Dissertation

Driver Recognition and Reaction to Unintended Acceleration

意図しない加速時のドライバの認知と応答

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Abstract

Recently, research on automation system development is attracting a lot of attention ranging from researchers to automotive industry manufacturers to leading technology brands. In 2008, the US National Highway Traffic Safety Administration's (NHTSA) National Motor Vehicle Crash Causation Survey reported that 98 percent of road accidents were caused by human error. Researchers estimate that automation technology will reduce human errors that can lead to road accidents. However, some accidents were related to self-driving automated vehicles. These accidents indicate that the system is far from perfect and that drivers still need to take control in dangerous situations. Drivers can sometimes rely too much on automation systems. Most drivers involved in an accident have admitted that they were not paying attention and not ready to take control at the time of the crash. Sometimes, the driver could take control but did not have enough time to make the safest decision. This situation shows that recognition time is crucial. Shorter recognition time means that the driver has plenty of time to think and react safely. In recent years, researchers have begun studying recognition and reaction times, but they were using highly simplified conditions. In cases of real accidents, the conditions are complex. Therefore, research on recognition and reaction times in complex and actual situations are critical.

Unintended accelerations can occur in vehicles unexpectedly and uncontrollably. Most studies related to unintended acceleration have focused on potential malfunctions in electronics that control the vehicle's powertrain, software defects, accelerator pedal entrapment, sticking, and missed application. Few studies have focused on human factors such as driver recognition and reaction times. Unintended accelerations occur without warning. For years, the NHTSA has received many incident reports related to unintended acceleration. Incident investigations by car manufacturers often find no fault. In many accidents related to unintended acceleration, drivers claim they were unable to regain control of the vehicle by braking. Some cases have resulted in severe injuries and deaths.

In this study, the primary purpose was to analyze the driver’s ability to recognize unintended acceleration in the automated vehicle. To achieve this goal, the author

divided the study into two phases. In phase one, the conditions were simple and the road used was a 5km straight road. In phase two, the conditions were complicated and imitated a real driving scenario. The roads used were straight, intersections, and left and right curved roads.

Recognition time and recognized velocity are two of the most important factors that can prevent crashes. Recognition time refers to the time it takes for the driver to recognize the unintended acceleration. Recognized velocity refers to the velocity at which the driver detected the unintended acceleration. The statistical tools used for analysis were the F-test, t-test, and ANOVA method.

The result show that drivers reacted differently depending on the situation, type of road, acceleration or deceleration, engine sound, and type of traffic conditions; for examples with and without a leading vehicle and type of pre-crash situation. Drivers react faster during deceleration-unintended acceleration than acceleration-unintended acceleration because neurons in the middle temporal lobe are more sensitive to deceleration visual stimuli. Drivers also realize unintended acceleration earlier and can take control without delay. Engine sound is one of the important indicators of unintended acceleration. Drivers recognize unintended acceleration earliest at the pre-crash scenario with a pedestrian because the pedestrian and the relative velocity of pedestrian from driver was the lowest, and the pedestrian was visible from a distance. Leading vehicles also affect the driver's ability to recognize velocity changes.

The implication of these results is that in developing an automated vehicle system related to driver recognition or reactions to unintended acceleration, researchers should consider curve direction as an important factor. These findings provide insights that can be useful in developing automated vehicles and silent vehicles. Recognition time and velocity are important factors that can help prevent a crash and improve road safety. Early detection gives drivers more time to make decisions in response to the road hazard. By developing advanced fail-safe systems, smart sensor technology, and pedestrian tracking, autonomous driving systems can be considered safe for future universal deployment in cars. These will also give car manufacturers insight into driver reaction to automation failure during unintended acceleration. Simultaneously with the development of automated vehicle technology, car manufacturers and engineers should develop multiple fail-safe systems. If the technology malfunctions, the system should be able to detect the malfunction in the vehicle, other surrounding vehicles, and use pedestrian tracking to avoid accidents.

