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Analysis for cooperative characteristics of driving by two human drivers using personality diagnosis

Yota Hasebe, Ryojun Ikeura, Soichiro Hayakawa and Shigeyoshi Tsutsumi

Graduate School of Engineering Department of Mechanical Engineering
Mie University
1577 Kurimamatiyatyo,Tsu-shi,Mie
418M138@m.mie-u.ac.jp

summary-Currently, the automatic driving technology of cars is developing rapidly. In the automatic driving level where the system monitors the driving environment under certain conditions such as highways and executes driving operations, it is necessary for the system to take over the sovereignty of driving from the system to the human at the system limit and to continue driving. At this time, the system and humans share driving sovereignty, so if the transfer of driving sovereignty is not carried out smoothly, driving operation after movement may become unstable and lead to an accident. In order to solve this problem, in this study, in order to transfer authority smoothly, we measured the cooperative driving behavior of two persons in the situation where authority transfer was necessary, and analyzed them from the viewpoint of personality diagnosis and energy flow. The experiment carried out using a driving simulator. We used an experimental device for experiments on cooperative driving of two humans with two steering wheels, two accelerator pedals and two brake pedals.

Index Terms – drivers, personality diagnosis, cooperative driving,

I. INTRODUCTION

Currently, with the advancement of autonomous driving technology, the level of autonomous driving is being defined. According to the definition of SAE (Automobile Engineers Association), this level is classified into 6 levels [1] (Table 1) from 0 to 5. Among them, at level 2, a plurality of controls in the front-rear direction and the left-right direction of the vehicle are performed, but the driver needs to continue to monitor the driving environment, and the driver needs to keep the steering as a restriction. At level 3, all acceleration, control, and steering are performed on the system side, and the driver is driving only at the system's functional limits. The major difference between the two levels is whether or not human monitoring is required when the system is operating. From level 3 onwards, the system performs all operational tasks when the system is operating.

Most of the automated driving technologies that are in practical use are up to level 2, and various companies are now aiming to establish and commercialize technologies of level 3 or higher. One of the problems for practical use of Level 3 is the transfer of driving sovereignty from the system side to the driver side at the time of system limit. When the driving sovereignty is transferred from the system to the driver, the system and the driver share the driving sovereignty. Consequently, if the intentions of the system and the driver are different, the stability may decrease and a serious accident may occur.

Therefore, this authority transfer must be able to be performed smoothly and safely while driving. In the future, with the widespread use of Autonomous Driving Level 3 vehicles, it is likely that such accidents will soon occur immediately after the transition of driving sovereignty.

In fact, during a test run of autonomous driving, a rear-end collision occurred immediately after the transfer of driving sovereignty from the system to humans [2].

Various researches are being conducted by each research institution on this issue. Merat, Mok et al. Showed that when switching sovereignty, the driver needs about 5-15 seconds to safely take over the sovereignty from the system [3][4]. In addition, Beukel et al, researched the relationship between situational awareness and crisis avoidance ability, focusing on the characteristics of driver steering and acceleration [5], and Hashiba et al.'s research focused on the number of sovereignty changes and the amount of torque when switching [6]. Also, in a study by Saito et al, he proposed a method for improving steering stability and vehicle stability through shared control between a human and a system called “Shared Control”, and examined a method for shifting driving sovereignty to the driver [7]. In this way, solutions are being sought from various directions for the problem of shifting the driving sovereignty from the automatic driving system to the driver.

From previous research, this research focused on the coordination of matching behavior with other human beings and the applicability of responding flexibly to things in response to the problem of shifting driving sovereignty from systems to humans. We are assuming automatic driving level 3, transfer of driving sovereignty between people through the joint driving state. This level is the passing of driving sovereignty between the car and the person, that is, the system and driver. However, we focused on the ability to coordinate the movements of other people and the adaptability to respond to things in a timely manner, and we thought that it would be possible to switch between driving sovereignty smoothly and safely by driving between humans.(Fig.1) Therefore, we aim to find smooth and safe driving characteristics and ultimately apply to automated driving systems by performing cooperative driving between humans and acquiring the process of passing driving sovereignty.

