Preventing accidents caused by unintended acceleration and subsequent continuous acceleration in automatic transmission vehicles

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Abstract: The purpose of this study is to provide a fundamental solution from the viewpoint of Human Factors to the numerous accidents caused by unintended acceleration involving automatic transmission vehicles. Annually, an average of 6,900 accidents of this type have occurred in Japan in the last decade with a remarkably high fatality rate of approximately 3.44 %. This high fatality rate is caused by vehicles colliding with an obstacle at full throttle acceleration with an apparent loss of braking effectiveness. The main cause of this type of accident is believed to be human error since evidence of electro-mechanical defects is very rarely discovered in accident investigations. The likely contributing factor behind this type of accident is possibly the similarity of throttle and brake pedal placement and the identical method of operation. This pedal layout leads to pedal misapplication when intending to stop the vehicle. To prevent this type of accident, the authors removed the conventional throttle pedal from the driver's foot space and installed a proprietary hand controlled throttle (HAC-T) system on the center console, which prevents the human error responsible for this type of accident. The HAC-T system was invented based on the viewpoint of Human-Machine Interfaces and aims to achieve a symbiotic human-vehicles driving system. The throttle body with control lever is installed on top of the center console in the prototype vehicle and is easily reached by drivers while maintaining visual contact with the road and surroundings. The HAC-T system consists of a hand controlled throttle system, an organ-type brake pedal with footstool, and a turning knob on the steering wheel. In conclusion, by creating a fundamental solution to prevent this type of accident, the HAC-T system is greatly anticipated.

Keyword: Human-Machine Interfaces; Symbiotic Vehicles Driving Systems

1 Introduction

1.1 History of automatic transmission vehicles

The automobile is vital for the physical distribution network and public transportation in modern society.
On the other hand, unintended injuries caused 93,803 deaths, 41% of which were associated with motor-vehicle crashes in 1960 [1]. In response to this, the National Traffic and Motor Vehicle Safety Act was enacted in 1966 to ensure motor vehicle and road traffic safety in the United States (U.S.).
The torque converter technology was invented in the U.S., and the all new fully automatic transmission vehicles (AT vehicle) was born in 1948. Automatic transmissions removed the clutch mechanisms and simplified driving, so it was called an "Easy drive" [2]. It quickly became popular in the U.S. and spread across the world. In the U.S., the diffusion of AT vehicles was 5% in 1945, and rose to over 90% in 1965 [1]. In Japan, the share of the new passenger AT vehicle sales was 48.8% in 1985, and increased to 98.3% in 2010 [3] (See Fig.1).

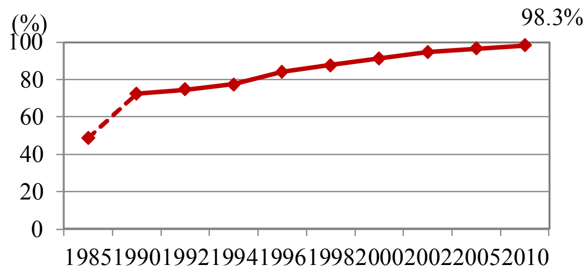

Fig. 1 Rate of passenger AT vehicles sales (Japan)

1.2 Disposition of accidents caused by unintended acceleration

Traffic accidents began to occur due to unintended acceleration (UA) and collision with an obstacle or falling from a multistory parking structure. In Japan, these were typically referred to as "Traffic accidents caused by pedal misapplication" or "Car Crash caused by Unintended Acceleration (CCUA)". CCUAs are characterized as collisions at maximum acceleration due to loss of control resulting in serious human injury and property damages. From 2000 to 2010, driver fatality rate in these accidents was 17 times greater than any other types of accidents according to the affiliate organization of Japanese police statistics from 2000 to 2009 [4] (See Fig.2).

