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Development of Reproducible Test Vehicle and Evaluation Scenario for Driver Pedal Behavior Analysis in Unexpected Emergency Situations

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Abstract

The purpose of this study is to analyze characteristics of driver behavior during unexpected traffic emergency situations such as sudden unintended acceleration or brake system failure by analyzing their pedal behaviors.

For this purpose it developed a test vehicle and a reproduction test scenario to create an unexpected situation. The reproduction test consisted of scenarios of sudden unexpected acceleration of vehicle, brake booster malfunction and jammed throttle pedal. Finally, we conducted the test with 80 driver lisence holders composed of female drivers and male drivers with less than 2 years of experience. The characteristics of driver behavior in normal state and expected and unexpected emergency situations were analyzed by using pedal angular velocity and effort, and camcorder recordings. The vehicle and scenario were used to conduct driver's pedal effort analysis and the findings will be used to create a smart safety system that recognizes and responds to drivers' behaviors.

Keywords*: Unexpected situations, Reproduction test, Driver pedal effort analysis, Driver pedal behavior, Sudden acceleration*

1. Introduction

As vehicle structures are becoming more complicated with more installments of electronic accessories, the potential risk of unexpected sudden acceleration is gradually increasing.

An abnormal accident refers to a traffic accident caused by unintended maneuver of vehicle by driver. More often than not, the drivers cannot find out the cause of the abnormal performance of the car. The causes of unexpected accidents are largely classified into unexpected situations due to vehicle problems and drivers' incorrect operation. Drivers' incorrect operation a major cause of accidents as it takes about 70% of causes of unintended vehicle accidents. [3]

Figure 1. Abnormal Sudden Acceleration Incidents

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Advanced car makers have developed and applied various safety devices to prevent unexpected accidents, including the brake override system (BOS), emergency assist system (EAS), drive start control and smart pedal system, but they have not been enough to respond to the cases of accidents caused by drivers' incorrect operation. Because the systems above cannot stop poor driver operations as they only take into consideration vehicular or surrounding conditions and completely overlook driver intentions.

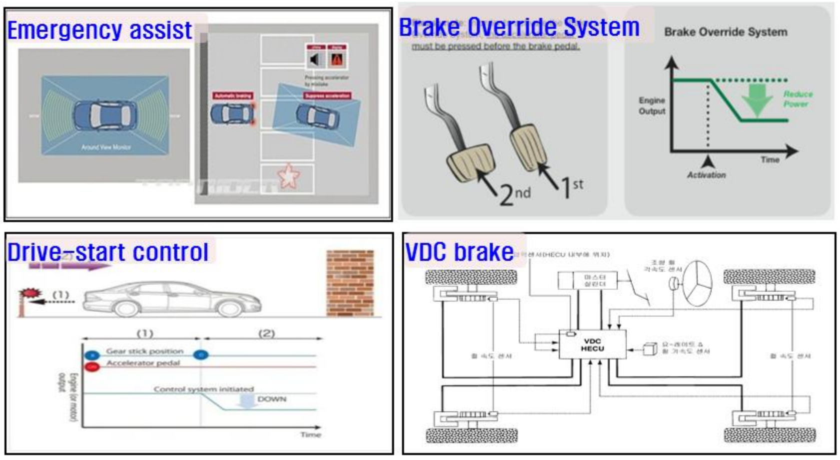

Figure 2. Different Types of Driver Assistance System

For these reasons, nowadays, safety devices are being developed to analyze the operating intention of drivers to respond to the accidents caused by drivers' incorrect operation.

It is absolutely necessary to analyze drivers' behavioral patterns in unexpected situations in order to develop safety devices that read drivers' operating intention, but it is very difficult to acquire actual data of drivers' behaviors in case of operating mistakes or unexpected situations. There have been many previous researches that tried to analyze driver behavior by reconstructing abnormal situations through simulation.[4] However, our current simulation technology is still constrained to recreate the urgency experienced by the drivers during actual emergencies. Also, it is virtually impossible to collect accurate data as they may vary depending on the adaptability to the game.

Therefore, this study was conducted to develop a method and vehicle that make it possible to analyze drivers' behaviors in unexpected situations and analyze drivers' behavioral patterns to develop and evaluate a smart safety system in the future.

