Driver behavior monitoring. Part II. Detection of driver's inattentiveness under distracting conditions

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Abstract

This paper discusses a method for detecting driver's inattentiveness. Our system for monitoring driving behavior in a fixed-based driving simulator measures the following data: body movement, driving posture, eye and head movements, blinks, instep position of the right leg, plethysmograms, facial temperature, steering angle, and strokes of the acceleration and brake pedals. Among several possible causes of driver's inattentiveness, such as over-trust in driving support system, lack of vigilance against traffic conditions, an important one may be occurrence of external events that requires a driver to perform an additional cognitive task. A typical example of such an event may be a negotiation with somebody on a serious matter. Such inattentiveness may occur even if he or she is a careful driver, since addition of a cognitive task usually increases driver's mental workload significantly. This paper investigated effects on driver's behavior when a driver is distracted by a secondary cognitive task that demands high mental workload. Two types were found as effects of performing mental arithmetic task on fixations. Both types of effects can be seen in one driver depending on traffic conditions. It has been found that likelihood of occurring type 1 or type 2 effects depends on a driver. With these findings, this paper developed and improved a driver-adaptable algorithm for detection of being in high tension. However, there were several drivers for whom the algorithm did not work well. It is thus necessary to develop a method to detect a driver's psychological state change into risky ones in a sensor fusion manner.

Résumé

INTRODUCTION

In order to reduce the number of traffic accidents, it is important to develop proactive safety technologies that provide a driver with an appropriate assist in a situation-adaptive manner (3). Development of real-time method for detecting driver's hypo vigilance or inattentiveness is a vital issue to implement such technologies. For example, a drowsiness detection system has been proposed in (1).

Driver's inattentiveness may be caused by external events that require a driver to perform a non-driving and possibly distracting cognitive task. Typical example may be a negotiation with somebody on a serious matter. Such cognitive tasks may increase driver's tension appreciably. There are some studies that have investigated effects of such tasks on driver's behavior. However, some contradiction may be found among the observations in those studies. For example, it has been found that fixations were shorter when a driver was imposed to perform a cognitive task (2). On the other hand, (8) has argued that fixations became longer during a cognitive task. That means it is difficult to develop a method for real-time detection of driver's being in high tension.

This paper proposes a method for detection of increase in driver's tension by taking into account driver-specific characteristics. Among several sensing data collected in our driving simulator, this paper discusses evaluating driver's tension through driver's eye movement.

DRIVER BEHAVIOR MONITORING SENSORS

FIGURE 1 shows our driving simulator (DS) which can simulate driving in an expressway. The system records automatically the following data: steering angle, and strokes of acceleration and brake pedals.

FIGURE 1 A driving simulator.

Our system for monitoring driving behavior consists of the following devices:

(i) Tactile sensors.
Sensor sheets are installed on the seat cushion and the seat back rest. The sensor sheets monitor the distribution of force on the seat and on the seat back rest. Driving posture and frequency of body movement can be measured with the sensors.

(ii) Eye and head trackers.
It is possible to identify the point at which a driver is looking by combining the data obtained with these sensors. Frequency of blinks may also be calculated.

(iii) A laser displacement sensor.
Once the driver hits the brake, his or her pedal stroke is recorded in the simulator. In order to determine whether a driver is prepared to hit the brake or not in a potentially risky driving condition, the instep position of the right leg is monitored with this sensor installed near the acceleration pedal.

(iv) Finger/ear plethysmograms measurement system.
Plethysmograms are used to evaluate driver's mental workload.

(v) An infrared thermal imaging camera.
The temperature at the driver's nose-tip is measured with this camera. It is shown that increase in the mental workload may cause the decrease in the tissue blood volume and the temperature at the nose-tip (6), (9).

(vi) Video cameras.
Driver's facial expression and driving posture are recorded.

Sensing devices described in the above are integrated in order to identify drivers' behavior via sensor fusion approach.

EYE MOVEMENTS UNDER DISTRACTING CONDITION

Experiment 1

Recarte and Nunes (8) examined effects of concurrent cognitive tasks on driver's eye fixations. They showed that fixations were longer during the spatial imagery task. On the other hand, Iida and Ito (2) showed that fixations were shorter when a driver was imposed to perform a mental arithmetic task during driving. These studies seem to contradict each other. In this experiment, we investigate effects of a concurrent cognitive task on fixations.

