Estimating and Visualizing Drivers' Emotions Using the Internet of Digital Reality

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***Abstract*—Recently, the development of self-driving technology has progressed rapidly. However, self-driving cars have not yet become widespread. Thus, with an aging population, accidents such as road rage and acceleration and brake accidents are likely to continue. Stress is one key reason for such dangerous driving. Thus, technologies must be developed to provide mental support to drivers as required. In this study, we considered estimating driver emotions as a first step along these lines. To this end, we developed a technology to estimate emotions by collecting data on biological signals such as brain waves, heart rate, body movement, and data on a driver's operating status while they are driving. In addition, we introduce a Positive and Negative Affect Schedule (PANAS) to express the psychological states experienced by drivers. We further present the results of an analysis of data on a driver's emotions from PANAS and data obtained from electroencephalogram (EEG) readings and other biological signals from a car. In addition, the relationship between this experimental environment and the Internet of Digital Reality (IoD) is described.**

***Index Terms*—Brainwave, EEG, Heartbeat, ECG, Accelerometer, CAN, Driving Simulator, Emotion Estimation, PANAS, IoD, CogInfoCom**

I. Introduction

Although various driver assistance technologies are being developed, human beings remain the primary drivers of road vehicles. Naturally, people can be influenced by various emotions and may drive dangerously or make mistakes, as shown in Fig. 1. In addition, new technologies designed to help drivers feel comfortable and safe while sharing the road must be widely developed and adopted in the future. Road rage [1] and other dangerous driving behaviors have been increasing in recent years. In June 2017, a driver who exhibited road rage on a highway was arrested for killing victims [2]. Anger and other driving factors may have led to this behavior.

Therefore, considerable research has recently been conducted on the effects of emotions on driving behavior. For example, a study at Hiroshima University determined that anger and sadness tend to cause excessive driving speed, whereas neutral emotions contribute to speed suppression. In addition, positive emotions such as happiness did not correlate with driving speed [3]. According to one study [4], driver behavior in anger-arousing situations on the road was characterized by "aggression," "suppression," and "hostility." The study also showed that drivers who had never been involved in a traffic accident were more likely to be angry. Therefore, we aimed to develop a service designed to reduce driver fatigue by estimating drivers' psychological states and encouraging them to take breaks or change their environment. Therefore, to measure a driver's emotions, we constructed an environment to collect biometric signals such as electroencephalogram (EEG) and electrocardiogram (ECG) data. In addition, we collected data related to driving operations recorded using a driving simulator (DS). These data were analyzed to obtain an index for measuring driver stress, as shown in Fig. 2.

The remainder of this study is organized as follows. Section 2 describes related research. Section 3 presents the results of some previous experiments, and Section 4 describes the experimental setup of the present work. Section 5 provides an overview of the experiments and discusses their results. Finally, Section 6 concludes by summarizing our findings and suggesting some avenues for future research.

II. Related works

A. *Drivers' emotions on the road*

Drivers' emotions are a major cause of traffic accidents. Emotions such as hurriedness, impatience, and irritation are believed to trigger dangerous driving behaviors. Several studies have addressed driver hazard avoidance. In many cases, researchers have provided safe driving functions such as sounding an alarm when dangerous conditions such as drowsiness are detected. While these methods detect visible external behaviors, some studies have also attempted to estimate emotions from brain waves. However, to the best of our knowledge, no system has been developed to estimate drivers' emotions, although some preliminary solutions have been proposed to determine drivers' emotional state [5]. Estimating a driver's emotions using facial expression recognition is challenging. However, a combination of emotion recognition from facial expressions and biometric signals representing the electrical characteristics of the skin is effective.

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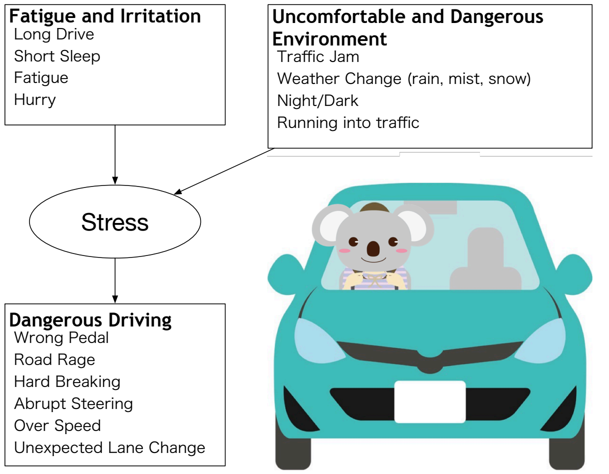


Fig. 1. Research target.