2. Analysis of Cases of Accidents in Unexpected Situations and Classification

This study gathered local and international cases of unexpected accidents and classified them into different types for the analysis. In order to consider all of the cases of accidents that can occur in relation to vehicles, the cases were categorized into three levels. The first level included malfunctioning of vehicles, poor manipulation of drivers, and mechanical defects based on the causes of accidents and the second level included stop, slow driving, acceleration, and deceleration by the behavioral condition of vehicles. In the third level, all accident situations were analyzed for startup, gear transmission, accelerator pedal operation, and brake pedal operation in different situations of driver manipulation.

Then, we organized different types of accidents in the three levels, summarized any overlaps, and categorized them into three classes, A, B and C, by their probability of actual occurrence and difficulty in reproduction.

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1st Level (Types of Sudden Acceleration)	2nd Level (Driving Condition)	3rd Level (Manipulation Type)	Accident Type (Anticipated)	Possibility (A, B, C)	Difficulty of Scenario	Anticipated Part of Defect
Malfunction (Engine and vehicle defects)	Stop	Upon startup (turning key)	Sudden acceleration upon startup	B	A	-Anti-startup system (brake) -Accelerator sensor (APS) -Engine ECU
		Upon gear transmission	Sudden acceleration when shifting from P to D or R	A	B	-Accelerator sensor (APS) -Engine ECU
		Upon acceleration	Sudden acceleration when operating accel erator while in stop	B	C	-Accelerator sensor (APS) -Engine ECU
		Upon brake	Sudden acceleration when operating brake	C	C	-Accelerator sensor (APS) -Engine ECU -Brake booster
	Slow driving (coasting)	No operation	Sudden acceleration while coasting	A	C	-Accelerator sensor (APS) -Engine ECU
		Upon gear transmission	Sudden acceleration when shifting gear (D to N or shift lever)	C	A	-Vehicle gear bar -Accelerator sensor (APS) -Engine ECU
	Acceleration	Upon gear transmission	Sudden acceleration when shifting gear in acceleration	C	A	-Vehicle gear bar -Accelerator sensor (APS) -Engine ECU
		Upon acceleration	Sudden acceleration when operating accel erator in acceleration	A	C	-Accelerator sensor (APS) -Engine ECU
	Deceleration	Upon gear transmission	Sudden acceleration when shifting gear (D to N or shift lever)	B	A	-Vehicle gear bar -Accelerator sensor (APS) -Engine ECU
		Upon brake	Sudden acceleration when operating brake	C	C	-Accelerator sensor (APS) -Engine ECU -Brake booster

Figure 3. Types of Abnormal Emergency Situation

The findings of analysis were sorted and used to make the final decision about the reproduction test scenarios considering the possibility of accident, considerations of smart safety system development, and possibility of reproduction test.

3. Reproduction Test Scenarios of Unexpected Situations

Three final reproduction test scenarios were established to conduct the reproduction test to reproduce unexpected situations caused by vehicle defects. Because the main purpose of this study is to analyze driver behavior during unexpected emergency situations, it is important for the drivers to not become aware that unexpected situation will occur. Once they discover something will take place, they will be better prepared for further unexpected situations, and we will not obtain data when they are flustered. Due to this reason, we were only able to conduct one test per driver. Therefore, reproduction tests selected scenarios of situations where the drivers can be most flustered and that can be most risky and has most cases of accidents.

The three scenarios of reproduction tests were: first, unexpected sudden acceleration that reproduced unexpected acceleration caused by vehicle defects; second, brake problem that reproduced vehicle brake booster defect; and third, accelerator pedal problem where the pedal is stuck. [1][2][5]

With regards to the three scenarios above, we reconstructed incidents by adding one additional scenario at random per driver to collect data on driver behavior in normal condition and unexpected and expected (warning light on) emergency situations.

4. Vehicle Remodeling For Reproduction Tests

The test vehicle was remodeled to reproduce a situation of unexpected sudden acceleration. Vehicle remodeling largely consisted of unexpected situation reproduction system, safety system, and data measuring system.

As for reproduction abnormal sudden unintended acceleration, we set up an APS signal control box to remotely control acceleration without the driver having to

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operate the accelerator. The brake system was remodeled ineffective by incapacitating the brake booster with a solenoid valve. Motor and wires were used to hold the accelerator all the way down.

