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Analysis of Driver's Characteristics in Driving Control Authority Transition Period

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Summary

In a three-level autonomous vehicle, driver intervention is essential. At this time, the transferring process of driving control authority to the driver should be occurred stably to prevent further accidents. In this study, driver's driving tendency is evaluated from input data by the driver such as rate of change of steering angle, acceleration and brake pedal data. The analysis of galvanic-skin response (GSR) is also performed in order to identify the changing tendency of GSR when changing the control authority. The Human-In-The-Loop (HITL) simulator has been developed for experiments on various driving control authority transition scenarios. Through the HITL simulation, changes of driving tendency and GSR data are conducted in the transition period of driving control authority. The results of HITL simulation show that the driving tendency is changed more aggressively and the value of GSR data tends to decrease in the case of control authority transition. A stable control authority transition algorithm can be developed through the application of these results.

Keywords Human-In-The-Loop, Autonomous Vehicles, Driving Control Authority Transition, Driving Tendency, Galvanic-Skin Response

1 Introduction

Existing autonomous vehicles have been developed to improve safety and convenience for drivers. However, most of existing autonomous vehicle have not considered driver's characteristics and driver-vehicle interaction. Characteristics of the drivers have a high influence on the convenience and safety of the autonomous vehicles [1]. Especially, it is essential that transfer the driving control authority safely. Because the transition of control authority is a process of interaction between the driver and vehicle, effective interaction can be achieved by understanding the characteristics of the driver [2]. N. Nourbakhsh, et al. [3] suggest the measurement of cognitive load through galvanic-skin response (GSR). S. F. Varotto, et al. [4] suggest the driving tendency is an important part of human factors. Generally, there are several human factors such as age, gender, driving tendency, driving experience and reliability of autonomous vehicles.

In this paper, driving tendency and the change of GSR as driver's characteristics in driving control authority transition period was researched. For that, the Human-In-The-Loop (HITL) simulator was developed using commercial software CarMaker. As the future work, research of the safety control transition can be progress based on the characteristics of the driver in driving control authority transition period.

2 Human-In-The-Loop Simulation

The characteristics of drivers in driving control authority transition period can be analyzed by collecting driving data of the driver. Also, driver's responses should be confirmed in the actual driving situation. In this research, the Human-In-The-Loop simulator was developed to experiment several scenarios of the driving control authority transition. The operating data of steering wheel, acceleration pedal (AP) and brake pedal (BP) and vehicle gear was sent to simulation PC as the input data and driving data collected in real time as the output data. Simultaneously, driver's GSR signal can be collected to confirm the biological response in driving control authority transition period.

2.1 Simulation Environment

The HITL simulator has been developed with CarMaker Program which is a commercial vehicle simulation software. In order to minimize the heterogeneity between real driving and virtual driving simulation, the simulation environment was created by reflecting the real road environment. There are some components of environment such as roads, buildings, trees, people, street furniture and vicinity vehicles as shown in Figure1. The picture on the left shows the simulation environment. The driver view of sitting in a vehicle can be seen on the right.

Figure1: Simulation Environment and Driver View

2.2 Data Communication

The driver uses a steering wheel which is used in commercial vehicles, acceleration and brake pedals and vehicle gear. Steering, AP, BP and gear data send to simulation through CAN communication. The signals input to Functional Mock-up (FMU) interface as FMU outputs. Necessary data were collected selectively from simulation through FMU interface as FMU inputs. Those data can be used to analysis driving tendency and driving characteristics.