It is reported that in Japan, the average number of CCUAs from 2000 to 2012 was approximately 6,900 cases [4] (See Fig.3). Additionally, no reports were submitted to police for CCUAs in manual transmission vehicles (MT vehicle).
It is assumed that if the vehicle unintentionally accelerated, the driver was not able to stop the engine or shift gears into neutral or park. It is possible to shift gears into park at low speeds (less than approximately 40km/h) and only in vehicles equipped with a mechanical gearshift system. If the driver forces a gearshift at high speeds (more than approximately 40km/h), the gear box will be damaged. On the other hand, it is not possible to shift to park while driving vehicles equipped with electronic gearshift systems.
Vehicle manufacturers insist the cause of CCUAs is a lack of experience with AT vehicles because these have only been on the market since the late 1950's. On the contrary, this is not a rational hypothesis because CCUAs continue to occur throughout the world as of 2015.
One such accident occurred in the U.S., in Santa Monica, California in, July 2006. An 86-year-old male driver rear-ended another vehicle stopped at a red light. According to the highway accident report of the National Transportation Safety Board (NTSB), 10 people died and 63 people were injured when the vehicle crossed intersection and entered a famer's market. One witness reported seeing no brake lights activated on the vehicle and another testified the driver was looking straight ahead with his hands on the steering wheel [5].
In 2010, a number of CCUAs occurred involving Japanese vehicles in the U.S. As a result, multiple lawsuits for liability of the damages were filed [7]. Probable cause of these CCUAs was attributed to a malfunction of the electronic control units (ECU) of the engines. The U.S. Secretary of Transportation took the lead in the accident investigation through both the National Highway Traffic Safety Administration (NHTSA) and National Aeronautics and Space Administration (NASA) in the Department of Transportation (DOT). In 2011, no malfunction in the ECUs was found and the U.S. DOT officially declared that probable cause of these CCUAs was 100% pedal misapplication [8][9]. In Japan, the occurrence rate of CCUAs is comparatively high in drivers over 65-years old and under 25-years old. CCUAs occurred in all age groups of licensed drivers (See Fig.4).
CCUAs have become a social problem with AT vehicles users in every country in the world. It is therefore necessary to develop a means to prevent CCUAs as soon as possible in response to this social need.

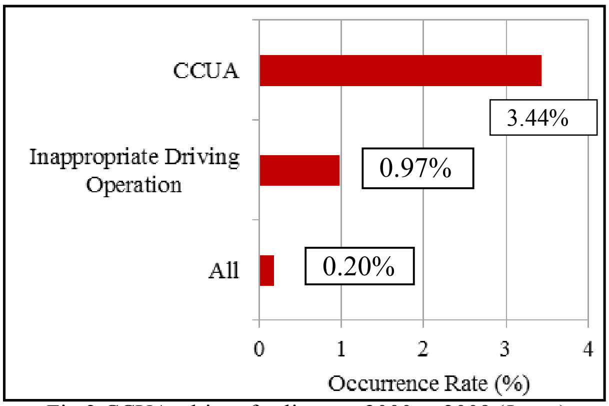

Fig.2 CCUAs driver fatality rate 2000 to 2009 (Japan)

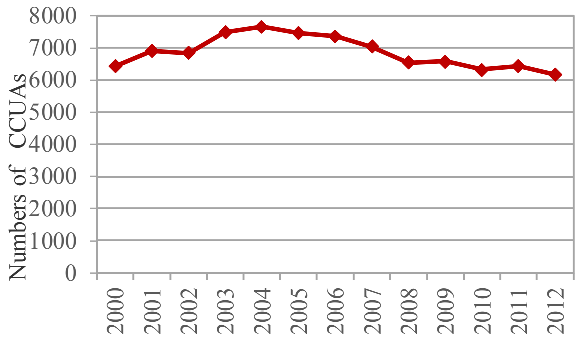

Fig. 3 CCUA statistics 2000 to 2012 (Japan)

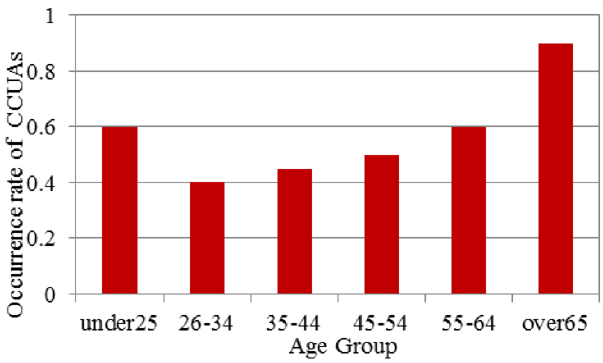

Fig.4 Driver age and CCUA occurrence correlation (2000-2009 Japan)

A statistical analysis of CCUAs has been carried out in North Carolina (NC), U.S., and reported to the U.S. public communities [9] (See Table 1). According to this report, CCUAs occurred at a comparatively high rate in drivers over 65-years old and those under 25-years old (especially those under 20 years), indicating a similar distribution pattern as the Japanese statistical data [7] (See Fig.5). In NC as well, CCUAs occurred in all groups of licensed drivers and it is likely that these rates are similar for older and younger drivers around the world. Other analysis of these NC Police Accident Reports from 1979 to 1995 indicate that a majority of pedal misapplications (over 92%) (a) occurred while the vehicle was in motion when the driver intended apply the brake to slow or stop the vehicle, (b) took place in low-stress situations, and (c) were related to

accidents labeled “unintended-acceleration episode at start-up” [8].
A more detailed analysis of CCUAs from 2004-2008 reveal a total of 1,529 of 2,408 cases (or 64%) occurred while the vehicle was in motion, and 600 cases (or 25%) of which involved driving forward to park. The second most common occurrence involved backing in priority over another at 254 cases, (or 11% of the total) [9] (See Table 2).