As a safety measure, the vehicle was remodeled to come to a full stop in case of vehicular malfunction or poor driving. We mounted a secondary cable-type brake system in the passenger seat for the driver to maneuver and on/off control devices in each crank sensors and ignition coil sensor for a remote shut down.

Measuring system was structured to analyze vehicular condition and driver behavior. We received various CAN signals to keep eyes on the condition of the car and installed multiple camcorders from multiple angles and measured pedal signals to analyze driver behavior. Furthermore, we installed warning lamp to reenact expected emergency situations and removed various safety systems from the vehicle that may activate during unusual situations.

Table 1. List of Vehicle Remodeling For Reproduction Tests

Classification	Test lists	Test methods
Systems for reproducing unexpected situation	Unintended sudden acceleration	APS sensor control
	Faulty brake	Brake booster on/off
	Sticking pedal	Motor + wire system
Safety systems	Emergency braking system	Auxiliary brake
	Engine stop system	Crank angle sensor on/off Ignition coil on/off
Measuring systems	CAN signal (various vehicle condition signal) pedal force, Pedal angular velocity *etc.*	
Etc.	BOS system off, warning lamps & alarm off, VDC, ABS off, red light for emergency situation, partition installation	

The unexpected sudden acceleration reproduction system produces the situation of and vehicle’ s malfunctioning and consists of a system that disables the brake booster, a system that unexpected acceleration generating and a system that fixation the accelerator pedal.

As for reproduction abnormal sudden unintended acceleration, we set up an APS signal control box to remotely control acceleration without the driver having to operate the accelerator. The control box was remodeled using the existing accelerator components and was connected in parallel with the accelerator. The brake was rendered ineffective by incapacitating the brake booster with a solenoid valve. Motor and wires were used to hold the accelerator all the way down.

We also made a smaller sub-control box to prevent the driver from noticing the test assistant operating the malfunction mechanisms.

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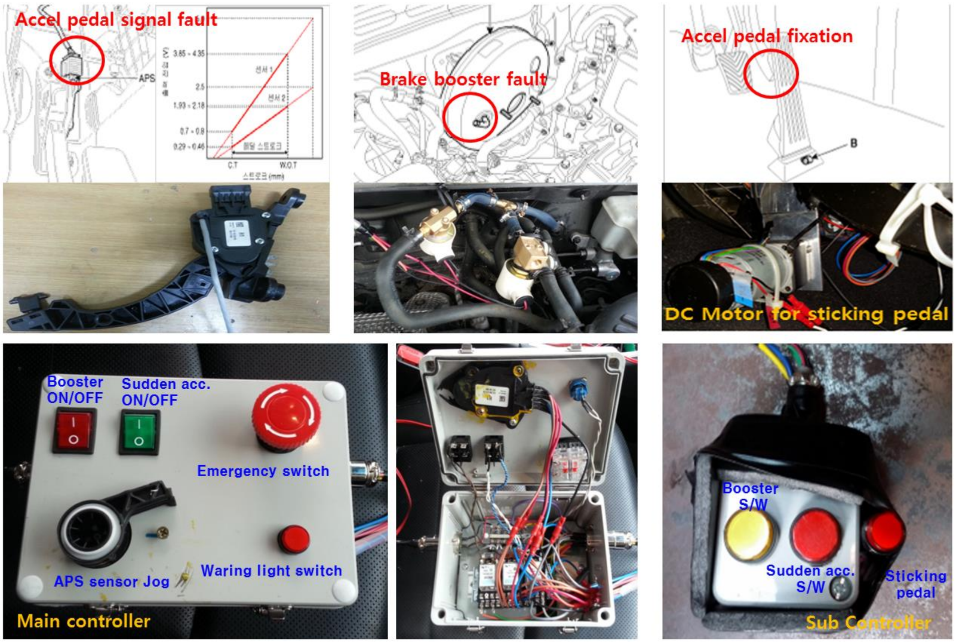

Figure 4. Unexpected Sudden Acceleration Reproduction System

The safety system is a system designed to safely respond to the unexpected situation that occurs during the test and consists of an auxiliary brake pedal, crank sensor on/off system, and ignition coil on/off system.