Method

Four graduate or undergraduate students (A to D) participated in the experiment. Each participant repeated a 16-minute run for four times with the DS. In each run, a participant was asked to perform a mental arithmetic (MA) task during the following 2-min time intervals, [2, 4], [6, 8], [10, 12], and [14, 16] (FIGURE 2). During an MA task phase, a participant was given a pair of one-digit numbers to be manipulated with addition/subtraction. Concretely speaking, a question such as “Eight plus five equals to?” is given repeatedly by the experimenter every three seconds. Participants needed to answer the questions immediately when they were given.

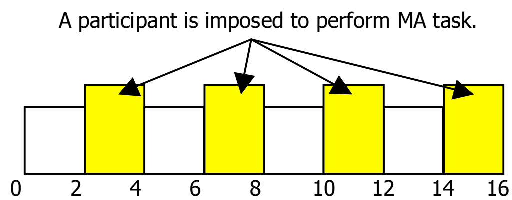
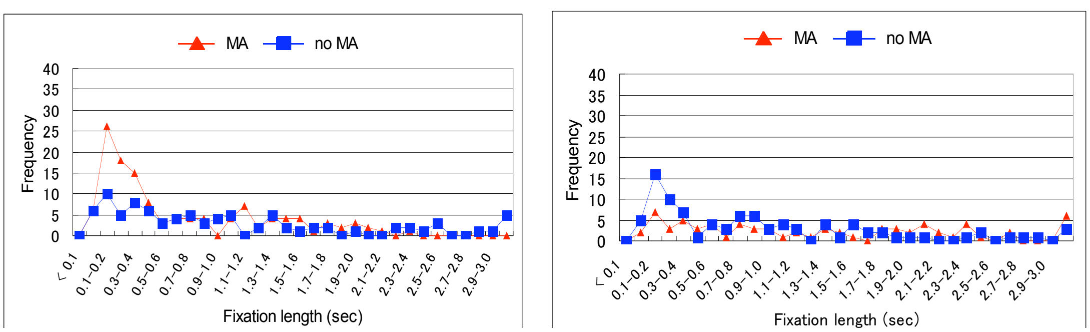


FIGURE 2 Schedule of the Experiment 1.

In order to extract pure effects of MA task, peaceful traffic conditions were given to the participants. In other words, there were no dangerous events such as a rapid deceleration of the forward vehicle or a dangerous cut-in from the next lane.

Results and Discussion

Two types of effects were observed on fixations: (1) longer fixations during an MA phase, and (2) shorter fixations during an MA phase. Typical examples of type 1 and 2 effects are shown in FIGURE 3. Note here that either type 1 or type 2 effect may occur in a same person. For example, type 1 effect occurred when the traffic was relatively congested.

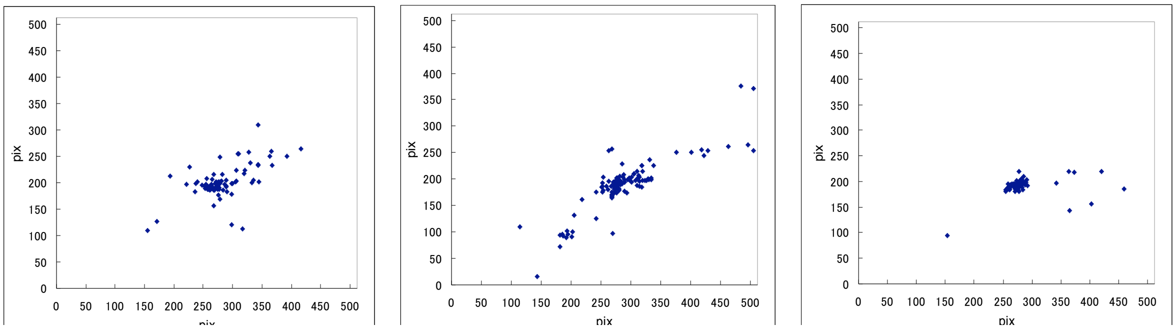


(a) Type 1 effect (4th run of participant C with ACC during [8, 12])

(b) Type 2 effect (4th run of participant C with ACC during [12, 16])

FIGURE 3 Examples of type 1 and 2 of effects on fixations.