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Chapter 1 Introduction

1.1 Human error and automated vehicle

In 2014, the Society of Automotive Engineers (SAE) issued and defined automated driving levels in the new SAE International Standard J3016. The SAE identified six levels of driving automation from no automation to full automation. Most of the open literature is related to SAE level 2, such as adaptive cruise control, lane keeping, and other technologies. Most researchers are interested in studies related to vehicle trajectory prediction in adaptive control [1], the transition from automated to manual [2], and others. However, in this study, the focus is on SAE level 3. The vehicle steering, accelerator pedal, and brake pedal are automatically controlled. Moreover, drivers can take control whenever they want.

Automated vehicles have aspects of safety critical control such as steering, braking, and accelerating without direct input from the driver. Recently, research on automation system developments is attracting plenty of attention ranging from researchers to automotive industry manufacturers to leading technology brands. According to CB Insight's investment, acquisition, and partnership database, approximately 33 cooperate groups are involved in the development of advanced driver assistance systems, also known as self-driving vehicles. Currently, the biggest companies engaged in this technology are Google and Tesla.

In 2008, US National Highway Traffic Safety Administration's (NHTSA) National Motor Vehicle Crash Causation Survey report showed that 98 percent of road accidents were caused by human error [3]. Self-driving vehicle technology can reduce human error. However, there have been a few accidents involving self-driving automated vehicle, such as those from Google and Tesla. On 7th May 2016, an accident with a tractor-trailer killed a driver who was using automated driving-assist, as shown in Figure 1.1.1 [4]. The automated system did not apply the brakes because it did not treat the tractor-trailer as a threat or obstacle to avoid. Instead, the system interpreted the tractor-trailer as an overhead sign [5]. This incident indicates that automation systems in vehicles are not perfect.

Vehicle automation systems are improving, but they still require the driver to take control during dangerous situations. However, drivers are sometimes unable to recognize the danger and take control. Most drivers involved in accidents admitted that they were not paying attention and were not ready to take control at the time of the crash. The driver became too dependent on the vehicle's abilities, and went from suspicion to overconfidence in the system. The primary purpose of this study is to analyze the driver’s ability to recognize unintended acceleration (UA) in dangerous situations.

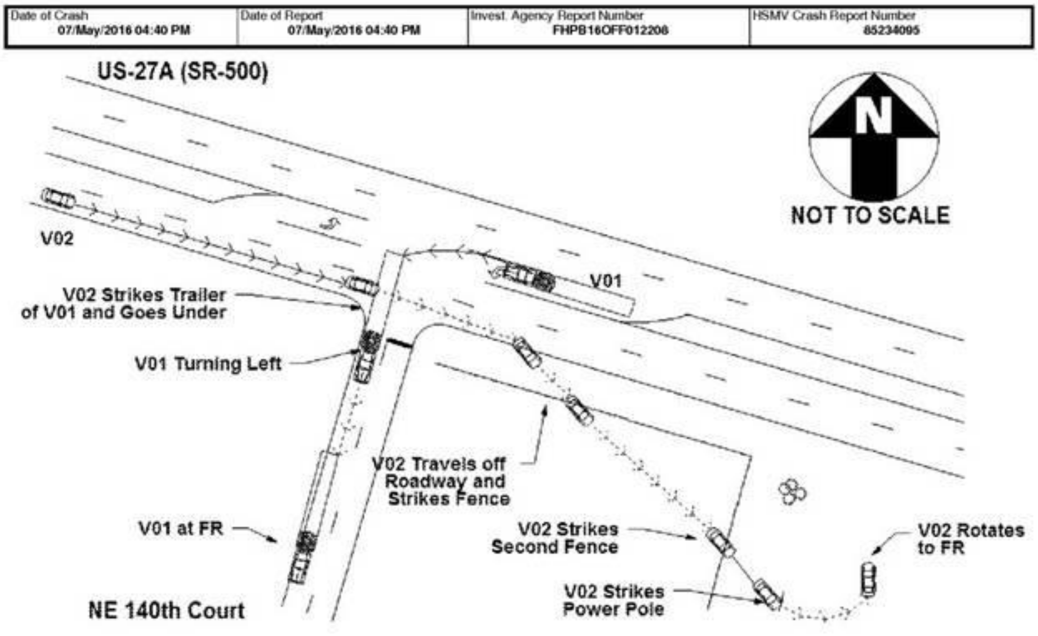

Figure 1.1.1 Tesla Accident report [4].