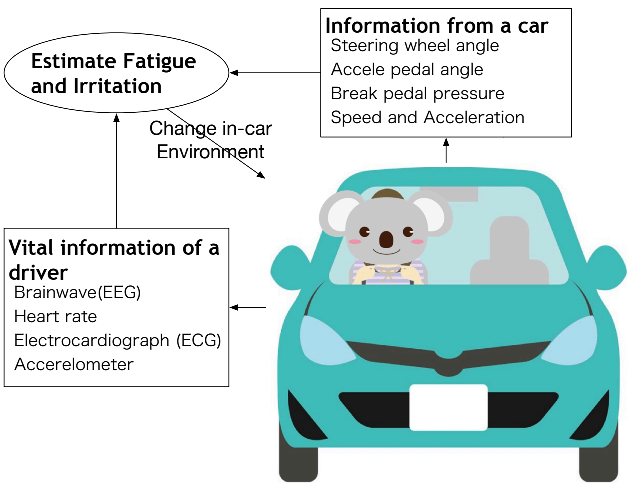


Fig. 2. Developing technologies.

In [6], the authors showed that their results were 114% better than those obtained using facial expressions and 146% better than using the electrical activity of the skin alone. Some studies have attempted to read emotions from ECGs. However, these data are imprecise and can only be used as a support [7]. Several studies have been conducted on the use of EEG signals. The National Institute of Technology developed a portable EEG system and used a driving simulator to characterize brain waves before a person begins driving in a dangerous situation [8].

B. IoD and CogInfoCom

Recently, a new concept called the “Internet of Digital Reality (IoD)” was proposed [9, 10]. In this study, we define IoD as follows. “The Internet of Digital Reality is a set of technologies that enables digital realities to be managed, transmitted, and harmonized in networked environments (both public and private), focusing on a higher level of user accessibility, immersiveness, and experience with the help of virtual reality and artificial intelligence. Connections among various cognitive entities are also handled at the end-user level of virtual reality displays and software and at the levels of network protocols and network management, physical media (wired or wireless), hardware interfaces, and other equipment.” IoD is an extension of cognitive info-communication (CogInfoCom) [11, 12].

CogInfoCom considers the link between the research areas of info-communications and cognitive sciences and various engineering applications that have emerged as a synergic combination of these sciences. Information and Communications Technology (ICT) convergence involves three traditional fields, including media, informatics, and communications [13]. CogInfoCom is placed between cognitive informatics and communication to realize a virtual world.

Several studies have been conducted on driver support using CogInfoCom and the IoD. For example, [14] introduced hybrid driving strategy optimization, which is a simulation method combined with CogInfoCom. Another study [15] reviewed existing standards and guidelines and explained the gap between the system and a complete description of the system and its environment, that is, in the context of CogInfoCom, the user. In addition, [16] integrated advanced information technologies such as eye tracking, virtual reality, and neural networks for cognitive task analysis as a precursor to behavioral analysis of humans. In Section IV, we explain the present work from the perspective of IoD and CogInfoCom.

III. Our Previous Work

We conducted a prior study on estimating drivers’ mental states in 2019 [17]. We measured the EEG signals of drivers while driving using a DS on September 20 and 26, 2019. The participants were three students attending Utsunomiya University, three employees of Utsunomiya University, and five employees of Toyota Customizing and Development Co., Ltd. We used a single-electrode EEG sensor developed by Mindsall Inc. [18]. This EEG sensor is lightweight and can send a signal to a receiver, such as a PC, via Bluetooth Low Energy (BLE). In the EEG sensor, a brainwave sensor application-specific integrated circuit (ASIC) called TGAM [19] was used, the primary chip of which detected brainwave data and calculated attention and mediation values. In the experiment, the test subjects drove 12 laps in a DS while wearing an EEG sensor. The course was a motor-racing circuit from a real-life scenario. The weather conditions varied during the drive. In some cases, it also rained. To provide additional excitation and influence user behavior, a loud noise was generated using an amplifier and played in the last corner of the test field.

Fig. 3 shows the attention and mediation data of an examinee familiar with driving. The following information can be observed from the figure:

- attention was stable,
- it was unaffected by rain or noise, and
- during the accident (course out), attention was lost.

Fig. 4 shows the attention and mediation data of an examinee who was unfamiliar with driving. Attention and mediation are outputs of TGAM. Attention reflects the strength of the beta wave over one second, and mediation reflects the strength of the alpha wave over one second. The following information may be observed from the figure.