When the type 1 effect occurs, the range at which a driver looks is wider than that under no-MA condition (e.g., see, FIGURE 4(b)). On the other hand, driver’s visual functional-field was reduced vertically and horizontally when the type 1 effect occurred, as shown in FIGURE 4 (c).



(a) no MA (b) Type 1 effect of MA (c) Type 2 effect of MA

FIGURE 4 Example of 2-D distribution of fixation points.

Experiment 2

The purpose of Experiment 2 is to investigate which type of the effects occurs more frequently in a natural driving condition that includes dangerous events, such as a steep cut-in of some other vehicle from the next lane.

Method

Ten graduate and undergraduate students (*a* to *j*) participated in Experiment 2. Each participant repeated a 6-min drive for 32 times. Among 32 runs, 16 runs were given under MA condition, and the remaining 16 runs under no-MA condition. The MA task was the same as the one in Experiment 1. Under MA condition, participants were asked to perform the MA tasks during the time interval of [2, 6]. The experimental schedule is shown in TABLE 1.

TABLE 1 Schedule of Experiment 2.

Day	1								2			3			4		
Run	1	2	3	4	5	6	7	8	1	• • •	8	1	• • •	8	1	• • •	8
MA	Y	N	Y	N	Y	N	Y	N	N	• • •	Y	Y	• • •	N	N	• • •	Y

After completion of all runs, a participant was asked to answer four questions on difficulty in driving when he or she was imposed to perform the MA task: (Q1) “Evaluate difficulty in driving, compared with no-MA condition,” (Q2) “Evaluate difficulty in allocating attention to the forward, compared with no-MA condition,” (Q3) “Evaluate difficulty in allocating attention to the right hand side, compared with no-MA condition,” and (Q4) “Evaluate difficulty in allocating attention to the backward, compared with no-MA condition.” FIGURE 5 is the scale used to solicit answers to the questions.

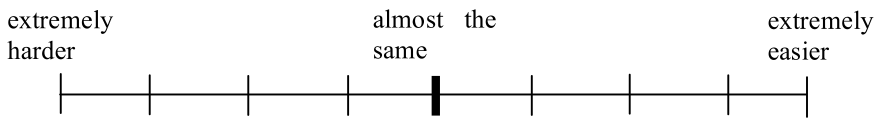
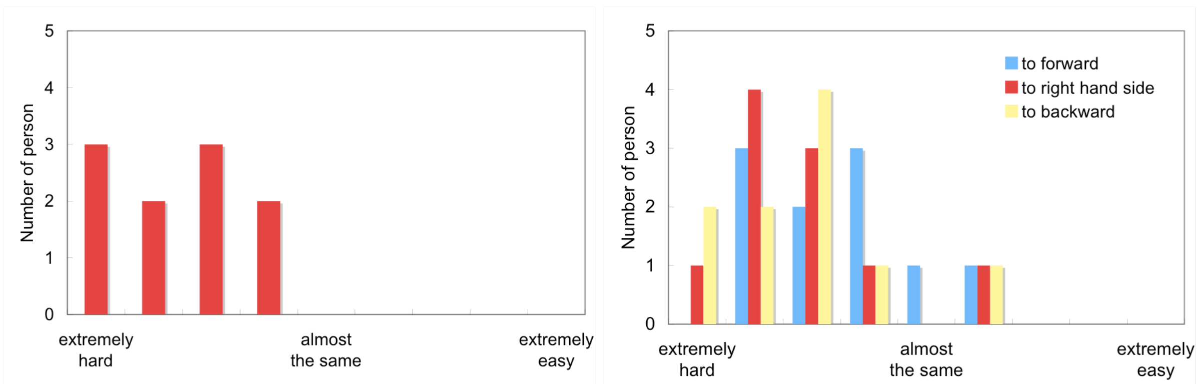


FIGURE 5 Subjective rating scale on difficulty in driving.

Results

FIGURE 6 depicts the results of subjective ratings. Driving under MA condition was perceived difficult for every participant (FIGURE 6(1)). FIGURE 6(2) suggests that allocating attention to the right hand side or the backward, in particular, were harder than that to the forward.



(1) Total difficulty (Q1) (2) Difficulty in paying attention (Q2-4)

FIGURE 6 Subjective rating of difficulty in driving when MA task is imposed.