Table 1 Prevalence of pedal misapplication crashes in the NMVCCS sample 2005-2007 (weighted).

(National motor vehicle crash causation survey)

Data Collection Year	Number and Percentage of Crashes by Type: Pedal Misapplication Crashes	All Other Crashes	Total
2005	865 (0.2%)	399,118 (99.8%)	399,983
2006	1,973 (0.2%)	851,478 (99.8%)	853,451
2007	2,090 (0.2%)	930,662 (99.8%)	932,752
Total	**4,928 (0.2%)**	**2,181,258 (99.8%)**	**2,186,186**

Table 2 Pre-crash maneuver

(North Carolina database 2004-2008)

Pre-Crash Maneuver	Number	Percent
Going straight ahead	929	39%
Parking	600	25%
Backing (priority over other)	254	11%
Making right turn	119	5%
Slowing or stopping	116	5%
Making left turn	113	5%
Leaving parked position	75	3%
Starting in roadway driveway	49	2%
Stopped in travel lane (Dr in)	27	1%
Parked out of travel lane	19	1%
Avoiding object in road	15	1%
Making U turn	15	1%
Changing lanes or merging	12	0%
Passing	3	0%
Parked in travel lane	3	0%
Other	59	2%
Total	**2,408**	**100%**

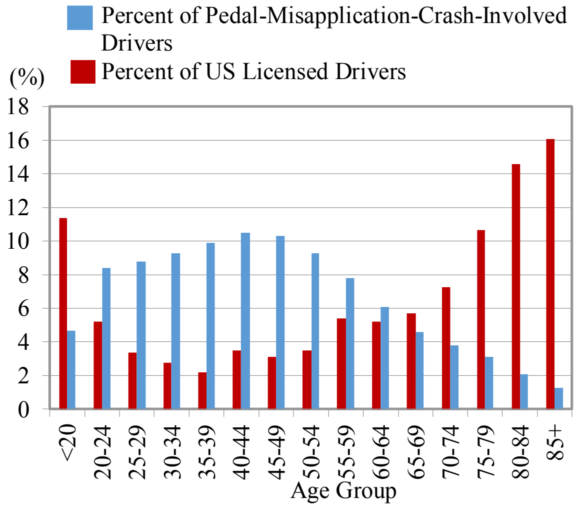

Fig.5 Percentage of drivers in pedal misapplication crashes Reported by the media (n=683) in 2000-2010 versus percentage of licensed drivers in the United States by 5-Year age groupings (n= 198,741,423)

1.3 Presumed contributing factors for CCUA

In a typical CCUA case, the driver intended to apply the brake to slow or stop the vehicle, but after applying the brake pedal, sudden UA occurred and subsequent full throttle acceleration resulted in a crash. Even after a collision, drivers often persist in their belief that they were applying the brake. Although it was perhaps the driver’s instinct to forcefully press the brake pedal to the floor, there has been no satisfactory explanation for why the driver continued to do so when the car unexpectedly accelerated instead of slowed. The similar placement of the gas pedal and brake pedal might possibly contribute to impeding the driver’s recognition of pedals in UA.

2 Conventional devices to prevent CCUA’s

2.1 AUTOMATIC BRAKING SYSTEM

Automobile manufacturers developed devices using radar waves (See Fig.6), sonar waves, infrared-laser beams (See Fig. 7) or cameras (See Fig. 8) as sensors for obstacle detection, in coupling with automatic braking systems [10]. They put these on the market as CCUA prevention devices. These devices include the function of preventing UA while parked and starting the driving cycle. In addition, these obstacle-sensing devices include cameras capable of monitoring the periphery of the vehicle body and recognizing the white lines of a parking lot to prevent UA at start-up.
Manufacturers have also provided emergency braking systems that can function at high-speeds (over 80 km/h) to minimize crash damages [10] whether or not the driver applies the brake. If the driver applies the brake, the automatic braking system will apply additional braking force and reduce collision damage. If the driver does not apply the brake, an automatic

emergency brake is activated. It is able to stop the vehicle as long as the relative speed difference between the two vehicles is less than approximately 30 km/h (See Fig. 6). These obstacle-sensing devices also include features such as an alert function for lane departure and a radar cruise control system coupled with moderate (non-emergency) automatic braking (See Fig.8).