Because the auxiliary brake system must operate even the booster fails, the pedal link was elongated and reinstalled. The length of pedal link was determined by comparing the result of braking tests where in one test, the length of pedal link was standard and in the other test, the booster malfunctioned. Based on the result, we discovered that the link had to be at least 1.8 to 2.8 times longer for safe brake system operation.

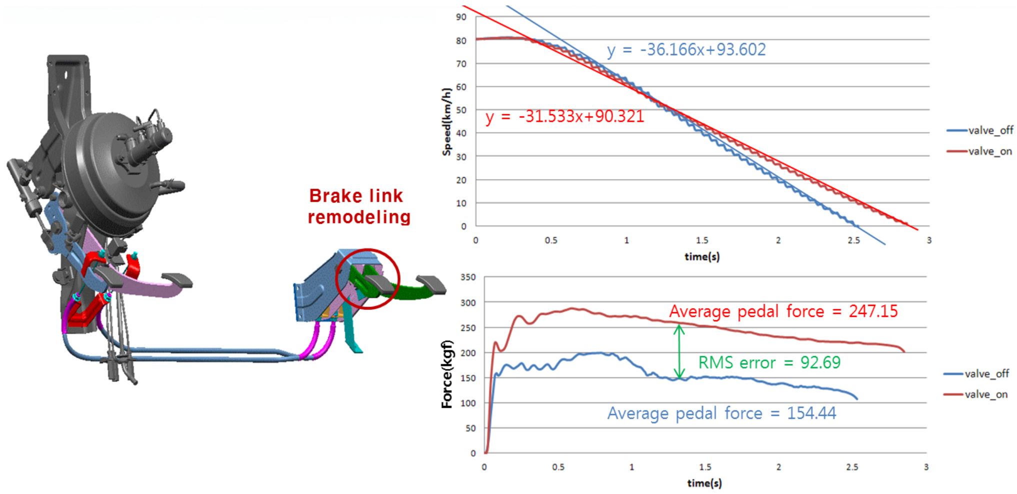

Figure 5. Auxiliary Brake and Braking Test Results in Booster Failure Condition

The measuring system was built to analyze the condition of vehicle and driver and consists of vehicle data acquisition system, GPS, and sensor and imaging device to analyze the behavior of driver.

In order to analyze vehicle conditions, we received information including vehicle speed, RPM, brake on/off signal, gear position, steering angle, and accelerator and throttle position sensors through CAN signal and measured brake / accelerator pedal angle, angular velocity and effort and signals from 3 camcorders including vehicle front view, driver view and driver feet view in order to analyze driver behavior.

Moreover, we installed vehicle safety lights to reconstruct unexpected situations noticed by the drivers. They were positioned out of line of sight of the drivers to minimize their sense of difference to the vehicles.

The developed test vehicle was used to analyze the driver's behavioral characteristics in the situation of unexpected sudden acceleration and will be used to assess the reliability of smart safety system in the future.