- Attention increased with laps.
- Drivers were affected by noise.
- When it started to rain, attention decreased immediately.
- During the accident, attention was lost.

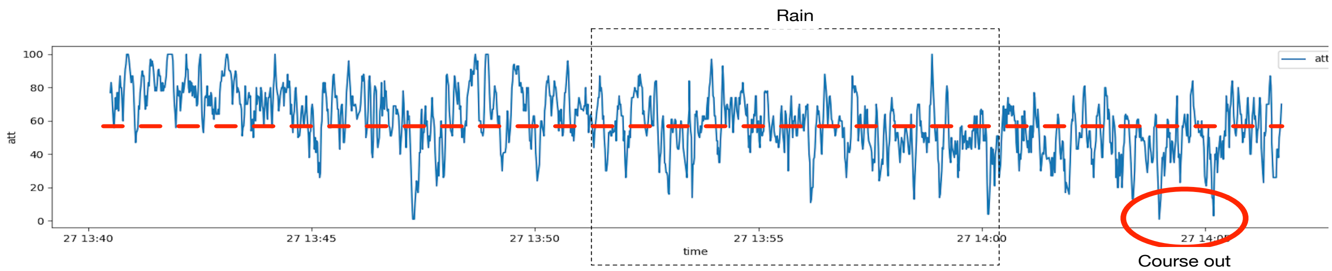


Fig. 3 Brainwave data (attention) of a driver familiar with driving.

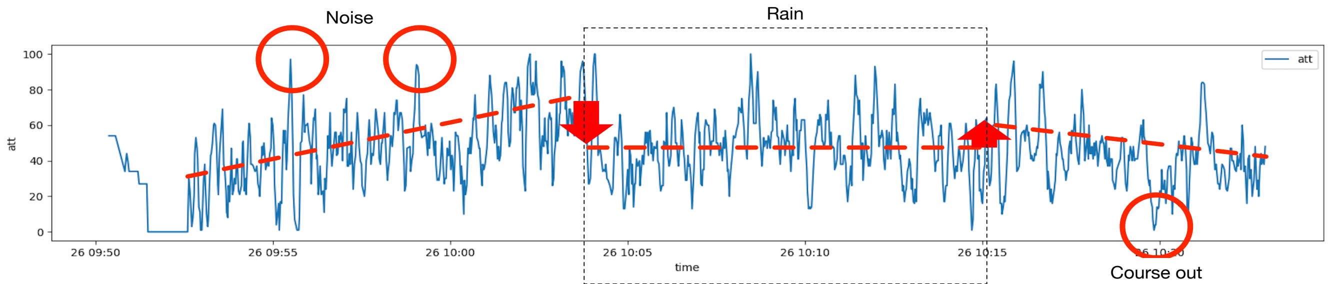
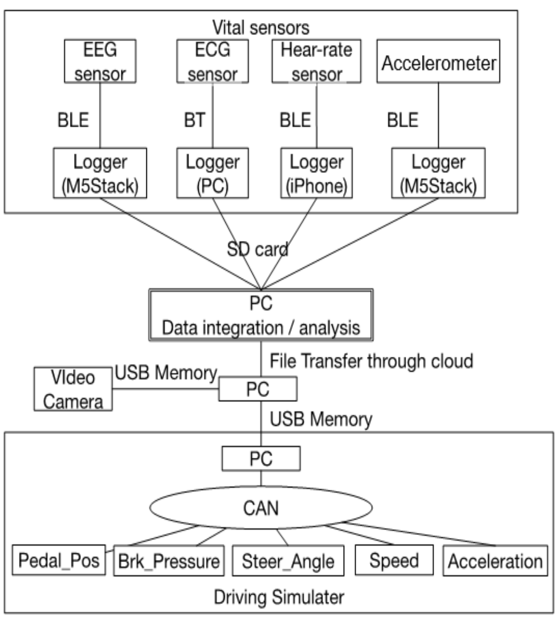


Fig. 4 Brainwave data (attention) of a driver unfamiliar with driving.

- Attention recovered when it stopped raining. However,



it gradually decreased. We believe that this was caused by fatigue.

From these results, we inferred some aspects of the drivers' mental states from the EEG data.

IV. Experimental Setup

A. Overview of the experiment

First, we designed an experimental environment to achieve the following:

- measure the movement of a driver using an accelerometer that could send data via BLE.
- record the drivers' EEG readings, and
- measure their heart rate.

Biosignals related to mental states can be measured in various ways, such as by measuring cortisol levels in saliva. However, to measure the biosignals continuously, we chose the above three datasets, including movement, EEG signals, and heart rate information.

