特集 ACC in Consideration of Visibility with Sensor Fusion Technology under the Concept of TACS*

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The ACC (Adaptive Cruise Control) system maintains the distance to preceding vehicles instead of drivers. However, drivers may feel uncomfortable, especially when visibility is poor, because, for example, drivers tend to maintain longer distances between vehicles when the preceding vehicle is large and blocks their frontal view, whereas the current ACC system tries to maintain the same distance between vehicles despite such conditions. This paper proposes a novel Visibility-ACC (V-ACC) system, which enhances the current ACC system by considering such driver behavior under the concept of TACS (Three-layer Architecture for Comfort and Safety). A driver model was built from the driver behavior database and a new distance control algorithm for the V-ACC system was constructed based on the driver model and newly developed sensor fusion system. A vehicle test was performed to evaluate the advantages of the new system.

Key words: TACS, Radar, Camera, Sensor fusion, ACC, Visibility

1. INTRODUCTION

The development of driver assistance systems that lead to better driver performance by detecting various surrounding situations is in progress. Many companies already have put them into production.

We think that driver assistance systems can be regarded as a control layer that is located between driver and vehicle. This layer works like a driving instructor; it recognizes the surrounding situation and then supports or restricts driver's operation to realize more comfortable or safer drive. (We call the concept of this 3-layers architecture "TACS (Three-layer Architecture for Comfort and Safety)"; we would like to explain about it at chapter 2.) The important thing is: the system must have a reference model of ideal driving corresponding to surrounding situations. In other words, to develop such system, it is necessary to analyze what kind of inputs a driver needs and what kind of behavior he does with those inputs.

Then, what are those inputs? It is well known that vision is the most important at driving to acquire information of surrounding situations. From a different point of view, we can also say that a driver will show some reaction if the driver's vision is insufficient, because he highly depends on his sight. Today's driver support system mainly focuses on how the system should act when any object can be seen by sensors. But we should also analyze how a driver reacts when objects can not be seen by his vision, in other words, when "visibility" is poor.

Factors of poor visibility at driving situation are the following three items[1] (see **Fig. 1** also):

(1) Illumination: Illumination is necessary to acquire information from vision because driver can not see anything at the utterly dark area. On the other hand, it is difficult to acquire information from vision in the backlight situation.

(2) Weather: It is hard to see in the rain, mist etc.

(3) Occlusion: When there is a solid object, such as walls, big trucks and so on, that blocks driver's view, he might not be able to acquire enough information. Such situation, something overlays others, is named occlusion and could be a big factor of poor visibility.

This paper analyzes the behavior of driver who has a poor visibility especially caused by the occlusion of the preceding vehicle the driver wants to follow, which is

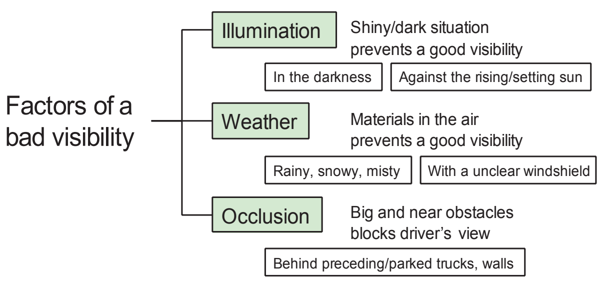

Fig. 1 Three major factors of a bad visibility for a driver

called "target vehicle".

There are many researches on the optimal following distance settings of ACC system (Adaptive Cruise Control system, which is one of the most popular driver support systems).[2)-6)] Nevertheless, the relationship between the following distance and blocked view size by the target vehicle was not cleared. This paper analyses it with real driving data of skillful drivers for different types of target vehicle to build a driver's behavior model, and then proposes a new distance setting method of ACC using this model and validates it with real system.

At chapter 2, general concept of TACS is explained at first. Chapter 3 analyzes the relationship between the occlusion by the target vehicle and driver's operation. Chapter 4 explains the method of the new distance control and the sensor fusion system consisting of a radar and a mono-camera to detect the size of the target vehicle. Chapter 5 explains the experimental result using real ACC system.

2. TACS CONCEPT

Automobiles had a two-layer architecture in the past century. In the coming couple of decades, the two-layer architecture will be replaced with the three-layer architecture in order to increase the comfort and the safety of the automobiles. The conventional two-layer architecture consists of the driver layer and the real-dynamics layer, and those two layers are connected to each other directly, as shown in **Fig. 2(a)**. The movement of the driver's foot on the acceleration pedal, for example, controls the amount of gas fed to the engine directly. With the two-layer architecture, the driver needs to push the acceleration pedal harder on an up-hill to keep the constant speed.