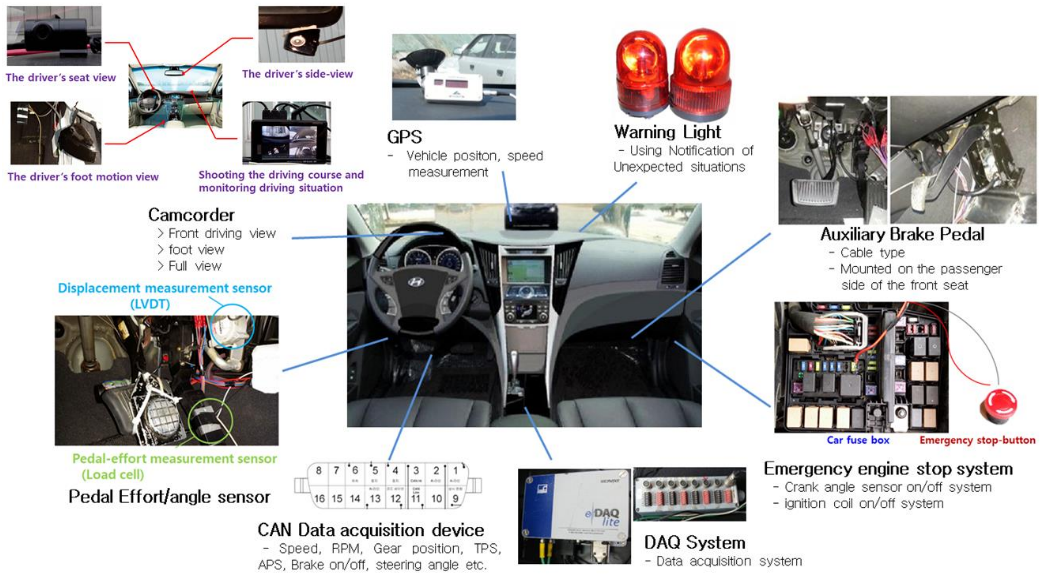

Figure 6. Data Measurement System and Safety System

5. Conditions of Reproduction Test of Unexpected Situation

Reproduction test of unexpected situation was conducted with about 80 novice and female drivers with less than 2 years of driving experience. The test took place at Korea Automotive Technology Institute's proving ground. The test method involved five cycles of normal driving and causing an unexpected situation in the double lane change zone as shown below. Driver's behavior was analyzed in this unexpected situation not predicted by driver. In the driving test, the scenario included a scenario of normal acceleration/deceleration, maximum acceleration/deceleration in normal driving and a scenario of expected sudden deceleration when warning light was turned on.

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Figure 7. Driving Route in Unexpected Situation Reproduction Tests

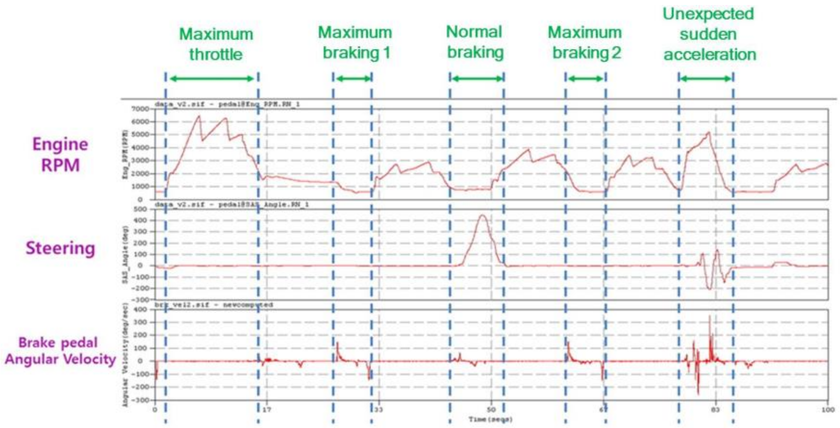

Figure 8. Example of Result Data in Unexpected Situation Reproduction Tests

6. Results of Unexpected Situation Reproduction Tests

As a result of test, most drivers tended to experience confusion when choosing the right pedal to operate in case of unexpected situations caused by vehicle problems. For this reason brake pedal effort or angular velocity were lower compared to predictable sudden situations. Also, drivers focused more on handling rather than on pedal behaviors to avoid risks in the double lane change zone. [6]

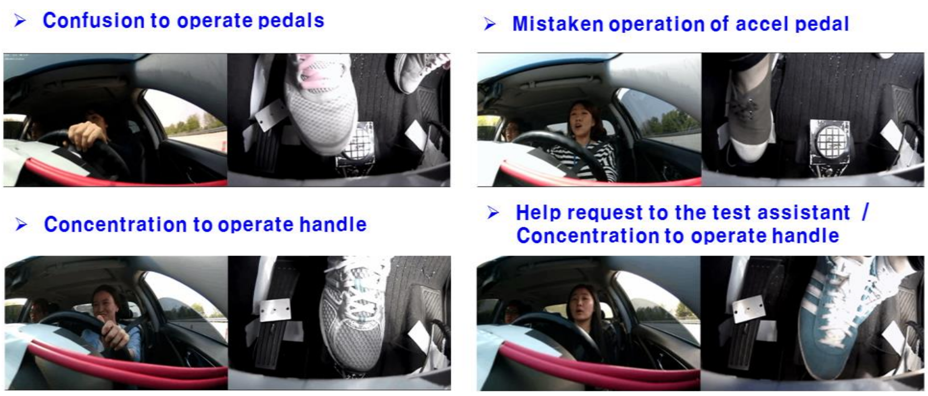

Figure 9. Analysis of Pedal Behavior in Unexpected Emergency Situation

Although quantitative comparison was difficult as the deviation of pedal effort or manipulation behavior varied from driver to driver, it was identified that in unexpected situations pedal effort generally increased by 2-5 times and angular velocity by 2-3 times compared to normal situations.