TABLE I
POSITIVE AND NEGATIVE AFFECT SCHEDULE (PANAS)

Positive affects	**Negative affects**
Attentive	Hostile
Active	Irritable
Alert	Ashamed
Excited	Guilty
Enthusiastic	Distressed
Determined	Upset
Inspired	Scared
Proud	Afraid
Interested	Jittery
Strong	Nervous

TABLE 2
OVERVIEW OF PANAS

	Positive affect	**Negative affect**
High Score	Concentrated Fun Active	Painful Discomfort
Low Score	Lethargy Sadness	Relaxed Calmness

From the DS, we collected the following data:

- accelerator pedal position,
- brake pressure,
- steering angle, and
- speed and acceleration.

Fig. 5 shows an overview of an experimental system. We primarily used BLE and M5stack [20] to collect biosignals. Driving data from the DS were collected through a controller area network (CAN, ISO 11898-1, and ISO 11898-2) [21, 22].

B. Estimating mental state using PANAS

The Positive and Negative Affect Schedule (PANAS) is a scale of emotions represented by 20 keywords that contain positive and negative emotions [23]. Table I lists the keywords used in this study. In addition, the positive and negative effects can be roughly recognized, as described in Table II (according to [24]). A high positive effect indicates an active situation, and a low negative effect indicates relaxation. In other cases, this situation means that the subject is not happy. We defined biosignals and information regarding the car's operation as relevant to the driver's mental state. However, all information must be linked to understand the driver's mental state in order to achieve the goals of this study. Unfortunately, the data from brainwaves, motion sensors, and information from the DS are analog. Another key is thus required to explain the mental state and add meaning to the data. Therefore, we decided to use the PANAS to investigate how drivers' mental states changed before and after driving in the DS. That is, we considered how fatigue from driving affected drivers.

Several studies have used the PANAS to estimate mental states. The authors of [25] explained the results of measuring stress during commuting using EEG data and PANAS. The results showed a high correlation between the EEG and PANAS scores. Reference [26] explained the effect of nonverbal biometric cues and signals in online communication using biometric data and PANAS, and [27] explained the effects of biofeedback on stress management. The PANAS was used to measure psychological effects before and after intervention. Reference [28] explained the results of measuring emotions in older patients with dementia using biosignals. They used the K-PANAS (the Korean version) as a measurement tool.

TABLE III
COURSE SETTING FOR TOKYO METROPOLITAN EXPRESSWAY ON DS

Time set for brightness	Duration (min.)	Weather, Light
14:00	5	Daytime, Fine, Light OFF
16:00	10	Twilight, Rain (70%), Fog(80%), Wet road (70%), Light OFF
18:00	10	Evening, Rain (70%), Fog(80%), Wet road (70%), Light OFF
20:00	10	Night, Rain (70%), Fog(80%), Wet road (70%), Light OFF
21:00	10	Night, Fine, Light ON,

TABLE IV
COURSE SETTING OF PARIS ON THE DS (COMBINATION OF TRAFFIC AND PEDESTRIANS)

Traffic
Traffic jam
Stop at traffic light
Increase Traffic
Lane change

Pedestrian
Walking
Running
Stop

C. Relation between IoD/CogInfoCom and this research

Fig. 6 shows the relationship between this study and IoD/CogInfoCom. The left-hand side of the figure concerns this study. Various pieces of information were gathered from the driver and the DS. The data were sent to the measurement environment through an ad hoc network using BLE and then analyzed. In addition, the PANAS data were added to the