Furthermore, personality diagnosis is performed on all subjects in order to develop a system adapted to different personalities for each driver, unlike machines. Then, we will conduct experiments to clarify what the safe driving sovereignty of each driver is without any sense of incongruity. The goal is to

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analyze the characteristics of the driver sovereignty at that time and finally develop an automatic driving algorithm suitable for each driver's personality.

Table.1 AUTOMATION LEVEL

	LEVEL 0	LEVEL 1	LEVEL 2	LEVEL 3	LEVEL 4	LEVEL 5
What does the human in the driver's seat have to do?	You are driving whenever these driver support features are engaged- even if your feat are of the pedals and you are not steering			You are not driving when these automated driving features are engaged - even if you are seated in"the driver's seat"		
	You must contantly supervise these support features; you must steer, brake or accelerate as needed to maintain safety			When the feature requests, you must drive	These automated driving features will not require you to take over driving	

Fig.1 Switching between people's driving sovereignty

II. PERSONALITY DIAGNOSIS

In this study, we used Dennou Inc.'s OD type safety test [8] to investigate the personality of each subject. The OD type safety test is one of driving aptitude tests, which answers several problems (composed of work inspection and questionnaire inspection, etc.) and derives the degree of safe driving and points to be noted for each driver.

There are 16 measurement items in the OD type safety test. This time, in order to see the difference of the experimental result by the personality of the subject, the experimental result is evaluated about the self-centeredness in the item of the personality characteristic among the items of the OD type safety test. The reason is that self-centeredness can affect the driving behavior easily, and it will be important for the transition of driving sovereignty between two people. This test was performed on all subjects in advance.

Self-centeredness measures the degree of selfishness and self-paced ness in all things, and is evaluated in three stages A to C. Interpretation of each evaluation is A evaluation "can cooperate with people, can think of things from the standpoint of the other party", B evaluation "somewhat more cooperative, but sometimes self-oriented behavior", C evaluation “There is a selfish place, and there is a strong tendency to think about things centered on oneself”.

A pair of A evaluations seems to be able to perform cooperative driving, but in developing an automatic driving system that suits all human characteristics, whether the passing of driving sovereignty between C evaluations is really bad I felt it was necessary to investigate.

In this study, there are a pair of subjects whose self-centricity item in the personality trait is a C evaluation, and a pair of subjects whose one self-centricity item is an A evaluation and the other is a C evaluation. We analyzed how the difference in the delivery of driver sovereignty changes.

III. EXPERIMENT ENVIRONMENT

i. Driving environment

Unless it is fully automatic driving, there is a scene where the sovereignty of driving operation is transferred to the driver when the system limit of the automatic driving system is reached. From the previous research, we assumed a situation where it was known in advance that the system would change from a scene where it was possible to perform automatic operation to an impossible scene, rather than a scene where it suddenly encountered system limitations. Therefore, the driver's sovereignty will be transferred slowly.

As a driving environment assuming this situation, driving behavior that changes lanes near the expressway interchange and gets off the expressway was set as an experiment. As shown in Fig.2, the road environment has a lane width of 3.5m, a lane change section of 300m, and an exit lane of 100m.

ii. Experimental method

In this experiment, there are four test subjects. Among them, one person was assigned the A evaluation for the personality characteristic self-centered item, and the remaining three were the C evaluation self-centered items. The person whose personality characteristic self-centricity is A is subject a, others 3 persons are subject b, c, and d. Subject a (system role) and subject b (driver role) are paired as "pair1". A pair of the subject c (system role) and the subject d (driver role) is “pair2”.

In this study, the subjects called driver A and driver B, and driver A is assigned to the system role and driver B is assigned to the driver role.

At the start of the driving experiment, first drive the vehicle to the vicinity of the branch point set by driver A alone. Next, communication is taken from the system side before the start of lane change, and the timing for starting cooperative driving is adjusted between subjects. Then, at the point where the driver B grasps the steering wheel and starts the driving operation, the cooperative driving is started. After the cooperative driving starts, the two subjects operate the linked steering wheel to change the lane. When the lane change is completed, driver A releases his hand from the steering wheel and finishes the experiment with only driver B performing the driving operation.