We confirmed that in normal situations, *i.e.* regular driving on roads and stopping at intersections, maximum throttle and brake pedal efforts were 4.5kgf and 20kgf, respectively.

In expected emergency situations (with the warning lamp on) on a straight 60 to 80 km/hour course, we discovered that most drivers pushed brake pedal down in one motion upon hearing warning noise with a max effort of 109kgf. Compared to regular driving, the drivers pushed down the brake pad with 2 to 7 times higher efforts in emergency situations.

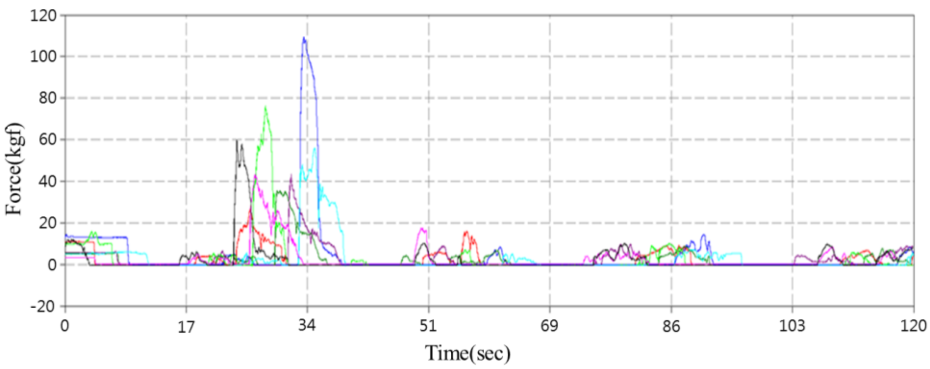

Figure 10. Brake Pedal Force in Expected Sudden Deceleration

When told to drive a 400m straight course as fast as they can, the highest accelerator effort came out to be 9kgf, which was about 2 to 3 times higher effort compared to that in regular driving. As a result, it was confirmed that drivers push down on the throttle pedal all the way down for rapid acceleration but do not exert much effort once the pedal hits the floor.

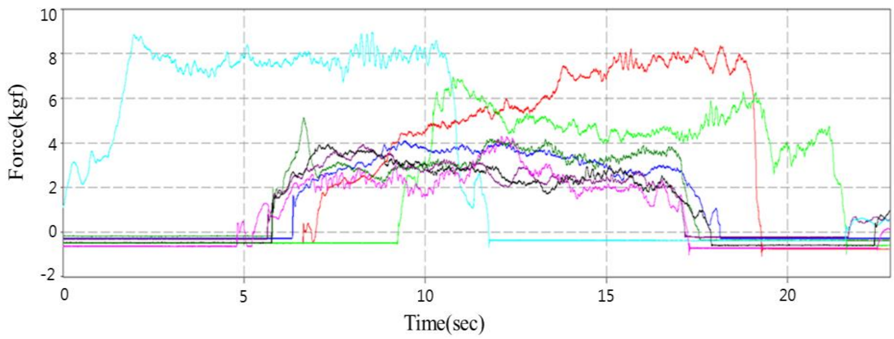

Figure 11. Throttle Pedal Force In Maximum Acceleration

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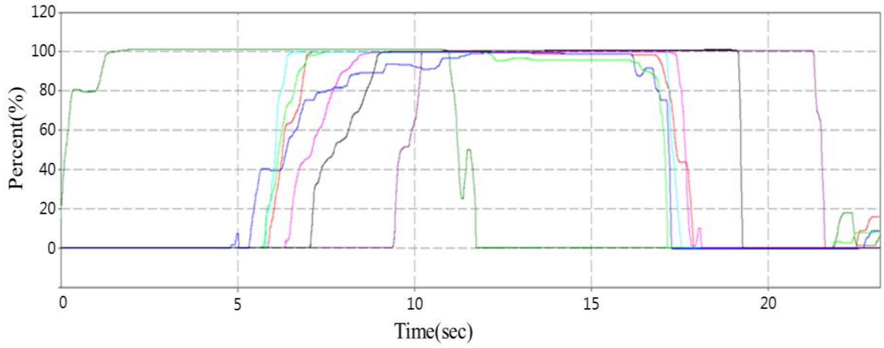

Figure 12. Throttle Pedal Open Value in Maximum Acceleration

We established that, in unexpected emergency situations, the drivers pushed down on the brake and acceleration pedals with max efforts of 47.7kgf and 28.2kgf, respectively.