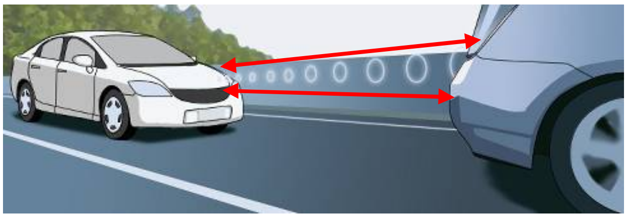

Fig. 6 Millimeter radar wave transceiver (long distance)

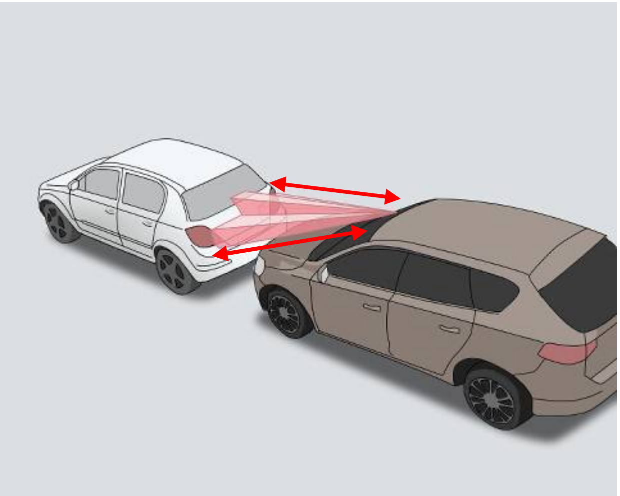

Fig.7 Infrared-laser beam (short distance)

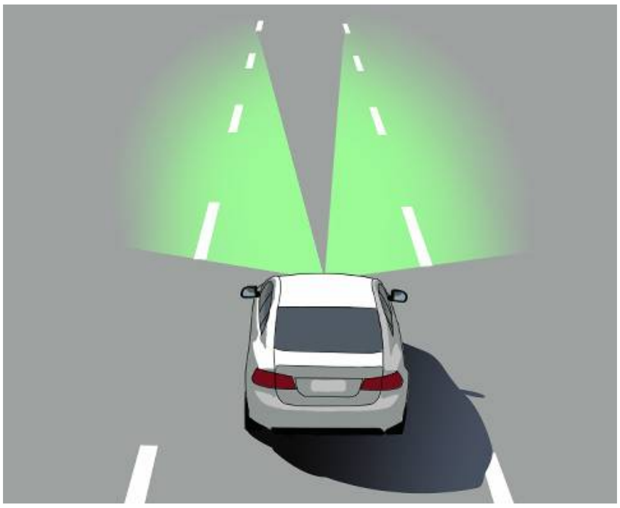

Fig.8 Lane departure alert (by cameras)

2.2 SDAS (Safe driving Assist System)

This device functions such that when the driver presses the gas pedal all the way to the floor and/or pre-determined position, it turns off the engine to prevent vehicle acceleration and CCUAs [11] (See Fig.9).

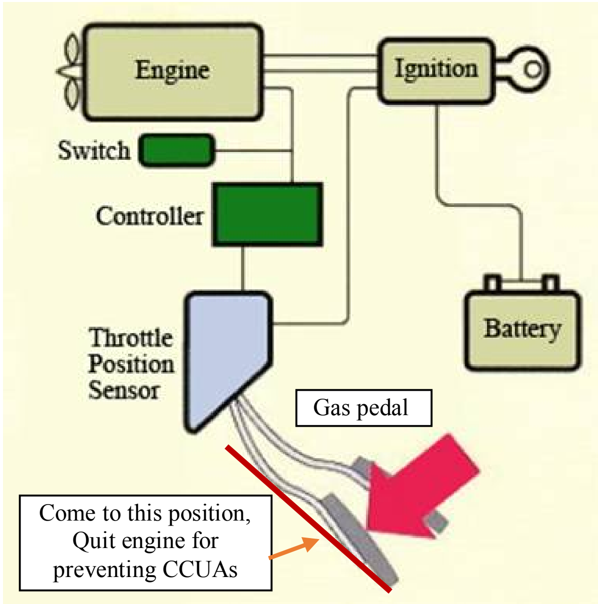

Fig.9 SDAS system diagram

2.3 STOP PEDAL

The gas pedal is mechanically attached/connected to the brake pedal suspension rod, so when the driver applies the gas pedal firmly and reaches a pre-determined position, the acceleration function is automatically released (See Fig.10). When the driver releases the gas pedal to its resting position, the pedal will return to its normal function as the accelerator. If the driver masters this driving procedure, he or she is theoretically able to drive with only the gas pedal, and not use the brake pedal [12].