In advance, the subjects were instructed to drive with two people until the lane change was completed, and explained that the subjects could freely decide the timing of the start and end of driving by communication with each other. Before starting the experiment, the subject practiced alone until he got used to the driving simulator, then explained the lane change operation on the expressway by two subjects, and started the experiment.

. Experimental device

Fig.3 shows a schematic diagram of the equipment. In order to allow two people to drive, we designed and manufactured an experimental device that used a timing belt and linked two steering wheels. (Fig.4)

The experiment is performed by a drive simulator, and the execution environment is displayed on the monitor. In order to observe the communication between the two, we record it with a video camera so that we can confirm it later. In addition, in order to prevent communication other than conversation, a partition plate is installed between the two people so that the subjects cannot see each other's steering and simulation screens. The acceleration and deceleration of the vehicle is performed by an accelerator pedal and a brake pedal, and both subjects can operate the accelerator pedal and the brake pedal. As the operation signal to the car, the one with the larger amount of depression is adopted.

The torque applied to the driver, the rotation angle of the steering wheel, the depression amount of the accelerator pedal, and the depression amount of the brake pedal are measured as operation data of each driver. These measurement data were imported into a PC, the vehicle dynamics were calculated based on the vehicle operation information, and the actual driving environment as seen by humans was displayed on the monitor. (Fig.5)

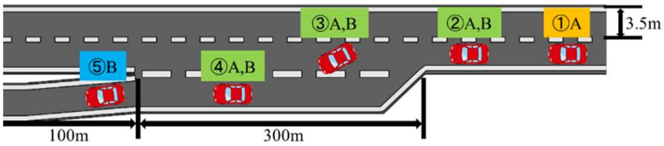
. Experimental procedure

Subjects will conduct a total of 10 experiments. After the subjects practiced the same course as the experiment twice in advance, the contents of the experiment were explained.

IV. JUDGMENT OF DRIVER SOVEREIGNTY STATUS

Regarding the judgment of sovereignty when transferring driver sovereignty from driver A to driver B, we pay attention to the exchange of energy between the two. We calculated the average torque from the measured torque of each driver and the angular velocity from the steering angle. We propose a method to calculate the energy per unit time using the calculated value and classify it into the following three states. Then, the process of passing the driving initiative is analyzed by adapting to the data obtained from the experiments.

The average torque of each driver is calculated by the following formula.



①Main line normal driving with driver A alone
②Driver B holds the steering wheel and intervenes in driving
③Lane change (steering in cooperative driving, restoration of vehicle orientation)
④End of lane change (cooperative driving, communication end)
⑤Normal driving with driver B alone

Fig.2 Lane change by cooperative operation

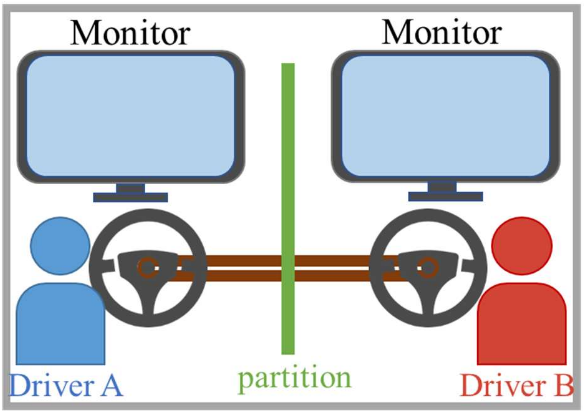
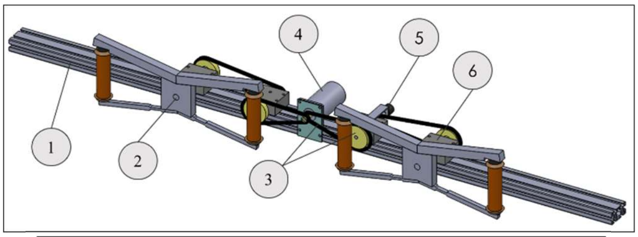


Fig.3 Outline of experiment



①Foundation rail ② handle ③ Timing belt , Timing pulley ④ motor ⑤ Potentiometer ⑥ Bearing block