1.2 Unintended acceleration (UA)

For many years, there have been plenty of accident reports related to UA, which happens when a vehicle accelerates without warning. Usually, after an investigation by the car manufacturer, it is often reported that no fault was found. In many cases, drivers claim that they were unable to regain control by braking. Some cases have resulted in serious injuries and deaths. Every year, numerous critical injuries and deaths related to UA occur. From 2000 to 2010, NHTSA received from 1200 to 2000 reports of UA. Forty-three complaints were related to fatal crashes that resulted in 52 deaths [6].

UAs occur in vehicles unexpectedly and uncontrollably. Most studies on UAs have focused on malfunctions in the electronics that control the vehicle's powertrain, software defects, accelerator pedal entrapment, sticking, and missed application [7,8]. Nevertheless, a few studies on human factors have focused on recognition times (RTs) and recognition velocities (RVs) when UAs occur. Niklas Strand et al. studied semi-automated versus highly automated driving in critical situations caused by automation failures or UAs [9]. Recognition time and velocity are some of the most important factors to prevent crashes. Early detection gives the driver more time in make decisions about the UA hazard. This study analyzes the correlations between RT and UAs.

1.2.1 Unintended acceleration (UA) and pedals error

In 1990, John Tomerlin and Mark W. Vernoy designed a test to determine whether pedal errors affected some vehicle manufacturers more than others. The test used eight passengers' vehicles, five imported and three domestic. Two type of tests were conducted, a static test and field test. In the static test, when a flashing stop sign appeared, the camera recorded the pedal activation. In the field test, at a certain position, the researcher will push the accelerator to full throttle and observe the subject's reactions. Out of 258 static tests performed with 129 subjects, 26 pedals errors were observed; in the field test, only one subject was unable to completely stop.

Pedal errors were apparently more common than generally assumed. In most cases, drivers could recognize and correct the mistake before any danger occurred. However, under different conditions, if the drivers were incapable of recognizing the error, UA may have resulted in a dangerous situation. [10]

In 2012, Yoshitake et al. investigated the influence of age on pedal errors while driving under different visual conditions. In the study, 20 young drivers and 20 older drivers participated. There were six tasks, consisting of pressing an accelerator or brake pedals task with two different visual stimuli. The results showed that in both groups, the pedal error rates increased with task difficulty. Except for the simple reaction condition, older drivers had longer recognition times compared to young drivers. The accelerator error rates were consistently two or three times higher than the brake error rates for both groups. The researchers suggested that human decision-making was one of the main factors that lead to pedal errors. Furthermore, older drivers have increased incident rates related to UA [11].

1.2.1.1.1 Unintended acceleration and driver reaction

Jooho Park, Donghyun Sung, and Woon Sung Lee conducted a driving simulator study on adaptive cruise control (ACC) failure. In ACC, the system automatically adjusts the vehicle speed and distance from the leading vehicle. The experiment examined three cases. The first was without ACC, the driver had to change vehicle speed and distance manually. The second was with ACC on; the ACC system adjusted vehicle speed and distance automatically. The third case was with ACC on and algorithm failure; the braking algorithm failed and decreased the speed and distance travelled. The virtual environment was a rural highway with a mix of two- and four-lane roads. The definition of reaction time in this study was the time when the leading vehicle started to decelerate to driver began to either brake or avoid collision by steering away. The driver reaction time in case 1 (without ACC) was the lowest followed by case 2 (with ACC), and the longest reaction time was case 3 (ACC with algorithm failure). When drivers relied blindly on ACC, it prevented them from recognizing the ACC failure sooner. Then, the time left to react to the leading vehicle's unexpected behavior was reduced, which may result in an accident. This suggests that the ACC has the adverse effect of behavioral adaptation. [12]

