving experiments to work as expected.

- Hypothesis 1: False positives for improper driving will be reduced by looking at the match between abnormal driving patterns based on the driving behavior analysis and danger perception based on the passenger's danger perception analysis.
- Hypothesis 2: There exist some danger perceptions that do not match abnormal driving patterns, which include most of all the improper driving that strongly depends on the traffic conditions, which cannot be detected by the driving behavior analysis.

B. *Experimental methods*

In the driving experiment, the speed and angular velocity of the vehicle and the heart rate of the passenger are measured every second while driving. The vehicle's speed and angular velocity are measured using the smartphone's sensors, and the passenger's heart rate is measured using the Apple Watch's optical heart rate sensor. One experiment consists of one-hour driving. After the driving, the actual driving situation was reviewed using video and notes recorded during the driving. Figures 4-7 show how the experiment took place.

- Figure 4: smartphone sensor that measures the vehicle's angle and angular velocity.
- Figure 5: Apple Watch measuring the passenger's heart rate.
- Figure 6: video camera on the windshield recoding the vehicle's forward image.
- Figure 7: Passengers taking notes when they perceive a danger.

In this experiment, we use a prototyping system implementing the proposed method in Figure 1, except for Situation Analysis, which is performed based on the passenger's own judgement by reviewing the recorded video after the experiment.

The subjects of this experiment are 17 university students with different driving experiences, and 50 sets of experiments took place. Table 1 shows the breakdown of the driving experience of the passengers, and Table 2 shows the breakdown of the combinations of driver and passenger by driving experience.

Figure 4. Measurement of vehicle speed and angular velocity using smartphone sensors

Figure 5. Measurement of passenger's heart rate using Apple Watch

Figure 6. Recording of the vehicle's forward image using a video camera

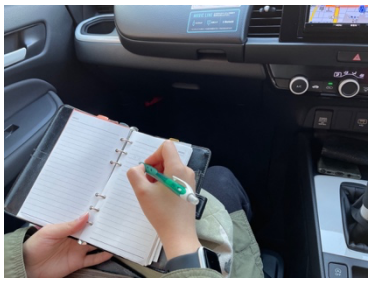

Figure 7. Passengers taking notes when they perceive a danger.

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TABLE I. BREAKDOWN OF PARTICIPANTS IN THE DRIVING EXPERIMENT

Participants' driving frequency	Number of people	Number of experiments
Drive on a daily basis	5 people	12 sets
Sometimes drive	4 people	10 sets
Don't usually drive	4 people	13 sets
No driver's license	4 people	15 sets
Total	17 people	50 sets

TABLE II. BREAKDOWN OF DRIVERS AND PASSENGERS BY DRIVING FREQUENCY

Driver's driving frequency	Passengers' driving frequency	Number of experiments
Drive on a daily basis	Drive on a daily basis	7 sets
	Sometimes drive	1 set
	Don't usually drive	8 sets
	No driver's license	4 sets
Sometimes drive	Drive on a daily basis	5 sets
	Sometimes drive	9 sets
	Don't usually drive	5 sets
	No driver's license	11 sets
Total		50 sets

C. *Results of experiments*

1) *Hypothesis 1*

A total of 56 abnormal driving patterns are detected by the driving behavior analysis. Of these, 9 cases match the passenger's danger perception. Figure 8 shows all the cases classified into four danger levels by the review of actual situation.