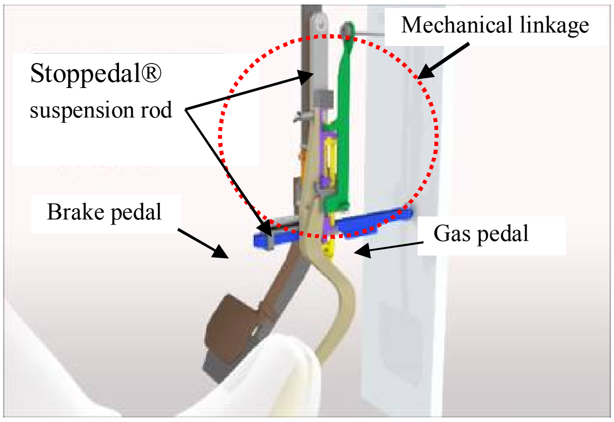

Fig. 10 STOP PEDAL Conceptual system diagram

2.4 NARUSE PEDAL

The NARUSE PEDAL is a device placed over top of the existing brake pedal. The gas pedal of this device operates by rotating the foot in clockwise direction using the right side of the right instep. This gas pedal operating procedure enables the driver to clearly distinguish which pedal is in use. Brake operation is the same as the existing type of brake. The driver places his or her right foot on the brake pedal throughout the driving cycle and when the brake is intentionally pressed, the brake lights turn on [13] (See Fig.11).

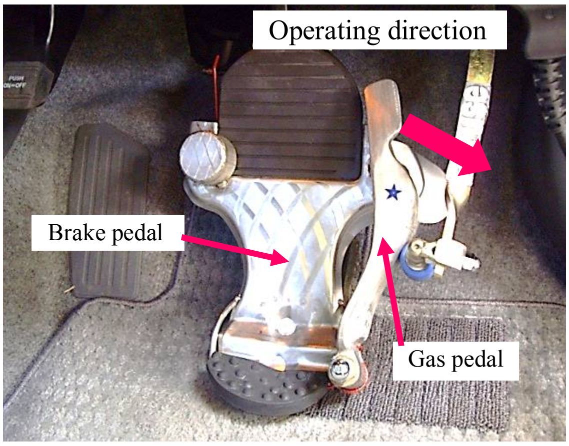

Fig. 11 NARUSE PEDAL

2.5 BLO (Brake system for left leg operation)

In some situations, it might be helpful to use the right leg for the gas pedal and left leg for the brake pedal. This operating procedure enables the driver to clearly discriminate between the pedals. The brake pedal is installed on far left of driving floor for easy operation by the left foot (See Fig.12). The pedal is installed on the vehicle floor with three (3) stud bolts. This allows the driver to place his or her left foot on the brake pedal throughout the driving cycle [14]. In Formula One racing, for example, competition vehicles use semi-AT transmissions, and the majority of professional drivers use their left leg for braking and right leg for accelerator [15] at the same time to maintain high engine revolution.

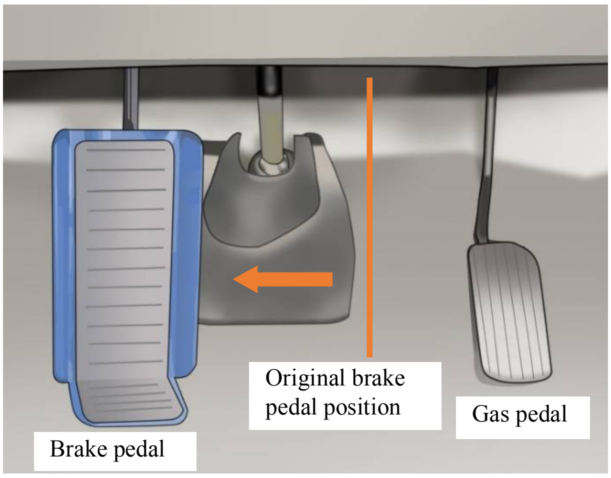

Fig. 12 BLO (Brake pedal for left foot operation)

3 Discussions

In the case of 2.1, the AUTOMATIC BRAKING SYSTEM works under the limited condition that the operator should not touch any of the operation apparatus except for the brake pedal. If the driver either intentionally or unintentionally applies the gas pedal, the AUTOMATIC BRAKING SYSTEM will be overridden. A system malfunction is hereby preempted so that the driver is able to override the automatic system by using the pedals [8]. In June, 2013, a major Japanese automobile manufacturer recalled over 20,000 of its vehicles due to a malfunction of the obstacle sensing devices in the AUTOMATIC BRAKING SYSTEM [16]. The UA prevention system keeps the vehicle from responding during start-up cycle, such as in a parking lot, so that this function is an exemption against automated system's integrity.