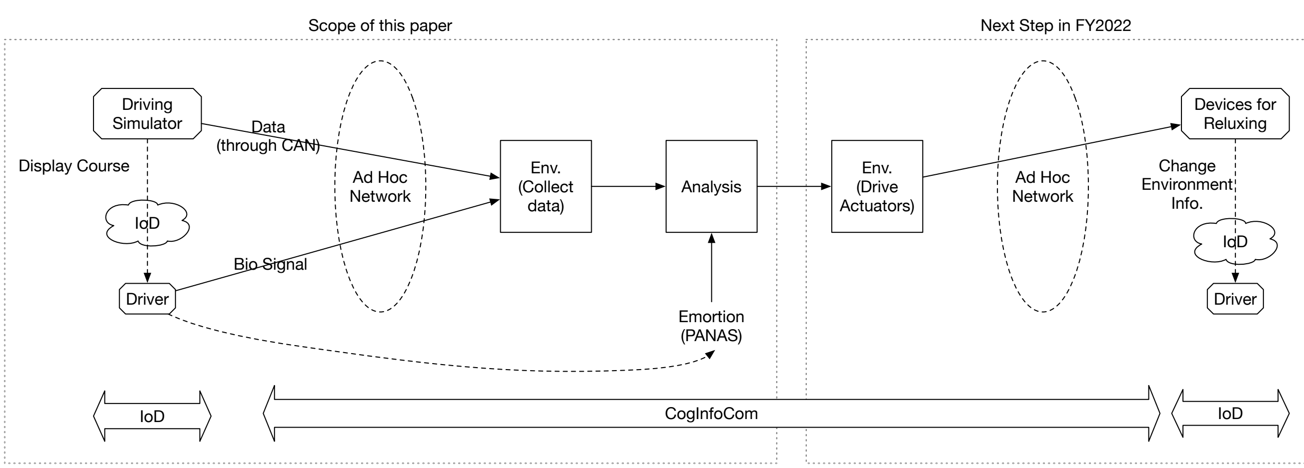


Fig. 6 System diagram for experiments.

analysis. As shown in Fig. 6, the part of the measurement environment shown on the left illustrates a function of the IoD that provides driver information regarding the route to take and road conditions to change stress levels. On the right, various devices that provide stimulation to the driver, such as music, fragrance, and lighting, present another function of the IoD. Information flow in the intervention process can be understood as CogInfoCom.

Based on the results of this analysis, signals were sent to devices (actuators) to control environmental variables such as music, fragrance, and lighting to provide drivers with awareness and stimulation and to reduce stress and fatigue.

D. *Experiment courses*

We set up two courses for the experiment, one representing part of the Tokyo Metropolitan Expressway and the other simulating part of a road in Paris.

1) Tokyo Metropolitan Expressway

As shown in Table III, the course of the Tokyo Metropolitan Expressway was set to darken as the day turned to night using the image-processing functions of the DS. In addition, weather variations such as rain, fog, and road surface reflections were added. By stimulating the driver with these changes and making the situation more stressful, the system was set up to facilitate the understanding of changes in biological signals such as brainwaves and body movements.

2) Paris

Simulation of Urban Mobility (SUMO) [29], an open-source road traffic simulator, was used to generate various traffic in the DS video and conditions similar to actual roads. We used SUMO to set up two situations on Paris roads that closely resembled driving on real roads. One involved a person suddenly jumping into traffic, and the other presented a situation in which the traffic gradually became congested, similar to actual road conditions. The reason for these two settings was to create situations in which the driver must be very careful while driving and pay attention.

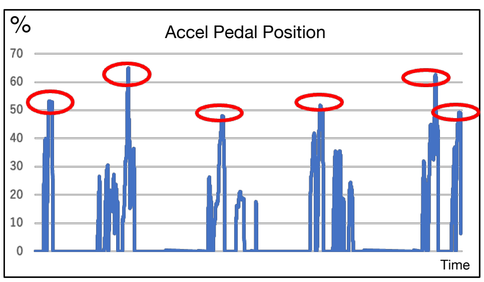
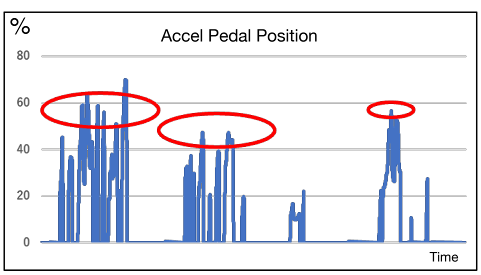


Fig. 7. Accelerator pedal (start).



Fig, 8. Accelerator pedal (end).

TABLE V
PANAS*

	Upset	Scared
Start	7	1
End	8	10
Difference (End-Start)	1	9

*Only items with large differences in PANAS are shown.

V. EXPERIMENT AND RESULTS

This experiment was performed for three days (2021.12.7, 2022.1.12, and 2022.1.18). We conducted the experiment on two simulated test courses, including the Tokyo Metropolitan Expressway and the streets of Paris. Each driving session lasted 45 min.

The experimenter was a student who occasionally drove (female, age 21). Before and after driving in the DS, the participants completed a PANAS checklist on a 20-point scale. The results of the biosignal, DS data, and PANAS analyses in various cases are provided as follows.

A. *Accelerator Pedal and Mental State (Paris)*

Figs. 7 and 8 show the data of the accelerator pedal position

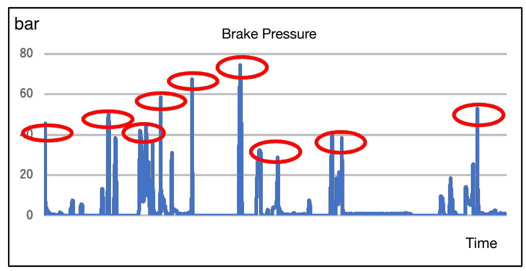


Fig. 9. Brake pressure (2021.12.7).