The novel three-layer architecture includes the "smart transfer layer" between the driver and real-dynamics layers as shown in **Fig. 2(b)**. The acceleration pedal, for example, is not connected to the engine directly. The acceleration pedal is an input device to express the driver's intentions. The smart transfer layer reads the driver's intentions and sends control signals to the real-dynamic layer. If sensors detect obstacles, for example, the smart transfer layer tries to guide the driver to reduce the vehicle speed by increasing the reaction force for the acceleration pedal.

The role of the smart transfer layer for automobiles is

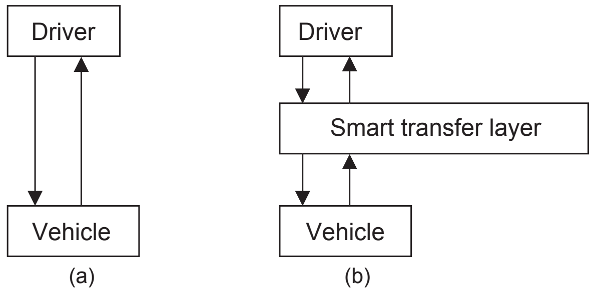

Fig. 2 Automobile architectures

similar to the roles of "operating system" and "application" for computers. Both allow more freedom to the human users compared to the two-layer architecture. The automobiles are expected to be more user friendly as "operating system" and "application" made computers more convenient.

The TACS concept allows the driver to keep all the control power. The conventional ACC (Adaptive Cruise Control) system lets the system control the vehicle speed. The driver can override the ACC but cannot keep controlling the speed. With the TACS-based ACC, the spring for the acceleration pedal has two regions; i.e., the soft and hard regions. The vehicle cruises at the speed recommended by the sensors if the driver pushes the acceleration pedal to the end of the soft region. The driver has the right to increase the speed by pushing the acceleration pedal into the hard spring region anytime. This means that the TACS provides more authorities to the drivers and makes the driving fun. The TACS is a human-oriented concept.

Research on the relations between the ideal driving and the understanding of the surrounding information is necessary to realize such an ideal system for the future. In the next chapter, the result of our research about the tendency of driver at the time of following target vehicle is explained.

3. POOR VISIBILITY AND DRIVER'S BEHAVIOR

It is said that a driver gets almost 90% of the information on a driving situation from his sight, especially in the effective view range of ± 4 degrees. The less a driver sees, the less quickly he can react to the dangerous situation.

Therefore, it is fatal issue for a driver to get enough information from his sight.

For example, let us think about a driver, who follows a preceding target vehicle. He does not only pay attention to the behavior of the target vehicle, but also cares about the situation in front of the target vehicle. At that point, the target vehicle is an obstruction, which blocks the driver's view. If the target vehicle size is too big and near, the driver would have a poor visibility. In such situation, the driver can not acquire enough information for safety driving.

Let us see **Fig. 3** as an example. Different target vehicle type has a different size of blocked view even if they are located at the same distance. You can imagine that it would be more stressful to drive in the case of **Fig. 3(a)** than **Fig. 3(b)** because of the lower visibility.

Therefore, skillful drivers tend to adjust the distance according to the size of the target vehicle to maintain his sufficient visibility. We focused on this driver's behavior, in other word, the relationship between distance control and driver's visibility, especially the effect of the blocked view by the target vehicle. Conventional ACC system does not consider it and will have a same distance for different target vehicles. The aim of this study is to formulate this behavior, and implement the new ACC distance setting to realize safer and more acceptable following distance. Such ACC system, named "Visibility-ACC (V-ACC)" is our target application.

We had an experiment at first to analyze the relationship between the target car type and the driver's preferred following distance.

3.1 Experimental method

(1) **Subject drivers**: 4 males whose ages are from 30 to 36 years old. Their driving experience is more than 10 years; they are skillful drivers.

(a)　(b)

Fig. 3 Different types of target vehicle at same distance (a: Truck, b: Compact) and visibilities

(2) **Test vehicle**: Upper-class passenger car with radar sensor, which can detect the distance and angle and the velocity between the host and the target vehicle with 10 frames per second. The host vehicle's speed can be measured with same frequency also.

(3) **Process of experiment**: Each subject driver follows three kinds of target vehicle (see **Table 1**) with manual driving (not using ACC system) on the same expressway that consists of straight road or slow curve, and it is clear enough to get visibility (not rainy or misty). We assumed the rear projection area (RPA), which means the blocked view size, as a parameter of the size of the target vehicle. Collected dataset is: distance and angle and relative velocity from radar sensor and velocity of the host vehicle. The period of the data is ten minutes, and two sets are collected for each type of target vehicle per subject driver. We had this experiment over two different days and acquired data for total 480 minutes. We use the data during steady following condition to the target vehicle, it means low relative velocity.