In 2013, research on driver performance with ACC was conducted by Josef Nilsson, Niklas Strand, Paolo Falcone, and Jonny Vinter. The primary research objective was to examine how the driver handled ACC failure and the effect on safety. Forty-eight subjects participated in this experiment in a moving base driving simulator equipped with ACC. The driving environment was rural highway resembling a real road in Sweden with a 110 km/h speed limit. There were four types of failure: UA, complete lack of deceleration, partial lack of deceleration, and speed limit violation. The results were categorized based on whether the driver managed to avoid collision or not. The results show that a partial lack of deceleration caused more collisions compared to the complete lack of deceleration. Most drivers opted to change lanes rather than apply the brakes when faced with acceleration and deceleration failure [13].

1.3 Automated vehicle and driver behavior

This section discusses the effects of automation on driver behavior while driving an automated vehicle.

1.3.1 Human factor, situation awareness and mental workload

This part will discuss human behavioral patterns in an automated vehicle. It considers how the driver behaves in an automated vehicle and how they react when they must switch to manual driving. Perception, recognition, prediction, decision, response selection, and task execution are the stages of information processing. The essential elements to understanding the cognitive process when humans drive are situation awareness and mental workload.

In 1995, Endsley categorized situation awareness into three levels. Level 1 is perception, the driver's ability to identify a factor that could be relevant to safety. For instance, the stimuli in a situation that attracts driver's attention may be important or not. Level 2 is recognition, the driver's ability to recognize the traffic situation by recalling knowledge from semantic memory (example: experience, road rules, etc.). Level 3 is the driver's prediction, based on knowledge stored in memory and judgment of the current situation [14]. Mental workload is defined as “the specification of the amount of information processing capacity used for the task performance" [15].

In a study by Hoeger and others, the result showed the mental workload is low in automated driving mode. The workload is low because the driving task is easier since drivers only monitor the system. Because of the reduced workload, situation awareness declines. The driver takes a longer time to react to situations [16]. Furthermore, this finding is consistent with those of other researchers that the situation awareness decreases as automation takes over the driving task (low mental workload) [17-23]. In a study by Verberne and others (2012), when the system reveals its intentions, drivers tend to trust the system and lose situation awareness instantaneously [24]. Stanton and Young (2000) added that system feedback, for instance, what the system is doing and why, also increases driver trust. Without driver confidence in the automated system, stress and mental workload will increase [25]. Hence, the lack of certainty and overconfidence might decrease safety because, in both conditions, the driver took a longer time to react.

1.3.2 Automated vehicle and driving task

In 2014, Merat and others conducted research on the transition to manual driving in a driving simulator. In the study, the participant had to regain control of the automated vehicle while driving on a motorway. At any random time, a variable message sign (VMS) appeared. The example of the message is shown in Figure 1.3.1. Before the experiment, the researcher already briefed participants to switch to manual control as soon as the message appeared. There were two conditions in this experiment. In the first condition, the switch to manual driving mode message appeared, and the participants were fully focused on the road in the fully automated driving mode. In the second condition, the message appeared when the participants were not fully focused the road (based on eye tracking equipment). The findings showed that drivers took an average of 10 s to make a full transition to manual driving mode. In the second condition, participants took approximately 35 to 40 s. The results show that during the situation when the driver was not giving full attention to driving, the message for the transition to manual control must be shown at the appropriate time, manner, and at low crash risk situations [26].

Figure 1.3.1 An example of VMS message and scenario used at the end of the drive.

A study on taking control of a highly-automated vehicle in a complicated traffic situation focused on the role of traffic density. The purpose of the study was to measure the impact of verbal tasks and traffic density on taking over performance. The highway had three lanes with three traffic density conditions: zero, ten, and twenty vehicles per kilometer. Half of the total participants engaged in a verbal task (20 questions), where they spoke on the phone while driving a highly-automated vehicle. The results show that with the presence of traffic, the participants took a longer time to take over, there was shorter time to collision, and more accidents occurred. On the other hand, the verbal task did not influence takeover quality. The researchers concluded that traffic density plays a significant role in the design and development of human-machine interactions in highly-automated vehicle and takeover situations [27].