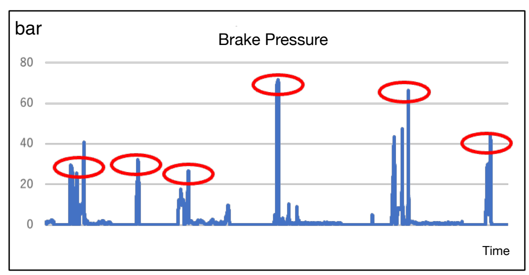


Fig. 10. Brake pressure (2022.1.18).

TABLE VI-1
PANAS (2021.12.7)

	Jittery	Attentive
Start	1	1
End	8	12
Difference (End-Start)	7	11

TABLE VI-2
PANAS (2022.1.18)

	Jittery	Attentive
Start	5	3
End	1	1
Difference (End-Start)	-4	-2

before and after driving in the DS on the Paris course in 2022.1.18. The driver appeared to be driving carefully in the first lap, stepping on the accelerator pedal six times (Fig. 7). In contrast, at the end of the final lap, the driver continued to step on the accelerator pedal, attempted to adjust while stepping on the accelerator pedal, and showed an affect that was not calm during the operation (Fig. 8).

Towards the end of the driving simulation, the roads often become crowded, and people sometimes jump into traffic. Here, drivers should proceed more carefully because of fatigue from driving for long periods or under stressful conditions, such as pedestrians jumping on the road unexpectedly. The PANAS showed that after driving, some values of the PANAS items indicating tiredness, such as "upset" and "scared," were higher (Table V). This suggests that a relationship may exist between accelerator pedal data and PANAS.

B. Brake Pedal and Mental State (Paris)

We compared the brake pressure data for 2021.12.7 (Fig. 8) and 2022.1.18 (Fig. 9). Comparing Figs. 9 and 10, the number of braking events in Fig. 9 was nine, whereas that in Fig. 10 was six. The braking strength exceeded 40 bars eight out of nine times, as shown in Fig. 9, whereas in Fig. 10, half of the cases were below 40 bars.

We now focus on the "jittery" and attentive items in PANAS, which indicate significant changes. In the situation shown in Fig. 9, a significant difference may be observed in the positive direction for these two items at the end of the drive (Table VI-1). In contrast, the situation shown in Fig. 10 was slightly negative (Table VI-2). This result indicates that the frequency and intensity of braking are related to emotions such as nervousness or attention. Higher frequency and intensity of braking may indicate increased tension and accelerated fatigue, as it shows an increased sense of nervousness and attention. Conversely, less frequent or weak braking may indicate less attention and more dangerous driving. In either case, if the change is more significant than usual, some stimulus must be provided to the drivers to get their attention and encourage them to be careful.

C. Accelerator Pedal and Mental State (Tokyo)

Here, we explain the relationship between the accelerator pedal and PANAS values when driving on the Tokyo Metropolitan Expressway course based on an experiment conducted on 2021.12.7.

As shown in Fig. 11, the driving and accelerator pedal operations were stable. Rainfall during the subsequent 20 min led to poor visibility. Thus, the driver's operation of the accelerator pedal was less intense, and she focused on driving.