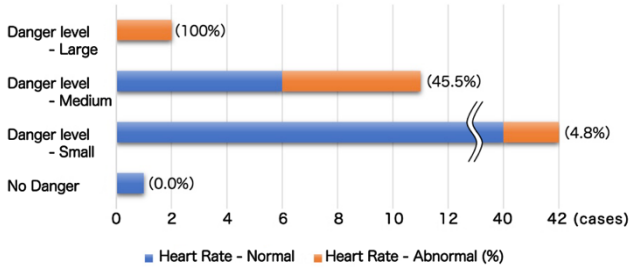

Figure 8. Relationship between abnormal driving patterns and passengers' perception of danger

Figure 1 shows that the passenger's danger perception responds in most situations where the actual danger level is high, and in contrast, the passenger's danger perception does not respond in most situations where the actual danger level is low. In this way, there is a tendency that the group of abnormal driving classified in higher danger level have more percentage of ones matching with passenger's danger perception. This proves Hypothesis 1 that false positives for improper driving in the driving behavior analysis can be reduced by using the results of the passenger's danger perception analysis.

2) *Hypothesis 2*

Of the results of detecting passenger's danger perceptions, 142 cases do not match the abnormal driving patterns. Table 3 shows the results of categorizing their causes based on the review of the actual situation one by one.

TABLE III. CATEGORIZATION OF THE ANALYZED CAUSE OF PASSENGER'S HEART RATE ABNORMALITIES

Dangerous driving	Outside threats	Emotional change	Unknown cause
18 cases	43 cases	62 cases	19 cases

Details of each item used in the classification and examples of actual occurrences are as follows.

a) Dangerous driving: 18 cases

- Anxiety or fear felt about the driver's dangerous driving (e.g., accelerating instead of stopping at a traffic light change, etc.)

b) Outside threats: 43 cases

- Perceived danger due to external factors, such as interruptions by other vehicles or pedestrians jumping out (e.g., a driver suddenly getting out of a stopped truck)
- Anxiety caused by environmental factors, such as narrowness of the road and poor visibility (e.g., glare from the western sun, thick fog, etc.)

c) Emotional change: 62 cases

- Excitement or surprise during conversation
- Drowsiness and fatigue

Hypothesis 2 proves correct, from the fact that many improper driving cases are included in the passenger's danger perceptions that do not match abnormal driving pattern, and few improper driving cases are seen that are not detected by either analysis.

However, the results showed that there are some cases other than improper driving among the passenger's heart rate abnormalities.

V. CONSIDERATIONS

From the fact that passenger's heart rate abnormalities have a correlation with the actual danger level of abnormal driving patterns, we found that our approach to using passenger's danger perceptions to reduce the false detection of improper driving is reasonable. In addition, we also found that the passenger's danger perceptions can cover most improper driving situations that the driving behavior analysis cannot detect. These results show that the proposed method can detect improper driving comprehensively and correctly.

However, the important issue to be settled to establish our proposed method is that there are some cases other than improper driving among the passenger's heart rate abnormalities, and therefore it is necessary to separate true danger perceptions from these cases to utilize them.

Moreover, we have not yet proved that the passenger's heart rate abnormalities are better than the driver's ones to capture the objective danger perception. We need to conduct

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further experiments, in which we collect both driver's and passenger's heart rate data at the same time.

Concerning the subjects of our experiments, we used almost the same aged university students, but it is necessary to use a wider variety of subjects to increase the validity of the experiments. Furthermore, to establish the proposed method, it is necessary to realize a method to analyze the passenger's danger perception that does not match abnormal driving patterns. However, it is difficult to do so at this moment because it requires a comprehensive understanding of the factors that cause the abnormal heart rate patterns to devise how to extract only true danger perceptions.

VI. CONCLUSION

In this paper, we proposed a method for detecting improper driving using driving behavior analysis, combined with the passenger's danger perception. The driving experiments showed that the proposed method can reduce the number of false positives for improper driving, and that it includes most of improper driving that the driving behavior analysis cannot detect because it strongly depends on traffic conditions. However, the passenger heart rate abnormalities include many cases not relating to improper driving, which need to be excluded.

In the future, we will further investigate the method for separating heart rate abnormality cases not related to improper driving. In addition, we will conduct more experiments to clarify the differences of causes of driver's and passenger's heart rate abnormalities and the differences in heart rate fluctuation due to driving experience.

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