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

Short paper

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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, which analyzes the driving itself from several sensor data, cannot accurately and comprehensively detect improper driving because it does not 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 and the danger perception by passengers. This method allows for comprehensive and correct detection of improper driving because passengers can objectively see both the driving and traffic situation. Experiments to apply this method showed its effectiveness. Furthermore, we conducted the other experiment to compare the passenger danger perception with driver's one. The results showed that drivers and passengers find out different types of dangerous driving, and that passengers perceive the driving more objectively. The results newly show that the use of objective analysis using the passenger's heart rate is effective in providing improvement to the driver.**

Keywords-Drive Analysis; Heart Rate; Passenger.

I. INTRODUCTION

Traffic accidents are one of the many serious problems in the modern society. One of the major causes of traffic accidents is improper driving by drivers, including driver errors and carelessness [2].

Support systems that point out the occurrence of improper driving and provide advice for improvement would be effective in preventing drivers from causing accidents. Driving behavior analysis is a method that uses sensors to measure the behavior of a car and detects abnormal driving patterns as improper driving, such as rapid acceleration and meandering. However, the driving behavior analysis is not highly accurate because only a few driving patterns can be analyzed without considering traffic situation, in which the driving takes places. Therefore, it is often the case where the driving behavior analysis wrongly detects or even misses improper driving. This problem can be a major drawback for such support systems to give appropriate advice to the drivers.

To solve this problem, we proposed a method that, in addition to the driving behavior analysis, utilizes passenger's danger perception of the traffic situation [1]. This paper fleshes out the contents to provide detailed discussion and evaluation of the method. The proposed method analyzes the variation of the passenger's heart rate to detect the passenger's danger perception, which is used to compare 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 cases where driving is deemed improper purely based on traffic situation, which cannot be detected by driving behavior analysis. The proposed method extracts such cases by analyzing the passenger's danger perceptions that do not match the occurrence of abnormal driving patterns. This allows for more comprehensive and accurate detection of improper driving.

To implement the proposed method, we devised a method to detect danger perception based on abnormal heart rate of the target. The criteria for determining heart rate abnormality are set through experiments.

An experiment was conducted to show that our method works effectively. The results show that the passenger's danger perceptions are useful to improve the accuracy of detecting the improper driving, and passenger-perception-only data, which are the passenger's danger perceptions without matching the abnormal driving patterns, include many cases of improper driving. Some, however, were caused by things unrelated to improper driving. These must be removed to determine passenger heart rate abnormalities as dangerous driving.

A comparative experiment was also conducted to compare the passenger danger perception with driver's one. The results showed that drivers and passengers find out different types of dangerous driving, and that passengers perceive driving more objectively. Moreover, it was found that drivers and passengers often perceive the different types of dangers, and so considering both may allow for a more comprehensive and accurate detection of improper driving.

In this paper, Section II describes existing methods for detecting improper driving and their problems. Section III proposes our method, and Section IV describes an experiment and its result to show the effectiveness of the method, and Section V discusses it. Section VI describes a

comparative experiment with the driver's danger perception and its results, and Section VII discusses it. Section VIII concludes this paper and discusses future prospects.

II. EXISTING METHODS FOR DETECTING IMPROPER DRIVING

A. Driving behavior analysis

Driving behavior analysis is a method that detects dangerous driving patterns by analyzing sensor data on the motion of a vehicle while driving [3][4]. 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. However, this method has a problem that it cannot comprehensively and accurately detect improper driving due to the following reasons:

- Not all abnormal driving patterns are covered.
- Traffic situations are never considered, and so it possibly detects incorrect improper driving.

Concerning the latter, this is because the criteria for determining whether a certain driving is improper or not vary depending on the traffic situation, in which it is taken place. That is, such criteria depend on the combination of driving pattern and the traffic situation.