The perceived difficulty in allocating attention to other vehicles may be observed through changes in distribution of fixation lengths (FL). A 6-min run is divided into three phases as shown in FIGURE 7. In order to extract the feature of the effect, we categorize fixations into three classes: see, FIGURE 8. Proportion of fixations in an interval to all is calculated every phase. When a type 1 effect occurs, the proportion of fixations in Interval 1 to all increases. On the other hand, the proportion decreases when a type 2 effect happens.

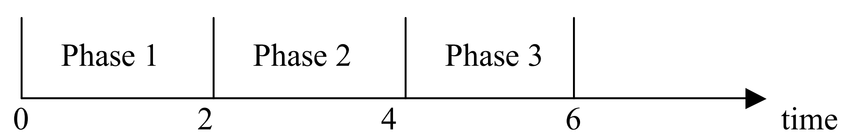


FIGURE 7 Three phases in a 6-min run.

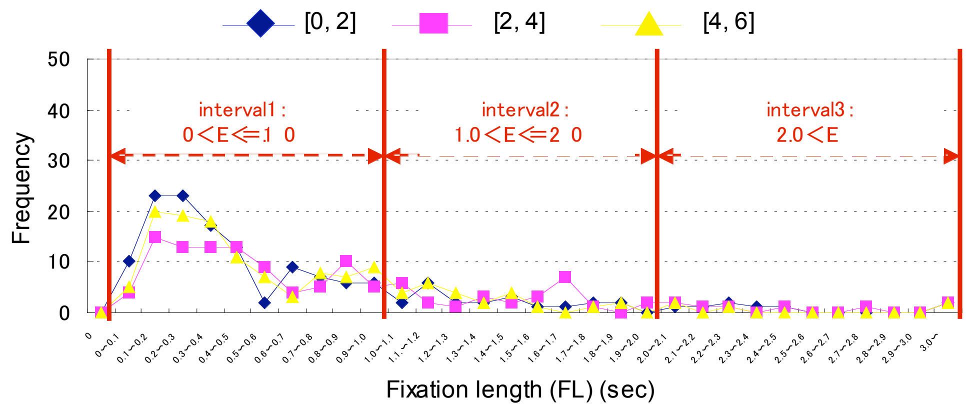
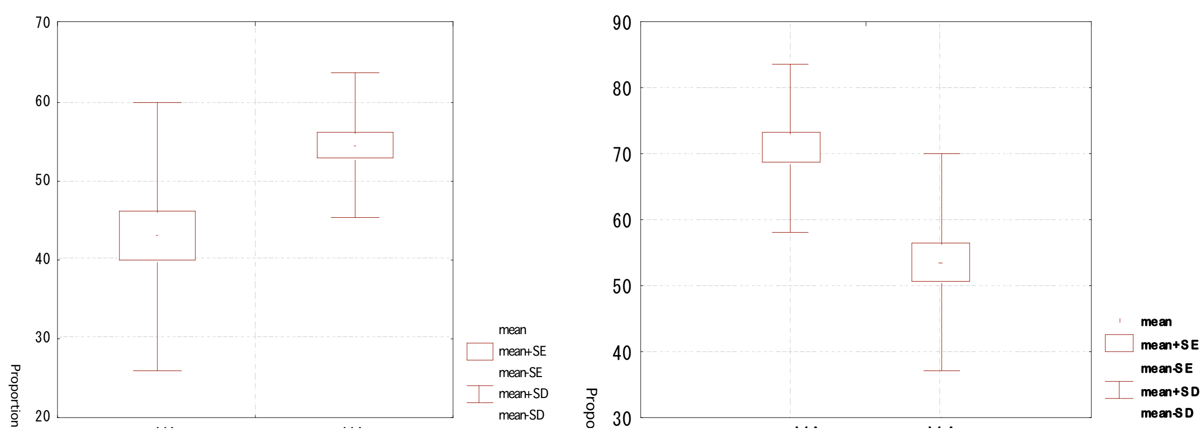


FIGURE 8 Categorization of fixation length.