1.4 Objective

Recently, most studies on recognition and reaction times used highly simplified traffic conditions. However, in real accidents, the traffic conditions were complex. In other words, the research on recognition and reaction times in complex and actual situations are critical. The focus of this study is driver reaction to UA in an automated vehicle. The primary purpose is to analyze the driver’s ability to recognize UA without warning in two phases.

1. In the first phase, the objective is to analyze the driver's recognition and reaction to UA under different visual and audio stimuli. The visual stimuli represented the urban and rural areas. The audio stimuli represented conventional vehicles and silent vehicles.

2. In the second phase, the objective is to analyze driver recognition and reaction to UA in a straight road, curved road, and intersection in the presence of another vehicle, bicycle, and pedestrian. The straight and curved roads were either with or without a leading vehicle.

Chapter 2 Experiment Apparatus

2.1 System structure

The system for this study is shown in Figure 2.1.1. The system consists of a driving simulator, audio system, sensor, and camera.

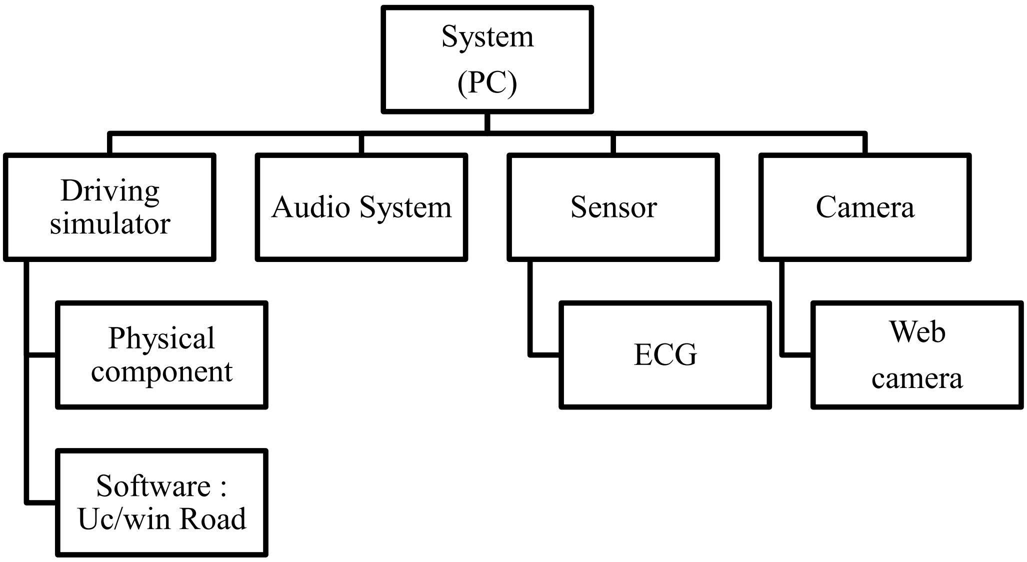

Figure 2.1.1 Experiment apparatus system.

2.2 Driving simulator

The driving simulator is as shown in Figures 2.2.1 and 2.2.2. It consists of three liquid crystal displays (LCD) on the left, right, and in front of the driver seat. Two speakers are on the right and left of the driver seat. The simulation software used was UC-WIN/Road ver.10.1.2 developed by FORUM 8, using 3D visual and virtual reality design. This software also includes functions such as Log Export Plug-in, which allows the user to export simulated data to a .csv file in the computer. The export data includes time, distance, velocity, and position of the user`s vehicle, leading vehicle, and surrounding and other objects in the scenario.