B. Driver's danger perception

Another approach to determining improper driving is to detect the danger perception while driving from the driver's own physiological data. There exist several methods to adopt this approach, such as detecting the danger perceptions by using heart rate variability [5], monitoring some visual behaviors that characterize a driver's level of vigilance [6], and estimating the driver's emotions [7]. 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 the driving behavior and the traffic situation, it is expected to provide more comprehensive coverage than the driving behavior analysis, such as pedestrians' sudden crossing or the other vehicles' improper driving.

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

- There are individual differences in the human heart rate and the way it changes, and these individual differences may affect the accuracy of hazard detection.
- Changes in heart rate can also occur outside of danger perception, causing false detection of danger perception.
- Because drivers perceive situations subjectively, they tend not to consider their driving to be problematic. Therefore, a driver's danger perception is not suitable for use in objective determination of improper driving.

III. PROPOSED METHOD

A. Approaches

To solve the problems of the existing methods shown in the previous section, we adopt an approach to use the passenger's danger perception. Since the passenger's danger perception is considered more objective than the driver's, the combination with driving behavior analysis would be effective.

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.

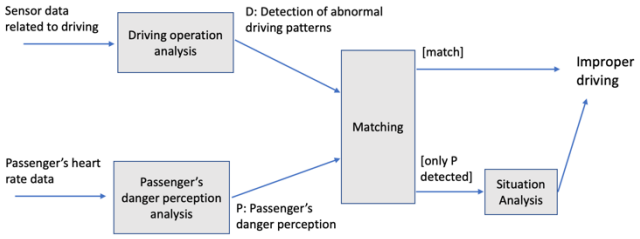

Figure 1. Proposed method for detecting improper driving using passenger's perception of danger

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. Then, 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. If they are matched, the detected patterns are determined to be improper driving. In addition, there are cases where driving is deemed improper purely based on traffic situation, which cannot be detected by driving behavior analysis. To extract such cases, the method picks up the passenger's danger perceptions that do not match the abnormal driving patterns. This allows for comprehensive and accurate detection of improper driving.

C. Passennger's danger perception analysis

The proposed method uses the danger perception analysis, analyzing the variation of the heart rate to find out 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

- 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 the high heart rate state. The heart rate is judge as high when it is over the threshold of the average heart rate plus 10.

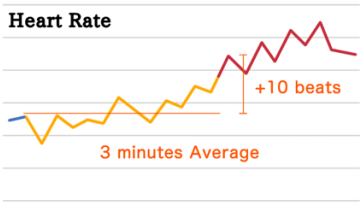

Figure 3. Heart rate variability during high heart rate state

The average heart rate is determined based on the data in the last three minutes. This compensates individual differences in the passenger's heart rate.

IV. EXPERIMENTAL EVALUATION 1

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 1-1: 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 1-2: 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. *Methods for the experiment*

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. Each driving 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, measuring 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: notes the passengers take 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.

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) *Verification of Hypothesis 1-1*

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.

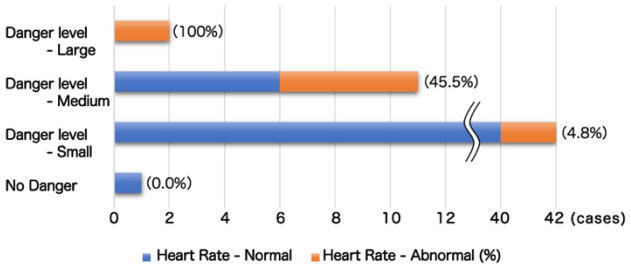

Figure 8. Relationship between abnormal driving patterns and passengers' perception of danger

Figure 8 shows that the passenger's danger perception occurs in most situations where the actual danger level is high, and in contrast, the passenger's danger perception does not occur in most situations where the actual danger level is low. There can be seen a tendency that the group of abnormal driving patterns classified in higher danger level have more percentage of ones matching with passenger's danger perception. This supports Hypothesis 1-1 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) *Verification of Hypothesis 1-2*

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 1-2 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. ANALYSIS OF THE RESULTS OF EXPERIMENT 1

From the fact that the higher danger level of abnormal driving patterns matches with passenger's heart rate abnormalities well, 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 of improper driving that the driving behavior analysis cannot

detect. These results show that the proposed method can detect improper driving comprehensively and correctly.