One-way ANOVA has been conducted on the proportion of fixations in Interval 1 to all using the data in Phases 2 and 3 for each participant. FIGURE 9 depicts the effect of performing the MA task on Participant *e* ($F(1, 31)=7.76$, $p=0.009$). The main effect of the secondary task was significant for Participants *a*, *c*, *f*, *g*, *i*, and *j*. These participants were categorized according to types of the effects:

- Type 1: FL in Interval 1 increases under MA condition
- Type 2: FL in Interval 1 decreases under MA condition

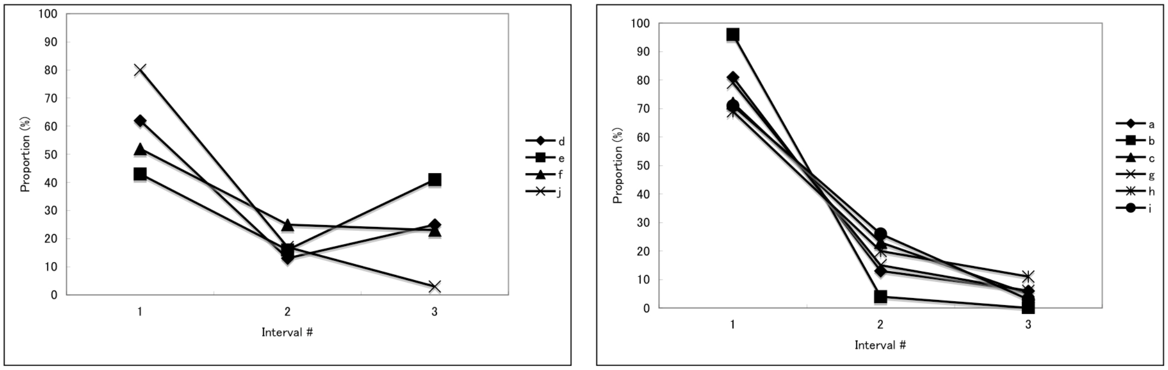
Participants *e*, *f*, and *j* were categorized into Type 1, and Participants *a*, *c*, *g*, and *i* into Type 2. Some drivers are likely to exhibit type 1 effect, while the others are prone to show type 2 effect.



(1) Type 1 (Participant *e*) (2) Type 2 (Participant *i*)

FIGURE 9 Effects of performing MA task on proportion of fixations in Interval 1 to all.

FIGURE 10 depicts that the proportion of fixations in Interval 1 is smaller in Type 1 (Participants *e*, *f*, and *j*) than in Type 2 (*a*, *c*, *g*, and *i*) under no-MA condition. This result suggests that a driver may be categorized into Type 1 if he or she usually tends to gaze a point. A driver who moves his or her eyes frequently, on the other hand, may be categorized into Type 2. Thus, according to eye movement data under no-MA conditions, Participant *d* is categorized into Type 1 and Participants *b* and *h* into Type 2, as shown in FIGURE 10.



(a) Type 1 (b) Type 2

FIGURE 10 Proportions of fixations in intervals 1-3 to all under no-MA condition.

ALGORITHM FOR DETECTING PERFORMANCE OF MA TASKS

Let f_1 be the proportion of fixations in Interval 1. Assume f_1 is normally distributed. Let m and s^2 denote the mean and variance of f_1 under no-MA task condition, respectively. An "ordinary range" is defined in this paper as the interval $[m - s, m + s]$. If type 1 effect occurs in a driver, f_1 may be greater than $m + s$. On the other hand, if type 2 effect happens in the driver, f_1 may be smaller than $m - s$.

According to the above thought, we developed Algorithm 1. The key idea is as follows:

"For Type 1(2) driver, the driver's tension is regarded as being high when the value of calculated f_1 by using the data during a phase is greater (smaller) than $m + s$ ($m - s$)."

Algorithm 1 was applied to the data of each participant. The parameters m and s are estimated from the data in Phases 2 and 3 under no-MA conditions. TABLE 2 depicts the performance of the algorithm. False alarm rates are reasonably low: the expected value of false alarm rate is about 15% due to the setting of the threshold ($m+ s$ or $m- s$). However, the hit rate of some participants was low. One of possible reasons would be that the two distributions (MA condition and no-MA condition) heavily overlap with each other.