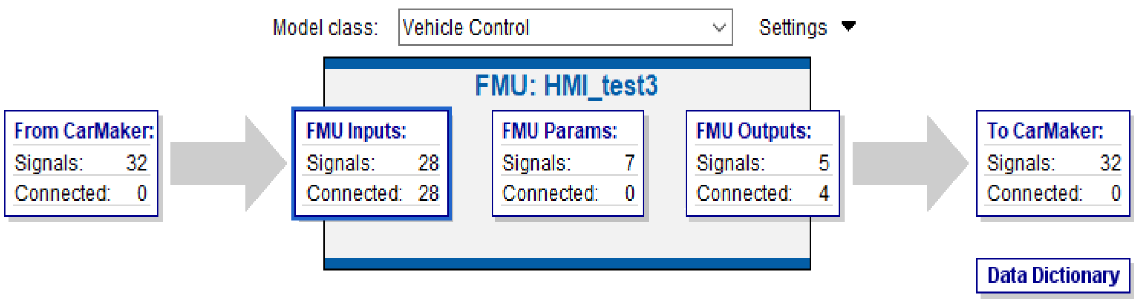

Figure2: Data Communication Process in FMU Interface

2.3 Experiment Design

The experiments are constructed the cases of partial autonomous driving including control authority transition scenarios and the general driving in which the driver directly travels all the routes. In other words, general manual driving and partial autonomous driving were conducted on the same route. In the manual driving, the drivers directly drive all the scenarios, so the driver deals with the danger or unexpected driving themselves. On the other hand, in the partial autonomous driving, the driver take-over control authority from vehicle and passes the section of danger or unexpected driving scenarios.

The experiment using HITL simulator was consist of scenarios of requiring driving control authority transition during autonomous driving. Several scenarios occur consecutively in a single experiment, and the autonomous driving and manual driving is repeatedly performed. The scenarios consist of construction on the driving road, jaywalk of pedestrians, dangerous mountain road and the entering a vehicle violating traffic signal on intersection as shown in Figure3.

Experiments were conducted on adults who have a driver's license and have driving experience at least a year. Totally, 20 male and female adults aged between 20 and 60 participated in this experiment and this experiment was performed on same conditions.

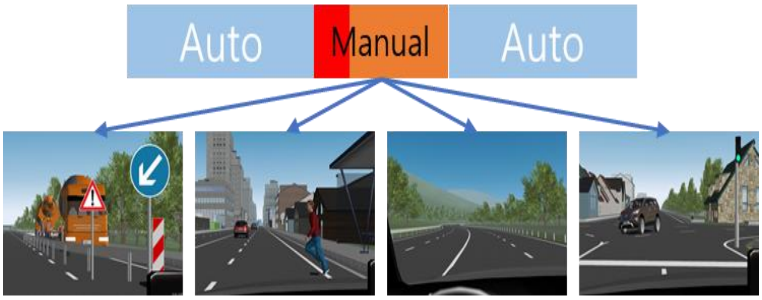

Figure3: Scenarios of Experiment

Figure4: HITL Simulation

3 Driver's Characteristics

There are a lot of driver's characteristics during driving. In this paper, focused on driving tendency and GSR signal among the characteristics of driver. The data of steering angle, AP and BP were obtained through the experiment, and the driving tendency of driver was analyzed using the data. Also, GSR were obtained and the tendency of GSR in the control authority transition period was analyzed.

3.1 Driving Tendency

According to [5], S. Jeon, et al. suggest that algorithm of driving tendency determination using HITL simulation. As the algorithm was applied, it is predicted that the driving tendency of control transition period is more aggressive than driving tendency of overall experiment. This result can be indicated that operation of steering and pedals become more aggressive in control transition period.

3.1.1 Method of Data Analysis

The driver's driving behavior characteristics in the manual driving and the partial autonomous driving are compared using rate of change of steering angle, AP and BP. The root mean square (RMS) value of rate of change of steering angle, AP and BP were compared.

3.1.2 Result

Table1 shows the ratio of number of sections in which the value tends to increase with respect to the entire number of sections for each person. The 45% of total experimenters showed a larger rate of change of steering angle in partial autonomous driving than manual driving in all sections. The 85% and 90% of total experimenters showed a larger rate of change of AP and BP in partial autonomous driving that in manual driving in all sections. The average ratio of number of sections in which the rate of change value increase with entire number of sections in partial autonomous driving compared to manual driving are 70.8%, 93.3% and 96.7% in the order of steering angle, AP and BP.

In summary, as a result of the comparison between the partial autonomous driving and manual driving experiments, the rate of change of each parameter was higher in partial autonomous driving. It means that the driver operates the vehicle more urgently than usual driving when the control authority is transferred. It implies that the driving tendency to tend to be more aggressive than the driving tendency in the general driving situation.