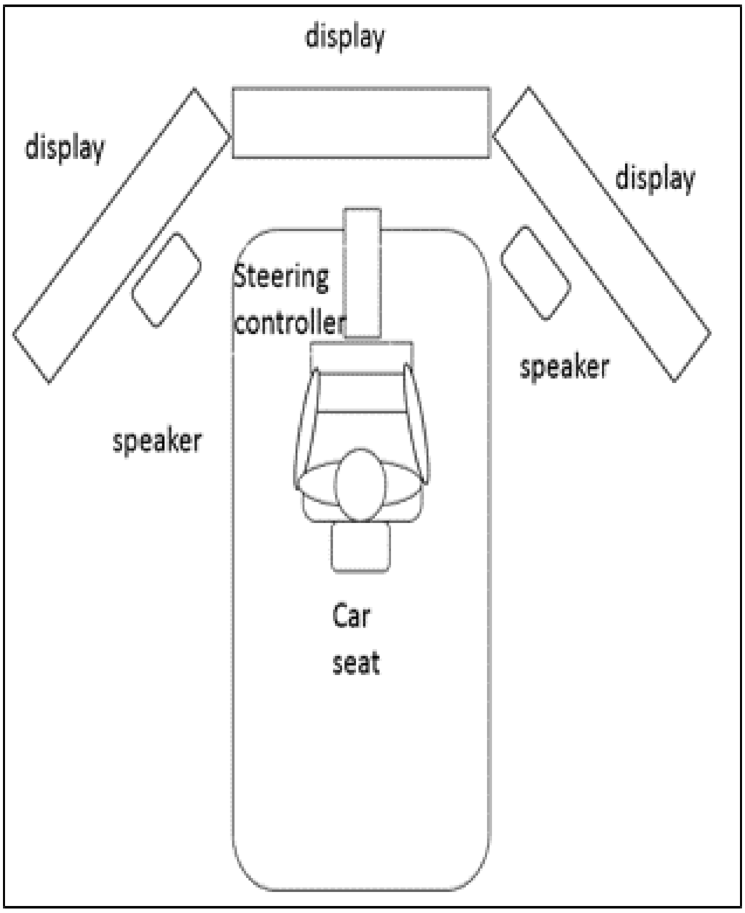

Figure 2.2.1 Driving simulator view from top.

Figure 2.2.2 Driving simulator.

2.2.1 Driving simulator information

The driving simulator contains two subsystems, a physical component and software component, as shown in Figure 2.2.3.

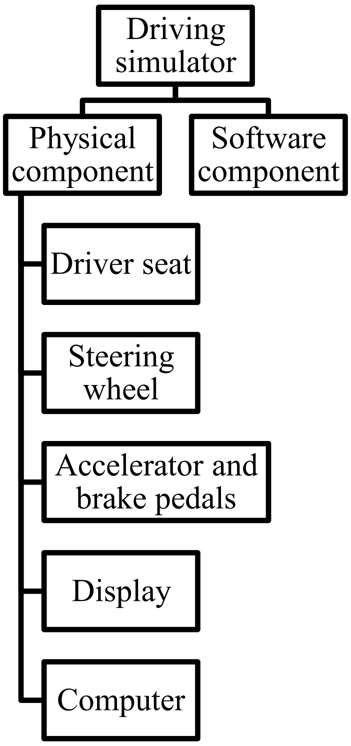

Figure 2.2.3. Driving simulator component.

2.2.2 Physical component

I. Driver seat

The driving simulator seat used in this study was a genuine Nissan Sunny car seat. The component specification, model name, and information are listed in Table 2.2.1.

Table 2.2.1 Driver seat specifications.

Nissan Sunny car seat			
Specification	Vertical length	Horizontal length	Height
Dimension (mm)	540	520	900

II. Steering wheel

The steering wheel used in the driving simulator is shown in Figure 2.2.4. The steering wheel has a diameter of 350 mm.

Figure 2.2.4 Steering wheel.

III. Accelerator and brake pedals

The accelerator and brake pedals are parts of the driving simulator component. The specification, model name, and component information are shown in Table 2.2.2 and Figure 2.2.5 below.

Table 2.2.2: Accelerator and brake pedal specifications.