TABLE 2 Hit and false alarm rates of Algorithm 1

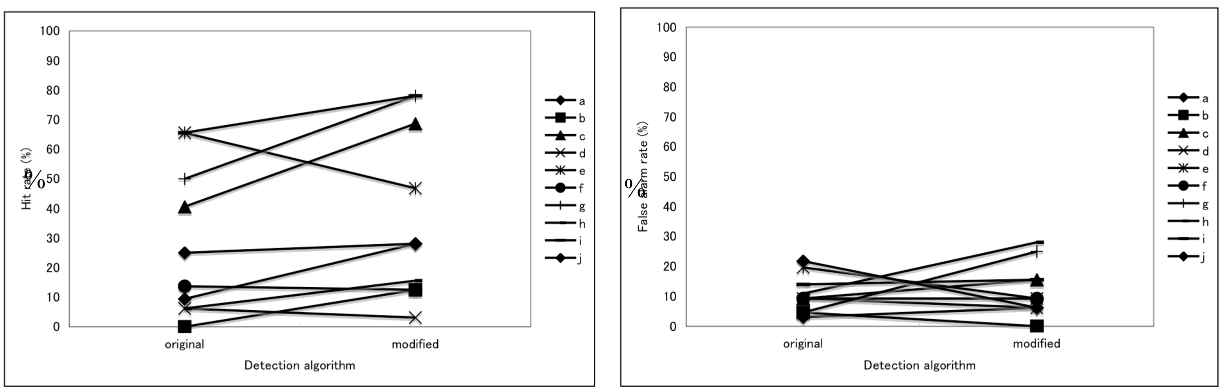
	Type 1				Type 2					
Participant	*e*	*f*	*h*	*j*	*a*	*b*	*c*	*D*	*g*	*i*
Hit rate	21/32 (65.6%)	6/32 (13.7%)	2/32 (6.2%)	8/32 (25.0%)	3/32 (9.4%)	0/32 (0.0%)	13/32 (40.6%)	2/32 (6.2%)	16/32 (50.0%)	21/32 (65.6%)
False alarm rate	12/64 (19.7%)	6/64 (9.3%)	7/64 (10.9%)	14/64 (21.8%)	2/64 (3.1%)	3/64 (4.6%)	9/64 (9.3%)	6/64 (9.3%)	3/64 (4.6%)	9/64 (14.0%)

Note: False alarm rate is calculated from the all no-MA phases (16 drives under no-MA condition x 3 phases + 16 driver under MA condition x 1 phase (Phase 1))

Taking the overlap into consideration, a modified algorithm has been developed (Algorithm 2). Let Δf_l be the difference between f_l in Phase 2 or 3 and that in Phase 1. Let *m*' and *s*' denote the mean and the standard deviation of Δf_l, respectively. The key idea of Algorithm 2 is as follows:

"For Type 1(2) driver, the driver's tension is regarded as high when the value of calculated Δf_l by using the data during a phase is greater (smaller) than $m' + s'$ ($m' - s'$)."

FIGURE 11 shows hit and false alarm rates of Algorithm 2 applied to the data in Experiment 2. Hit rates increased in many participants. However, there were six participants whose hit rates were still low. Some other approaches are necessary for this kind of drivers.



(a) Hit rate (b) False alarm rate

FIGURE 11 Comparison between Algorithms 1 and 2

The detection rate can be improved by adjusting the threshold appropriately. Let $m' + \alpha s'$ or $m' - \alpha s'$ be the threshold in Algorithm 2. TABLE 2 is the case in which α=1. Several values of α have been applied to the test for Participants *c, e, g*, and *i*. TABLE 3 shows one of results where α=0.43. The hit rates increased while the false alarm rates remained low.

TABLE 3 Result of tuning the threshold in Algorithm 2 (α=0.43)

	Type 1	Type 2		
Participant	*e*	*c*	*g*	*i*
Hit rate	19/32 (59.3%)	24/32 (75.0%)	27/32 (84.4%)	28/32 (87.5%)
False alarm rate	3/64 (4.7%)	6/64 (9.4%)	11/64 (17.2%)	7/64 (10.9%)

CONCLUDING REMARKS

Using a driving simulator with driver behavior monitoring sensors, two types were found as effects of mental arithmetic task on fixations. Both types of effects can be seen in one driver depending on traffic conditions. It has been found that likelihood of occurring type 1 or type 2 effect depends on a driver. With these findings, this paper developed and improved a driver-adaptable algorithm for detection of being in high tension. However, there were several drivers for whom the algorithm did not work well. It is thus necessary to develop a method to detect a driver's psychological state change into risky ones in a sensor fusion manner.

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