It is important to note that the vast majority of pedal misapplications occur during the driving cycle [10] and malfunctions appear randomly. Therefore, the AUTOMATIC BRAKING SYSTEM have limited effectiveness in the prevention of CCUAs.

In the case of 2.2, SDAS are considered reasonably effective to prevent CCUAs. However, when a driver forcefully presses the gas pedal to the pre-determined position, such as when mergeing onto the expressway or other similar situations, the engine will unintentionally quit. Once the engine is gone off, power steering and vacuum powered hydraulic assisted brake systems will fail as well. A substantial number of accidents have been reported due to these engine shut downs [18].

In the case of 2.3, a STOP PEDAL is also considered reasonably effective to prevent CCUAs. Nevertheless, when the driver operates the gas pedal forcefully to the pre-determined position, it may possibly work as a brake. It might cause a hazardous situation in a critical driving situation where acceleration is necessary.

In the case of 2.4, the NARUSE PEDAL is considered reasonably effective to prevent CCUA's. The acceleration function of the NARUSE PEDAL is operated entirely differently from the brake pedal so that the driver can clearly discriminate the active pedal. However, misapplications of the NARUSE PEDAL have been reported, although none of these reports involved continuous operation of the gas pedal [17]. One additional obstacle to wide-spread acceptance of the NARUSE PEDAL is its installed position. Since the NARUSE PEDAL is outfitted over the existing brake pedal, the majority of drivers will feel discomfort with using their right foot to operate the brake pedal. In the case of 2.5, use of the left leg to operate the brake (BLO) is considered reasonably effective to prevent CCUAs. However a skilled and experienced driver of a MT vehicle may potentially misapply the brake pedal as if it were the clutch pedal, causing abrupt heavy braking action.

4 Hand Controlled Throttle/ Brake System (HAC-T System)

The primary contributing factor for CCUA's is pedal misapplication [6][8][9]. For this reason, the HAC-T system simply removes the gas pedal from the driving floor to prevent the misapplication of the gas pedal. The brake pedal works with the existing brake system.

4.1 System configuration

This system consists of (1) a hand-controlled throttle (See Fig.13, 14 & 15), (2) a right-leg-controlled brake (See Fig.13 & 19), (3) two steering wheel turning knobs (See Fig.13 & 18), (4) an extended turn signal lever (ETSL See Fig.18) / turn signal push button switch (TSPS left / right) (See fig.17) and (5) a mist wiper push button switch (MWPS See Fig.17). The hand controlled throttle body is a modified throttle position sensor, taken from the engine firewall and installed onto the center console (See Fig.13 & 14). To operate, the driver grasps the hand controlled throttle body with his or her palm and pushes the throttle lever forward with the ball of the thumb (See Fig.15). Double coil springs are installed inside the throttle lever, automatically returning the engine to the idling position when the lever is released. The traveling stroke of the lever is 2-5 mm in normal city driving including on the expressway (See Fig.15). The brake pedal is installed on the right hand side of the driving floor with three (3) stud bolts and is connected with a crank shaped rod to the root of the existing brake rod (See Fig.19) in the former position of the gas pedal (See Fig.19). When the driver senses a hazardous situation while driving, immediate braking application is permitted. The HAC-T brake system can be installed in any position of the driving floor so that it is feasible for left or right leg disabled people to use. Two single hand-operated turning knobs enable single hand operation of the steering wheel, such as on an upslope corner. These are installed at the 2- and 4 o'clock position on the steering wheel (See Fig.13 & 18). Furthermore, a speed sensitive type of power steering system for drivers with weak gripping strength, such as the elderly and female is also installed. Additionally, a two-way turn signal system is also installed. An extended turn signal lever is installed on the existing turn signal lever to enable activation by grasping the turning knob (See Fig.13 & 18). Finger operated turn signal buttons are also installed on the hand controlled throttle body (See Fig.17). The right turn signal switch is operated with the forefinger and the left turn signal switch is operated with the fourth finger or the middle finger (See Fig.17). Both push button switches are push-ON and push-OFF. The mist wiper function push button switch (to wipe the windshield for one cycle) is also available for the little finger or the fourth finger operation on the hand controlled throttle body along with one time water spray function (See Fig.17).