However, the important issues to establish our method are:

- to extract only passenger's danger perceptions from all the passenger's heart rate abnormalities.
- to analyze and classify the passenger's danger perception that does not match abnormal driving patterns.

However, the above issues are difficult to settled at this moment because they require a comprehensive understanding of the factors that cause the abnormal heart rate.

VI. EXPERIMENTAL EVALUATION 2

A. Purpose of the experiment

Because the experiments in the previous section did not measure driver's heart rate abnormality, and therefore we could not yet prove that the passenger's heart rate abnormality is more suitable for detecting objective danger perception than the driver's one.

In this section, we set the following three hypotheses, which show the validity of the proposed method adopting the passenger's danger perception by comparison with driver's one:

- Hypothesis 2-1: Driver's heart rate abnormality matches the driver's danger perception, and a danger that the driver is unaware cannot be detected by driver danger perception.
- Hypothesis 2-2: Passengers can provide a more objective danger perception than the driver, including improper driving that the driver is unaware of.
- Hypothesis 2-3: While drivers are more careful to external dangers and can perceive more small dangers than the passengers, passengers can perceive improper driving and its situation more objectively. Therefore, the passengers can find the driver's improvement points.

B. Methods for the experiment

In the experiment, we used both driver's and passenger's danger perception.

The driver's and passenger's heart rate are measured using the Apple Watch's optical heart rate sensor. After the experiment, the recorded video was reviewed, and a review was conducted based on the judgment of the driver and passengers through discussion. Figures 9 and 10 show how the experiment took place.

- Figure 9: Apple Watch, measuring the driver's heart rate.
- Figure 10: Driver and passenger reviewing the video after the end of driving.

The subjects of this experiment are 6 university students with different driving experiences, and 5 sets of experiments took place. Each experiment consists of one-hour driving. Table 4 shows the breakdown of the driving experience of the passengers, and Table 5 shows the breakdown of the combinations of driver and passenger by driving experience.

Figure 9. Measurement of driver's heart rate using Apple Watch

Figure 10. Driver and passenger reviewing the video after the end of driving

TABLE IV. BREAKDOWN OF PARTICIPANTS IN THE DRIVING EXPERIMENT

Participants' driving frequency	Number of people
Drive on a daily basis	1 people
Sometimes drive	2 people
Don't usually drive	1 people
No driver's license	2 people
Total	6 people

TABLE V. 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	0 set
	Sometimes drive	1 set
	Don't usually drive	0 set
	No driver's license	1 set
Sometimes drive	Drive on a daily basis	0 set
	Sometimes drive	0 set
	Don't usually drive	1 set
	No driver's license	2 sets
Total		5 sets

C. Results of experiments

1) Verification of Hypothesis 2-1 & Hypothesis 2-2

A total of 107 abnormalities were detected by the driver's and passenger's danger perception. Table 6 shows the results of classifying the causes of the abnormalities one by one by checking the actual situation, along with the presence or absence of abnormal heart rate of the driver and passenger.

TABLE VI. COMBINATION OF HEART RATE ABNORMALITIES AND CAUSE CLASSIFICATION RESULTS

Abnormal heart rate	Cause			
	Dangerous driving	External factors	Environmental factors	Other
Both	3 cases	2 cases	1 case	8 cases
Driver only	4 cases	21 cases	4 cases	39 cases
Passenger only	3 cases	4 cases	7 cases	11 cases
Total	**10 cases**	**27 cases**	**12 cases**	**58 cases**

Of the cases where heart rate abnormalities were detected, the following is a breakdown of the actual abnormal driving patterns found.

- Both parties had a heart rate abnormality: 3 cases
- Heart rate abnormality only in the driver: 4 cases
- Heart rate abnormality only in the passenger: 3 cases

Table 7 shows the breakdown of the awareness of improper driving by the driver and passenger in these 10 cases.