3.2 Experimental results

Figure 4 shows the frequency distribution map of the TTH (Time To Headway) for driver A.

In the ACC algorithm, the following distance is usually expressed as TTH, which is defined as follows:

$$T(s) = R(m) / V(m/s)$$

where R is the distance from the host vehicle to the target vehicle, and V is the host velocity. TTH has almost same meaning as "following distance", but it is better expression than distance because the appropriate TTH value tends to be almost constant even if the host velocity is changed and the appropriate distance is also changed.

TTH is also a good measure to analyze the tendency of

Table 1 Three kinds of target vehicle and their sizes

	Width (m)	Height (m)	Projection (m^2)
Compact	1.660	1.500	2.490
Middle	1.730	1.430	2.474
Truck	2.490	2.980	7.420

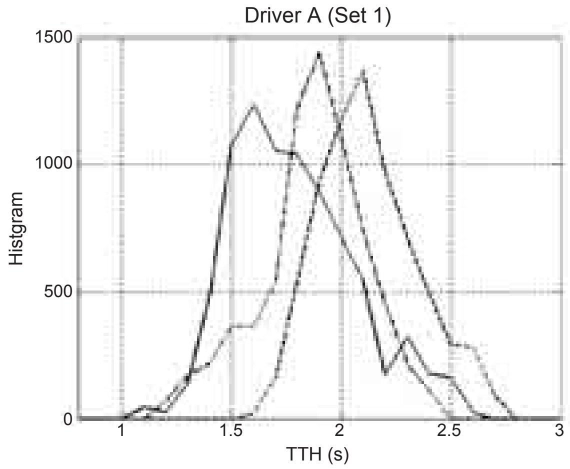

Fig. 4 Frequency distribution map of TTH for driver A: solid line for compact car, dash-dotted line for middle car and broken line for truck

driver's following distance. Each distribution in **Fig. 4** has almost same shape with a peak at the middle. **Table 2** shows a result of all drivers. Those results show a tendency that the driver takes more TTH for a truck than a compact car, and that standard deviations are almost same value of about 0.3 second. Every driver had different TTH mean values, but same tendency. Driving situations were almost same, so we can say that this tendency was caused by the difference of the target vehicle.

3.3 Analysis and formulation

From the experiment, we can easily say that every driver changes TTH according to the size of the target vehicle. The larger the size of the target vehicle is, the longer the appropriate TTH becomes. We want to formulate it and make a driver's model, but problem is, each driver has a different TTH value.

It could be said from **Table 2** that the mean TTH values of driver A tend to be always smaller than those of driver B or D. Those of driver C are on the contrary larger than the others. So we tried to normalize it by dividing by the TTH for the compact car in order to compress the effect of the difference of the driver. **Table 3** shows the result of TTH ratio. From this table, we can say that TTH will be about 1.2 larger in case of truck than that of compact car. In case of middle car, which has almost same RPA as compact car, the TTH ratio is also almost same value of 1.04 on average.

Table 2 TTH results for each vehicle

		Compact	Middle	Truck
Driver A	Mean	1.78	1.87	2.12
	SD	0.24	0.24	0.23
Driver B	Mean	1.66	1.55	1.90
	SD	0.30	0.30	0.44
Driver C	Mean	1.83	2.00	2.35
	SD	0.29	0.32	0.35
Driver D	Mean	1.58	1.62	1.83
	SD	0.20	0.22	0.26

Figure 5 shows the plot between the RPA and TTH for every driver. We assumed that the relationship between RPA and TTH ratio would be expressed by linear line shown in **Fig. 5**. By using RPA as an additional parameter in ACC system to modify TTH with this line as a TTH gain value, ACC system can adapt to the target vehicle size, in other words, the system can consider the reduced visibility caused by the target vehicle.

In the next chapter, we will propose a new ACC system named V-ACC (Visibility-ACC), using this parameter.