4.2 **Distinctive features of the HAC-T system**

Hand (finger) application of the throttle is more delicate than leg application. It is possible to control the engine revolution in as small as 100 RPM increments. The right foot placement of the HAC-T brake pedal (See Fig.19) fulfills the natural driving position for the driver because the HAC-T brake pedal is installed in the position of the removed gas pedal and immediate application is feasible without changing leg position. According to a judicial precedent of the Supreme Court in Japan, changing the leg position from the gas pedal to the brake pedal takes an average of 0.8 seconds plus alpha.

New types of accidents, caused by engine shutdown in vehicles equipped with power steering (PS) and vacuum powered hydraulic assisted brake system (VPHB) are occurring. The majority of this type of accident occurs during hill start driving [10]. Once the engine shuts off, all PS and VPHB lose function, resulting in loss of directional control and braking ability [18]. To avoid this, many new vehicles are equipped with hill start assist devices [10][18] but in the HAC-T system, it is possible to operate the throttle and brake simultaneously so that hill start is no longer problematic. The system was installed in a prototype vehicle in 2013, and has been driven more than 15,000 km on public roads in 2015. The prototype vehicle passed Japanese official vehicle inspection in 2014.

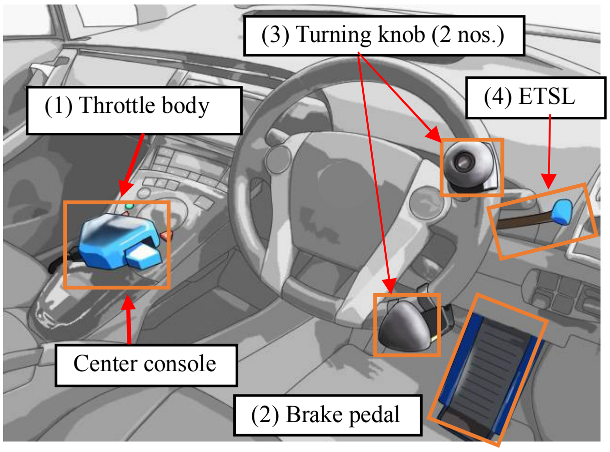

Fig.13 System layout overview

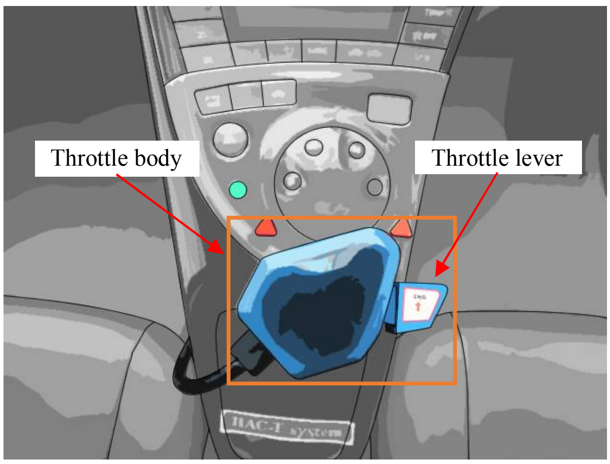

Fig.14 Hand controlled throttle body

(HAC-T system, top view)

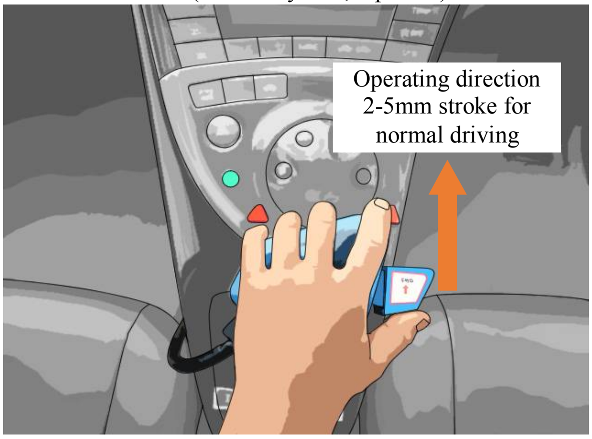

Fig.15 Direction of operation (top view)

(TSPS & WMPS, top view)