Table1: Ratio of number of sections in which the value increases with entire number of sections in partial autonomous driving compared to manual driving

Experimenter	Steering Angle	Acceleration Pedal	Brake Pedal
1	0.67	1.00	1.00
2	1.00	1.00	1.00
3	0.33	1.00	0.67
4	1.00	1.00	1.00
5	1.00	1.00	1.00
6	1.00	1.00	1.00
7	0.00	1.00	1.00
8	0.00	1.00	1.00
9	0.50	1.00	1.00
10	0.67	0.33	0.67
11	1.00	0.67	1.00
12	1.00	1.00	1.00
13	0.50	1.00	1.00
14	0.50	1.00	1.00
15	1.00	1.00	1.00
16	1.00	0.67	1.00
17	1.00	1.00	1.00
18	0.67	1.00	1.00
19	0.67	1.00	1.00
20	0.67	1.00	1.00
Average	0.71	0.93	0.97

3.2 Galvanic Skin Response

The GSR is a measuring the skin conductance, it depends on the moisture level of skin. In the experiment, the GSR was measured by a sensor at fingers. The electrical conductance between two points of fingers is measured as an ohmmeter [6]. Through the sweating level, the electrical skin resistance is changed. The lower resistance is measured at higher moisture level.

Figure5: Sensor of GSR [6]

Table2: Range of sensing data [6]

Parameter	Unit	Range
Conductance	Siemens	0-20
Resistance	Ohms	10 K-100 K
Voltage	Volts	0-5

3.2.1 Data Processing

The raw data of collected GSR and filtered data are shown in Figure6. To obtain the usable data from the raw data, raw data was filtered by Chebyshev filter with lowpass type. Through the filtering, the tendency of GSR can be confirmed clearly.

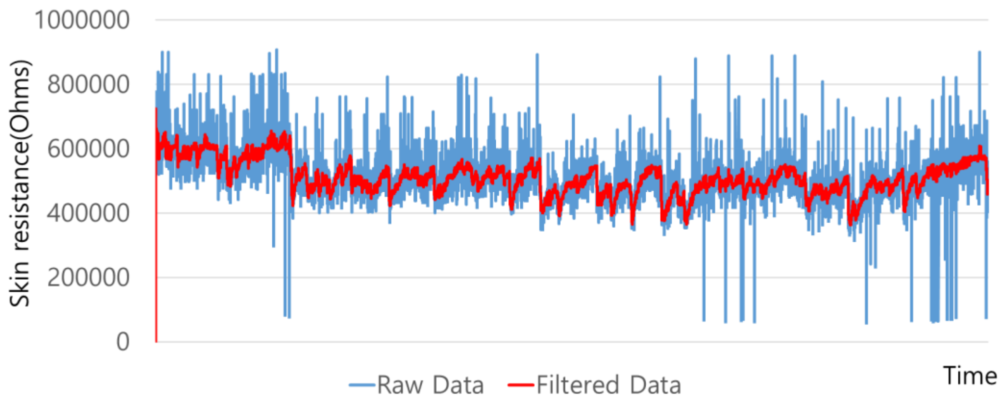

Figure6: Data Processing of GSR Raw Data

3.2.2 Result

Driver's GSR signal during manual driving and partial autonomous driving were expressed on Fiqure7.

First, comparing the GSR data form two driving experiments, the GSR value of manual driving is higher than autonomous driving in general. It cannot be predicted whether the partial autonomous driving was performed with higher tension or lower tension during the experiment. However, according to the result of the survey, it can be predicted that if those who have a high pressure on the urgent situation of driving control transition or have the lower reliability of autonomous vehicles, the value of skin resistance is lower in partial autonomous driving than manual driving. In other words, GSR data can be shown the different tendency through individualities. Therefore, each person's adaptability of situations and reliability of autonomous vehicles should be considered with GSR data.

Secondly, there are two points which are expressed with red circle in Figure7. Those indicate the period of driving control authority transition. That is, the period in which the rate of change of GSR decrease rapidly is observed in the control transition period of partial autonomous driving. Although there is individual variation of rate of change, same aspect was shown in most of all. This result implies that the GSR data can be used as a comparative factor for determination of driver emotion state.