Fig.4 Linked Steering

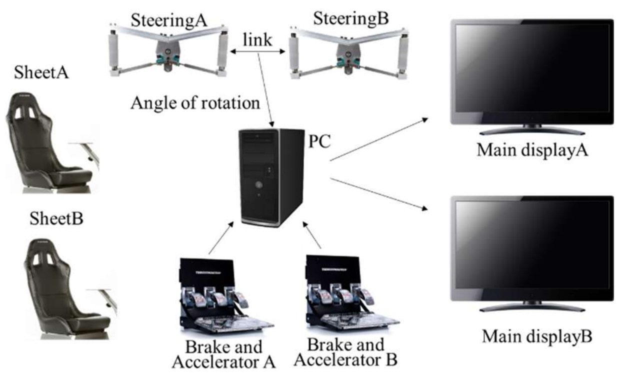


Fig.5 Outline of experiment device

torque applied to the steering wheel than driver B, and inputs torques in opposite directions each other. Since the driver A is

$$\bar{\tau}_A(t) = \frac{1}{\Delta T}\int_{t-\Delta T}^{t} \tau_A(s)ds \qquad (1)$$

$$\bar{\tau}_B(t) = \frac{1}{\Delta T}\int_{t-\Delta T}^{t} \tau_B(s)ds \qquad (2)$$

(τ_A=Torque that Driver A gives to steering, τ_B=Torque that Driver B gives to steering,ΔT=Judgment time interval (0.1s))

Further, the steering angular velocity $\omega(t)$ is calculated from the following equation by differentiating the steering angle $\theta(t)$.

$$\omega(t) = \frac{1}{\Delta T}(\theta_t - \theta_{t-\Delta t}) \qquad (3)$$

Using these $\bar{\tau}_A(t)$,$\bar{\tau}_B(t)$ and $\omega(t)$, the driver sovereignty states are classified into three "driver A energy supply state", "driver B energy supply state", and "both driver energy supply states".

"Driver A energy supply state" is a state as shown in the following equation.

performed in opposite directions each other. Since the driver B is steering more strongly than the driver A, the steering is

$$\omega|\bar{\tau}_A(t)| > |\bar{\tau}_B(t)| \text{ , } \bar{\tau}_A(t) \times \omega(t) > 0, \quad \bar{\tau}_B(t) \times \omega(t) < 0 \qquad (4)$$

This driver A supply state is a state in which driver A has higher performing a stronger steering operation, the steering is operated in the direction in which the driver A has turned. Therefore, it can be said that the driver A is leading from the viewpoint of energy.

"Driver B energy supply state" is a state as shown in the following equation.

$$\omega|\bar{\tau}_A(t)| > |\bar{\tau}_B(t)| \text{ , } \bar{\tau}_A(t) \times \omega(t) < 0, \quad \bar{\tau}_B(t) \times \omega(t) > 0 \qquad (5)$$

This driver B supply state is the reverse pattern of the driver A supply state. Driver B is in a state where the torque applied to the steering is stronger than that of driver A and inputs are operated in the direction that the driver B has turned. Therefore, it can be said that Driver B is leading from an energy perspective.

"Both driver energy supply state" is a state as shown in the following equation.

$$\bar{\tau}_A(t) \times \omega(t) > 0 \text{ , } \bar{\tau}_B(t) \times \omega(t) > 0 \qquad (6)$$

Both driver energy supply states are states in which the steering operation is performed in the same direction regardless of the magnitude of torque applied to the steering wheel. Since the steering operation is performed in a state where no load is applied to each other, there is no loss of energy, and it is considered that the operation can be performed without requiring extra force.

VI. EXPERIMENTAL RESULTS

In this experiment, both pair1 and pair2 are used for analysis only in the latter half, which are accustomed to driving off the expressway with two people. We judged the three states of "Driver A energy supply state", "Driver B energy supply state", and "Both driver energy supply state" shown above, and we calculated the time ratio of the driving state per one for the latter half of the experiment. Table 2 summarizes the two sets of time ratios. In addition, Fig.6 shows the ratio of "both driver energy supply state" to the time during cooperative driving for each pair in the last five experiments of pair1 and pair2.