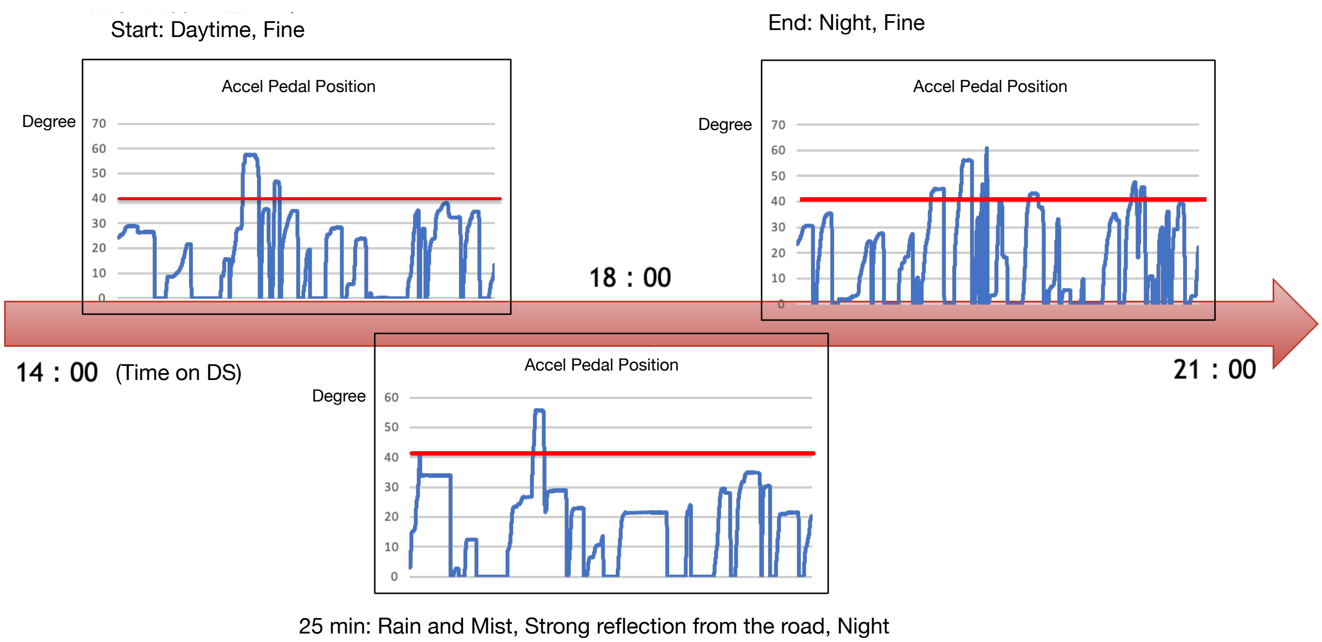


Fig. 11. Accelerator pedal (2021.12.7).

TABLE VII
PANAS (2021.12.7)

	Positive						Negative				
	Active	Enthusiastic	Interested	Excited	Proud	Attentive	Irritable	Jittery	Afraid	Guilty	Scared
Start	13	11	14	13	17	15	3	1	15	1	1
End	1	1	1	1	1	1	18	18	20	19	18
Difference (End-Start)	-12	-10	-13	-12	-16	-14	15	17	15	17	17

Near the end of the drive, the depression of the accelerator pedal tended to exceed 40° in a few locations, while it was nighttime, and the weather had improved. Rough driving can be attributed to fatigue caused by long-distance driving and poor concentration while driving in rainy weather.

Table VII presents the PANAS analysis results. After driving, positive affect scores decreased, and negative affect scores increased. This indicates that the driver was tired after driving for a long distance. Therefore, the Tokyo Metropolitan Expressway course differed from the Paris course in its lack of people and traffic, and attention significantly decreased after driving. This significantly differed from the conditions of the Paris simulation. Conversely, we infer that the presence of people and cars results in more cautious driving.

In addition, the driver's attention appeared to decrease over time, particularly as feelings of fatigue, upset, and fear intensified.

D. *Brainwaves and Mental State (Tokyo)*

We analyzed the relationship between brainwaves and PANAS based on an experiment conducted on 2022.1.12. Fig. 12 displays the values of the alpha wave (from 8 to 14 Hz) and beta wave (from 14 to 30 Hz), which are the results of the Fast Fourier Transformation (FFT) of the brainwaves. As shown in Fig. 12, the beta wave increased and the alpha wave decreased in the second half of each lap. Based on this result, the driver was evidently concentrated at the end of the lap, and her stress level increased.

The results of PANAS shown in Table VIII indicate the following.

- No change was observed in the Upset or Scared affects, which indicated negative effects such as fatigue.
- The Irritable item score was one before driving and 18 after driving, indicating that significant stress occurred.

E. *Heart rate and Mental State (Tokyo, Paris)*

Finally, we conducted a comparative analysis of heart rate and PANAS. As shown in Fig. 13, the driver's heart rate increased at the beginning of both the Paris and Tokyo Metropolitan Expressway experiments. However, at the end of the drives, her heart rate decreased when driving on the Tokyo Metropolitan Expressway and increased when driving on roads in Paris.