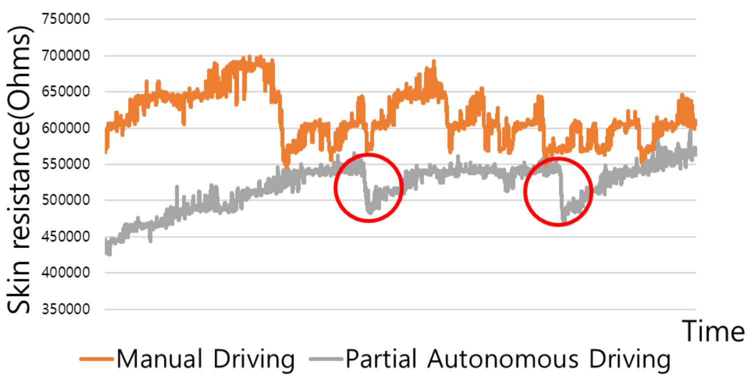

Figure7: GSR of manual driving and partial autonomous driving

The values of average skin resistance were compared between the previous period of control authority transition and the corresponding to control authority transition period. Before the transition, the drivers receive the alarms for induction of recognition. Next, they recognize the situation called scenarios and take-over the control authority. After the transition, drivers pass the danger or unexpected situations. All the period should be included as control authority transition period. Therefore, each the 15 seconds interval of before and after the point of transition from the autonomous driving mode to manual driving mode is considered as control authority transition period. That is, it is 30 seconds. And the previous 30 seconds as previous period of transition is considered.

Comparing the average skin resistance value in the previous of transition and transition period, the data tends to decrease in the transition period. In the case of 19 of 20 experiments, the average skin resistance in period of transition is lower than the average skin resistance in previous period of transition. As a result, the skin resistance is decreased due to the moisture level which means sweating is increased in the period.

Based on the results of this study, it is possible to predict the driver's tension and cognitive load when the autonomous vehicles transfer the authority of control to the drivers.

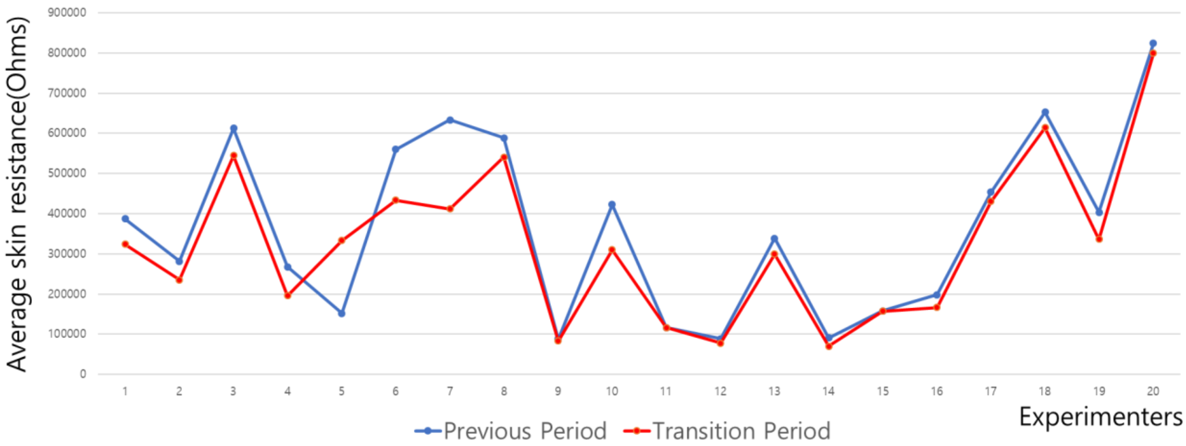

Figure8: Average GSR in previous and present control authority transition period

4 Conclusion

The HITL simulator has been developed to analyze driver's characteristics using CarMaker and various simulations have been carried out using the developed simulator. The HITL simulation results show that driving tendency is changed more aggressively than normal driving and the value of GSR data tends to decrease in transition period of control authority for partial autonomous vehicles. It means that the driver operates the vehicle more urgently than usual driving when the control authority is transferred. Furthermore, it is predicted that people who are driving partial autonomous vehicle have the burden of transition of control authority. A stable control authority transition algorithm can be developed through the application of these results.

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