Table 3 TTH ratio for different target vehicles

	Compact	Middle	Truck
Driver A	1.00	1.07	1.26
Driver B	1.00	1.02	1.22
Driver C	1.00	1.08	1.19
Driver D	1.00	0.98	1.20

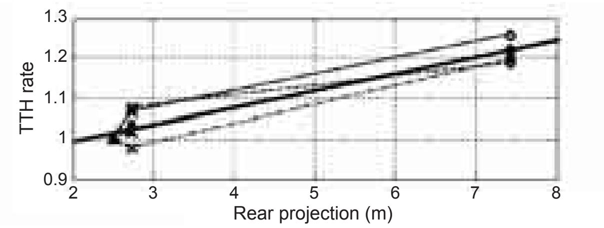

Fig. 5 Tendency of drivers' TTH (A: solid, B: broken, C: dotted, D: dash-dotted) with different preceding vehicles that have different rear projection area size (triangle: compact, cross: middle, circle: truck, solid circle: average TTH rate of each vehicles). TTH is shown as a ratio of the compact car TTH. Thick solid line is the TTH gain settings for the experimental ACC system.

4. DISTANCE CONTROL ALGORITHM FOR V-ACC

In this chapter, we offer a new method of distance control for ACC system and also a new sensor which detects the RPA of target vehicle.

4.1 New distance control algorithm

Figure 6 shows a distance control block diagram of V-ACC. A usual system has a TTH select switch, for example long, middle or short. Base value of control target TTH is calculated basically from this switch. TTH deviation between control target TTH and real TTH is one of the inputs of the acceleration controller. In V-ACC, the TTH gain value is multiplied to the base control target TTH. This gain is calculated by using the RPA value of the target vehicle detected by sensor, and TTH gain map shown in **Fig. 5**.

4.2 Process flow

The proposed ACC algorithm process is as follows:

(1) The target vehicle is detected and its distance, center position, relative velocity, width, height and classification are measured by the sensor system (explained in the next section).

(2) The RPA of the target vehicle is calculated from width, height and classification.

(3) The TTH gain is calculated by using RPA and the switch (as explained in the former section).

(4) The final target TTH is calculated by multiplying the TTH gain to the standard target TTH value.

(5) The final target TTH is realized by controlling throttle and brake actuator just like a usual ACC system.

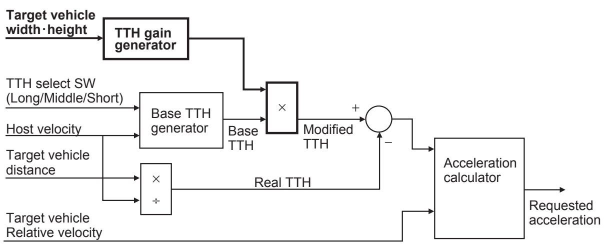

Fig. 6 Distance control block diagram of V-ACC Thick lines and blocks are added to conventional ACC.

4.3 Forward vehicle detection sensor for V-ACC

To realize this V-ACC, the advanced sensor system, which can detects RPA, is necessary. We had already developed the sensor fusion system, which uses a radar sensor and a mono-camera[7], and added a RPA detection function this time. This sensor fusion system is briefly described in this section.

The sensor system consists of a MMW (Milli-Meter Wave) radar and a camera sensor shown in **Fig. 7**. Target car image will be clipped out from whole image by using object position data acquired by MMW radar to reduce computational load of image processing. Then the image processing will be done on the clipped image to acquire the accurate horizontal position, width and height.

Width and height of the target is basically extracted by using vertical and horizontal edge image. To secure the robustness, other detection methods, for example shadow shape and symmetry detection of the target rear image and radar wave reflection intensity, are also hired to estimate comprehensively.

Those outputs are synthesized using Bayesian causal networks in our sensor fusion system[7] to calculate the total estimation result. **Figure 8** is the causal model for the estimation of height. It depends on the classification and width of the target car, and detected by the image detection algorithm such as rear window detection, vertical and horizontal edge verification. Height is constant value, so depends also on previous value. Classification and width are also estimated with this model and other detection methods simultaneously.

Figure 9 shows an example result of the sensor system. A rectangle means a detected position and size of the object. We can say that the sensor system detects the height and width (RPA) well.