The PANAS data showed that the positive affect scores after driving were lower with a decreasing heart rate (Table IX-1) and higher with an increased heart rate (Table IX-2). There may be a correlation between an increase in heart rate and positive

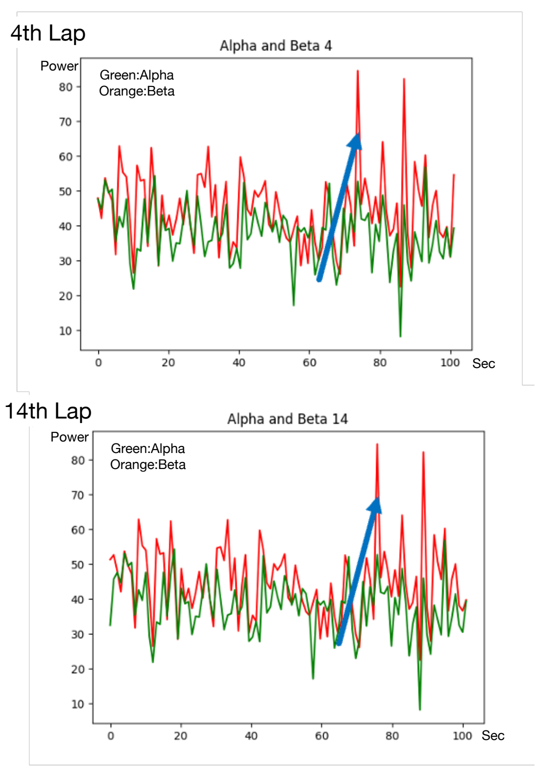


Fig. 12. Brainwaves (2022.1.12).

TABLE VIII
PANAS (2022.1.12)

	Irritable	Afraid	Upset	Scared
Start	1	1	1	1
End	18	1	1	1
Difference (End-Start)	17	0	0	0

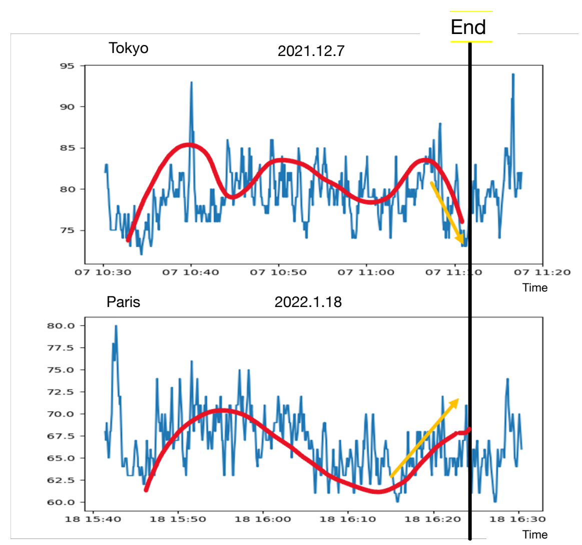


Fig. 13. Heart rate (2021.12.7 and 2022.1.18).

TABLE IX-1
PANAS (TOKYO)

		Strong	Inspired	Alert	Determined
Tokyo	Start	3	12	6	6
	End	1	9	1	1
	Difference (End-Start)	-2	-3	-5	-5

TABLE IX-2
PANAS (PARIS)

		Strong	Inspired	Alert	Determined
Paris	Start	1	1	1	1
	End	10	10	10	11
	Difference (End-Start)	9	9	9	10

affect scores. We infer that the variations in heart rate and changes in positive effects are correlated.

VI. Conclusions

In this study, we have presented the results of an analysis of data on a driver's emotions obtained from PANAS, EEG readings, and other biological signals, as well as data from a car. In addition, we have explained the relationship between the experimental environment and the IoD.

Owing to the difficulty in visualizing the driver’s emotions from biosignals and vehicle data alone, PANAS data were analyzed using other sensors to estimate emotions. The results show that the PANAS can be used as an indicator for estimating a driver’s emotions.

This research provides a method for obtaining information on psychological states from car operation data and heartbeat information, which can be obtained relatively easily without special devices.

Although stress varies individually, most drivers typically experience some stress, regardless of their level of familiarity or experience with driving. Providing a comfortable driving environment for all drivers is possible by estimating stress and developing specialized technologies for this purpose.

Based on these findings, we can describe some promising directions for future studies.

Because the ECG sensor did not work well in the experimental environment, the ECG data were analyzed with PANAS to obtain a more detailed relationship between the drivers’ emotions and the data from ECGs, EEGs, other biosignals, and driving.

Given that the PANAS questionnaire can only be administered before and after the test drive, we plan to investigate methods to administer the questionnaire while participants are driving.

Moreover, the extent to which brain waves and other biosignals would differ when obtained while a subject was driving a real car compared to a DS must be investigated.

In future work, we aim to contribute to the development of devices that change abient aspects such as light, fragrance, lighting, music, and conversation according to a driver’s estimated mental state. Moreover, we plan to investigate how brainwaves change in response to these factors and the degree of improvement in terms of mental state that may be expected.

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