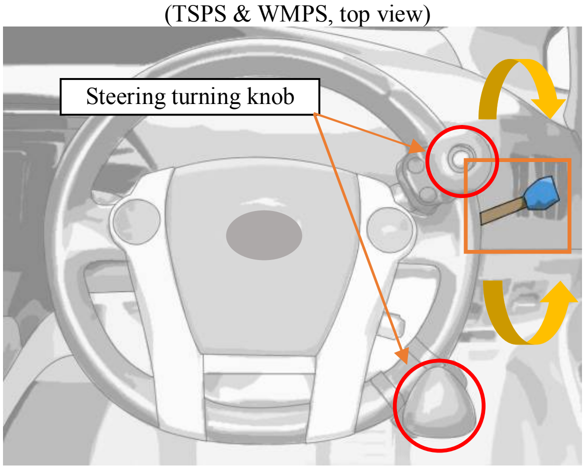

Fig. 18 Extended turning signal lever (top view)

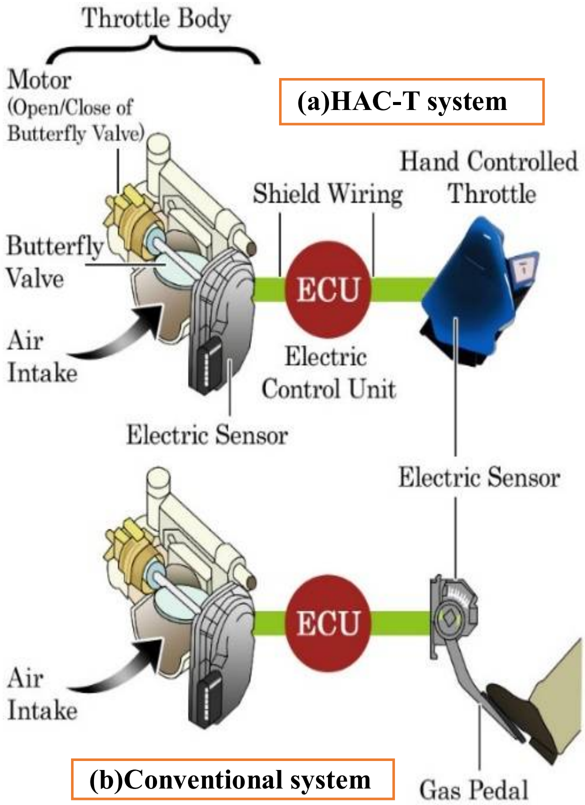

Fig. 16 Throttle Position Sensor Conceptual Diagram

Fig. 19 Brake pedal (front-side view)

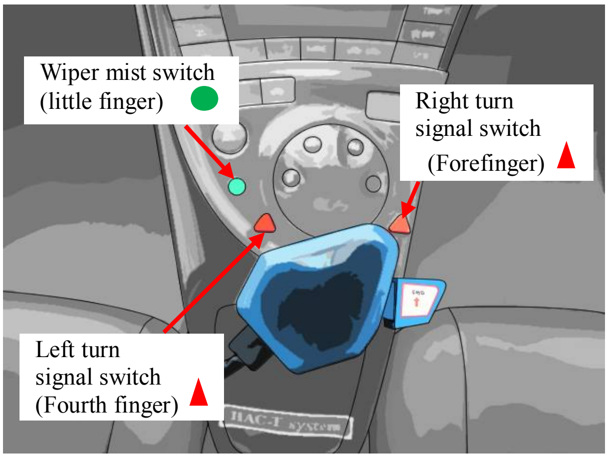

Fig.17 Turn signal switch and wiper mist switch

5 Conclusion

The AUTOMATIC BRAKING SYSTEM discussed in section 2.1 does not function if the driver applies a control apparatus such as the gas pedal. In this case, the automatic system is overridden and UA occurs subsequently to the loss of control can result in a crash. It is also concerning that a system malfunction can arise in any random situation. If this occurs in an automatic system and results in an accident, the driver is entirely responsible. This system is therefore considered slightly incomplete for preventing CCUAs. Both the SDAS discussed in section 2.2 and the STOP PEDAL in section 2.3 are useful for preventing CCUA's but other hazardous situations, such as unintentional braking when acceleration is necessary, may arise. Furthermore, in the case of SDAS, accidents may occur when the engine quits and inducing engine driven hydraulic mechanism quits unexpectedly. From the view point of Human-Machine interfaces, the NARUSE PEDAL discussed in section 2.4 is one of the more convincing devices to prevent CCUAs. However, driver may feel some discomfort as discussed in section 3. The HAC-T system is a very promising means to prevent CCUAs. However, the versatility of vehicle controllability such as single hand steering operation, in comparison with the traditional vehicle needs to be validated through driving experiments in the near future.

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