From Table.2, "Driver A energy supply state" and "Driver B energy supply state" were lower in pair1 than in pair2. In addition, "both driver energy supply state" was about 20% higher pair1 than for pair2. From Fig.6, the ratio of the "both driver energy supply state" for each experiment to the coordinated operation time is that pair1 accounts for more than 1/3 of the total cooperative operation, but pair 2 were only 2 trials that were more than 1/3 of the total cooperative operation.

VII. DISCUSSION

From the results in Table 2, pair1 is 20% higher than pair2 in the "Both driver energy supply state", and we think pair1 can be steered with less load and not put extra power than pair2. In addition, from Fig.6, the time ratio of each experiment in pair1's "Both driver energy supply state" accounts for more than 1/3 of the total of the cooperative operation, and more than 70% in the 10th experiment.

The time ratio for each experiment of "both driver energy supply state" of pair2 is the highest for the sixth, and then falls. As a result, it can be said that pair1 was able to perform an ideal cooperative driving operation throughout the second half of the experiment, and was able to transfer the driving sovereignty without any sense of incongruity for the subject.

On the other hand, it is considered that pair2 was not able to perform the cooperative operation better every time the experiment was repeated, because the operation of the cooperative operation was varied throughout the experiment.

Therefore, in this experiment, it can be said that the driving sovereignty of pair1 can be utilized in the automatic driving system rather than pair2. In other words, it can be said that a smooth transition of driving sovereignty can be achieved if a person with a good self-centered evaluation is used as the system.

However, the state of energy supply may differ from the driver's own intention, and a steering operation of one subject is a load of the steering operation of another subject, except for the "both driver energy supply state".

It can also be considered that by adjusting the force applied to the steering wheel, an intended operation can be executed in the transmission of energy to the steering wheel even if the other party is in the energy supply state.

Therefore, it is necessary to subjectively evaluate whether the subject himself is leading or passive and compare it with the experimental results.

Table. 2 ENERGY SUPPLY STATE

	Driver A energy supply state	Driver B energy supply state	Both driver energy supply state
pair1	22.38%	19.89%	57.73%
pair2	29.26%	32.98%	37.77%

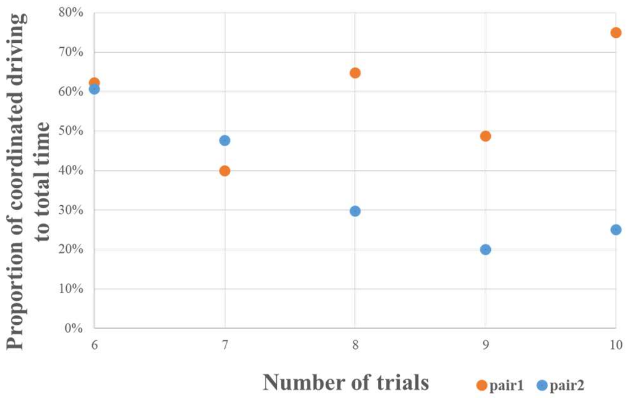


Fig.6 Both driver energy supply state

VIII. CONCLUSION

In this research, we conducted a cooperative driving experiment of two people to develop a system that can transfer the driving sovereignty in autonomous driving smoothly and safely. We are focusing on the energy transition between the two steering operations, we analyzed the process of driver sovereignty transfer between the two persons.

The experimental results show that even the pairs with bad self-centricity evaluations of personality diagnosis are transferring their driving sovereignty in cooperation with each other. However, from the experimental results, we think that it is better to obtain data on cooperative driving for a pair whose self-centeredness is A evaluation as a system role than a pair whose self-centeredness is C evaluation.

Moreover, it is necessary to evaluate subjectively using a questionnaire, because it is not possible to judge all from the data how the subject felt during cooperative driving.

In the future, subjective evaluation will be incorporated so that cooperative driving can be evaluated smoothly and safely, and test results should be evaluated not only by self-centeredness but also by other personality and movement characteristics. Then, the driving behavior is classified as a pattern in association with the personality test of the subject, and finally, the development of an automatic driving system that considers the personality of the human driver is aimed at.

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