TABLE VII. RESULTS OF CLASSIFICATION OF HEART RATE ABNORMALITY AND AWARENESS.

Abnormal heart rate	Awareness		
	Both	Driver only	Passenger only
Both	2 cases	1 case	0 case
Driver only	1 case	3 cases	0 case
Passenger only	0 case	0 case	3 cases

In all cases where abnormalities were detected in the driver's heart rate, the driver himself was aware that he did improper driving. On the other hand, in cases where no abnormalities were detected in the driver's heart rate, the driver was not aware of improper driving. As shown above, the driver's heart rate abnormality has a strong correlation with the driver's awareness of improper driving.

In addition, there were 3 cases of improper driving that the driver was unaware, but the passenger felt that the driving was dangerous, and the abnormal heart rate of the passenger made it possible to detect it.

2) Verification of Hypothesis 2-3

The major causes of the driver's and passenger's heart rate abnormality that did not match abnormal driving patterns as follows.

- Driver: **external** factors: 21 cases, including other vehicles, pedestrians, or other factors may pose a danger to my vehicle, and I was worried and alarmed.
- Passenger: **environmental** factors: 7 cases, including narrow roads, poor visibility, and other factors caused dangerous driving conditions that made me feel anxious and uncomfortable.

There are 21 cases of driver's danger perception caused by external factors were detected. In many of these cases, the driver quickly predicts the possibility of danger based on the surrounding situation.

On the other hand, there are 7 cases of passenger's danger perception caused by environmental factors were detected. These cases capture passenger's anxiety and discomfort about driving in a particular traffic situation.

VII. ANALYSIS OF THE RESULTS OF EXPERIMENT 2

Firstly, 10 dangerous driving situations were detected by the driver's improper driving. Among them, the drivers were aware of their own improper driving when it was detected by the driver's heart rate abnormality, and, on the other hand, improper driving that the driver was unaware was not detected by the driver's heart rate abnormality. This supports Hypothesis 2-1 since the driver's awareness of improper driving is related to whether the driver's heart rate abnormality exists or not.

Secondly, there were 3 cases of improper driving that the driver was unaware of, but the passenger was aware of the danger. In these cases, heart rate abnormality of the passenger was detected. This supports Hypothesis 2-2 since the passenger objectively perceived the situation to recognize improper driving. The driver's danger perception detects many dangers from external factors. While driving, drivers need to pay more attention to their surroundings than their passengers. For this reason, we consider that the driver can notice existing or potential dangers caused by external factors or the possibility of such danger. On the other hand, passengers are aware of many danger perceptions from environmental factors. Thus, drivers and passengers pay attention to different things, and perceive different types of dangers.

Thirdly, we speculate that drivers are unconsciously aware of their surroundings and are alert to the possibility that an external factor may actually occur. On the other hand, passengers objectively perceive dangers in the current situation. This suggests that the passenger's danger perception is more suitable for recognizing the actual dangerous traffic situation and for providing drivers for effective advice for improvement. This supports Hypothesis 2-3.

Furthermore, since drivers and passengers perceive different types of dangers, utilizing both types of danger perceptions may allow for more comprehensive and accurate detection of improper driving.

Only five experiments were conducted, in which only a few dangers were detected. Therefore, it appears to be necessary to conduct more experiments to get more robust results in danger perception by both drivers and passengers. 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.

VIII. Conclusion and Future Outlook

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 addition, a comparative experiment of driver's and passenger's danger perception showed that passengers can more objectively perceive improper driving that the driver is unaware of. And also, since the types of danger that drivers and passengers can perceive are different, utilizing both of the two factors may provide a more comprehensive and accurate detection of improper driving.

In the future, we will improve our method based on the findings in this paper into a comprehensive and accurate method for detecting improper driving. We also aim to implement a driving improvement support system using this method that provides effective advice to drivers.

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