Manufactured by Thrustmaster	
Specification	Dimension (mm)
Diameter length	40 (W) x 90 (H)

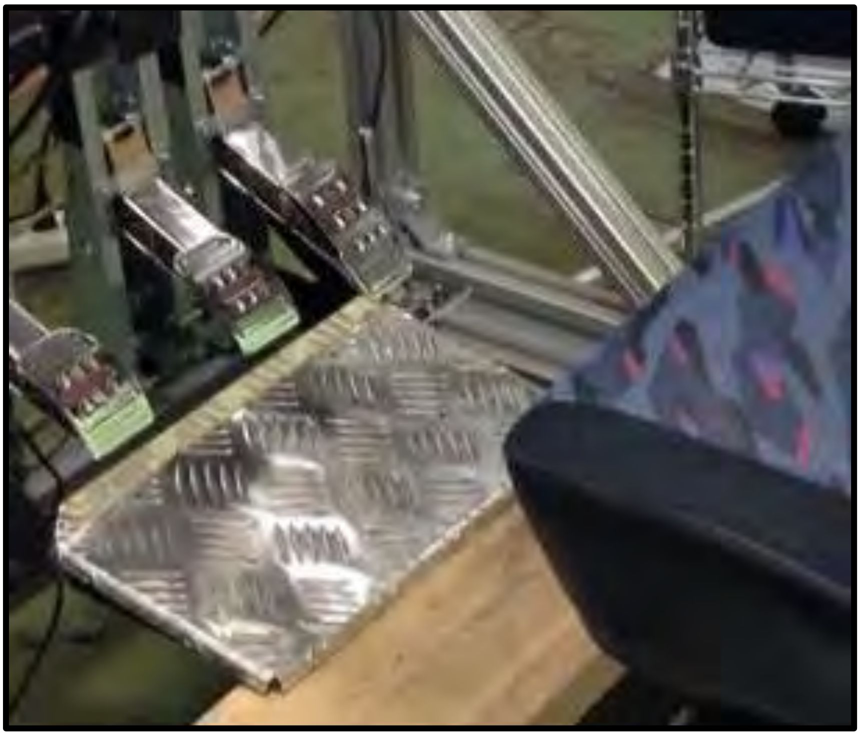

Figure 2.2.5 Accelerator and brake pedals.

IV. Display

One of the driving simulator components is the display. The specification, model name, and display information are shown in Table 2.2.3 and Figure 2.2.6 below.

Table 2.2.3: Display specifications.

Manufactured by Sharp	
Specification	Dimension (mm)
Model name	LC-60Z9
Display size	60 inch（132.9×74.8/152.5）
Pixel number	1920x1080

Figure 2.2.6 LCD Display.

V. Computer

The specifications of the computer used in the driving simulator, model name, and components information are shown in Table 2.2.4.

Table 2.2.4 Computer specification.

Manufacture by TSUKUMO BTO	
Video control, data analysis, driving simulation data collection	
Specification	Dimension
Format	G-GEAR GA7J-I64/XT
CPU	Intel ® Core I'-5930K
Processor	3.7Ghz
Memory	16GB (4GBx4)
OS	Windows 7® Professional 64 bit
Graphic board	NVDIA GeForce GTX 980Ti 6GB

VI. Simulation software-UC/win software

The simulation software used in this study was UC-WIN/Road ver.10.1.2 developed by FORUM 8, using comprehensive 3D visual technology and the interactive concept of virtual reality design. The simulation software's specifications, model name, and component information are listed in Table 2.2.5.

Table 2.2.5. Software specifications.

Manufacture by Forum 8	
Specification	Dimension
Format	C-win/Road Ver10.1.2

2.3 Sound system

2.3.1 Speaker

The speaker is one of components of the driving simulator as shown in Figure 2.3.1. The specification, model name, and component information are listed in Table 2.3.1.

Table 2.3.1 Speaker specifications.

Manufactured by Bose Corporation			
Specification	Format	Input	Impedance
Dimension	301AVM	120W(rms) 400 W (peak)	8Ω

Figure 2.3.1 Speaker.

2.3.2 Amplifier

The specifications of the amplifier used in the driving simulator, model name, and component information are shown in Table 2.3.2 and Figure 2.3.2.