Based on driver pedal behavior by video recordings, we confirmed that many hesitated during unexpected emergency situations and therefore resulted in lessened brake pedal efforts compared to expected emergency situations.

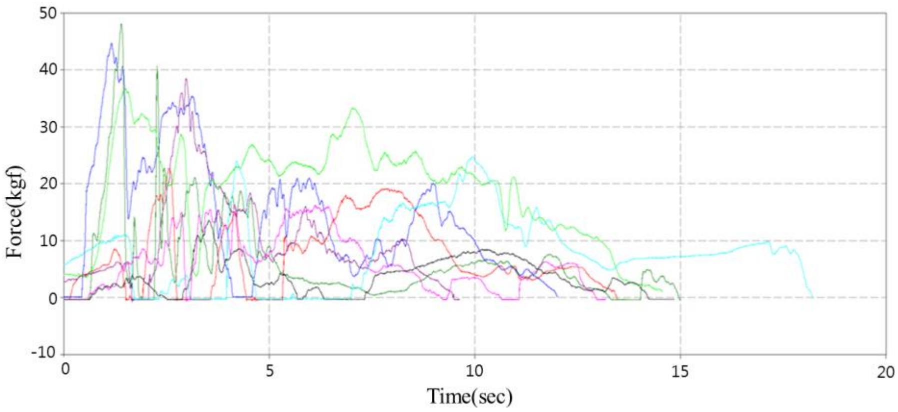

Figure 13. Brake Pedal Force in Unexpected Sudden Acceleration

It was discovered that most of the drivers were confused with pedal maneuver during unexpected emergency situations and incorrectly pushed down on the acceleration pedal. There were two categories of incorrect operation of pedals. One is where they press on the brake pedal until reaching 1 to 1.5kgf then switching off to pressing the acceleration pedal and then back to the brake pedal. The other one is confusing acceleration pedal with brake pedal and mistakenly exerting high effort on the acceleration pedal.

In the second case above, the maximum effort reached up to 28.2kgf, which was 7 times higher force compared to that in normal driving conditions.

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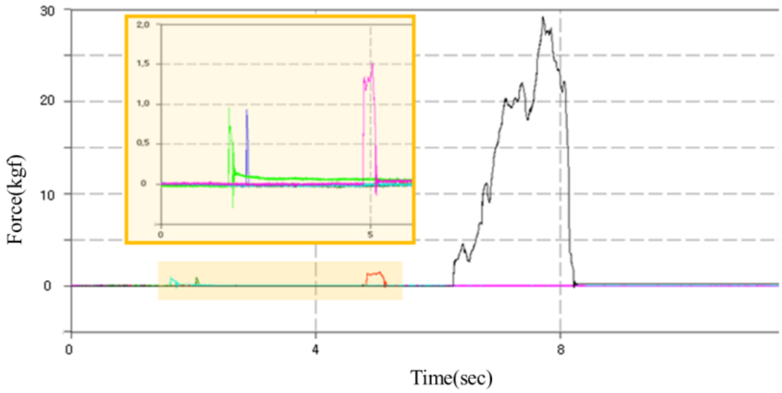

Figure 14. Throttle Pedal Force in Unexpected Sudden Acceleration

The drivers displayed varying pedal behaviors, and therefore, they cannot be deemed general results. There needs to be further supplementary testing in order to acquire more accurate analysis of driver pedal behavior.

7. Conclusions

Vehicles were remodeled for the unexpected situation reproduction test and the reproduction test to analyze drivers' behaviors. As a result, behavioral patterns varied significantly by from driver to driver and more samples would be needed for a more systematic analysis in the future.

In case of real vehicle driving test, there is the issue of drivers' safety unlike virtual simulations, so the test involved only minor risks with rubber cones and could not engender drivers' responses in urgent situations.

Additional tests will be conducted to find the tendency of drivers' behavioral patterns in urgent situations by reinforcing the reproduction test scenarios and further remodeling the vehicles to engender drivers' behaviors in more urgent situations

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