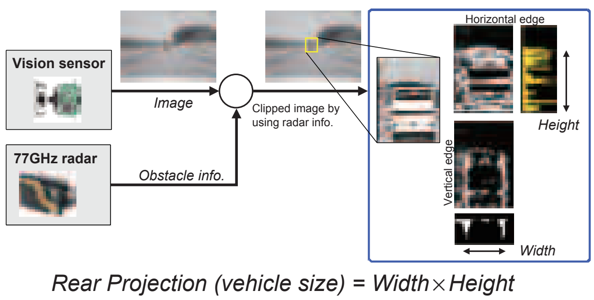

Fig. 7 Data flow of RPA detection

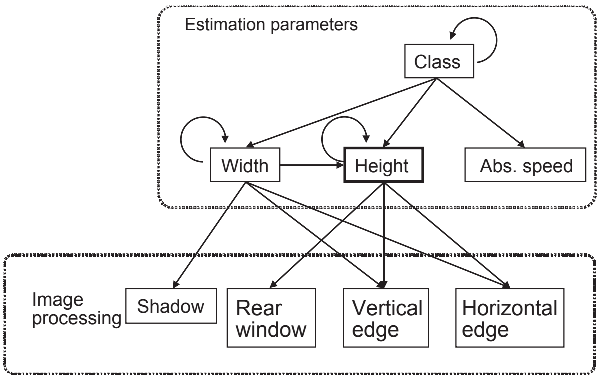

Fig. 8　Bayesian causal network for height estimation

Fig. 9　Rear projection area detection result

5. V-ACC EXPERIMENTAL RESULTS

To confirm the effect of the proposed V-ACC system that contributes to keep more appropriate and safer distance to secure a driver's vision, we had an experiment of the proposed distance control using a test vehicle with the sensor that we mentioned in chapter 4.

Figure 10 shows an actual scene of the V-ACC control, and **Fig. 11** shows actual following distance and TTH data for two different target vehicle types, compact car and truck, during the V-ACC activation at speeds of 80km/h. In this case, TTH value of 2.00 s is applied when a compact car is the target. This is a base TTH value and same as that of a conventional ACC. This means there is no difference between conventional ACC and V-ACC when the target is small. In the case of truck target, V-ACC system calculates the modified TTH based on the size of the target vehicle, so TTH value is larger than usual and the following distance is wider, about 2.4 s.

We can say that the V-ACC actually realized the larger distance by calculating RPA and setting larger TTH, in other words, the blocked view size is reduced. The size of RPA is reduced to 77% of that of the conventional ACC in average in this case (**Fig. 12**).

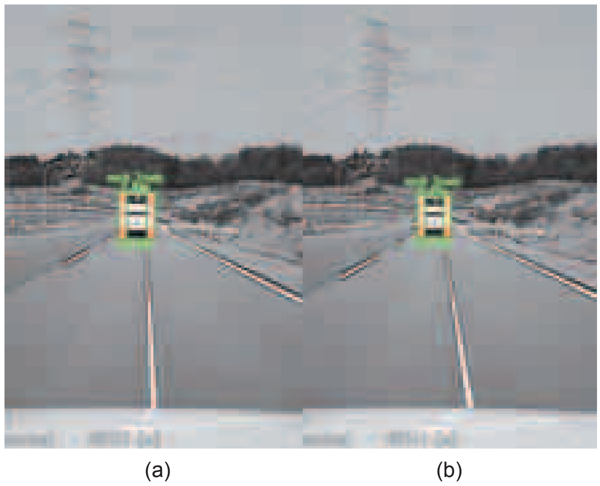

Fig. 10　Actual following scene during conventional ACC (a) and V-ACC (b). Incase of V-ACC, TTH value is larger than usual and the following distance is wider.

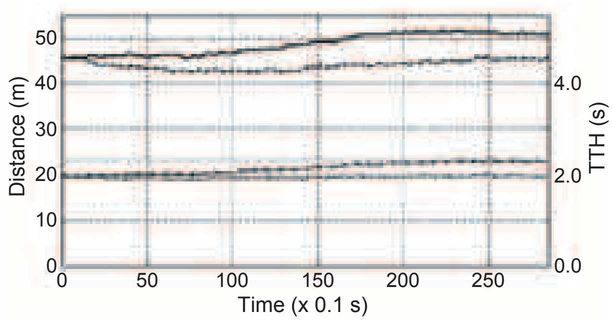

Fig. 11　Following distance and TTH during V-ACC (solid and broken line: distance, dash-dotted and dotted line: TTH, solid and dotted: truck, broken and dash-dotted: compact vehicle)

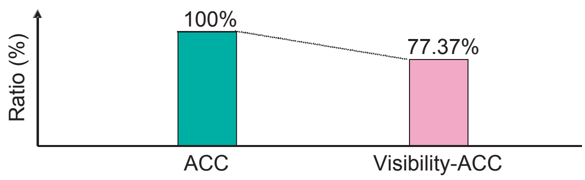

Fig. 12　Improvement of blocked view size between conventional ACC and V-ACC

6. CONCLUSION

We achieved followings in this paper:

(1) It is confirmed that the size of the preceding target vehicle affects the driver's following distance. The bigger the target vehicle is, the longer distance the driver wants to maintain. It means, poor visibility (blocked vision by the preceding vehicle in this case) affects the appropriate distance value between the host and target vehicle.

(2) A new distance control method for ACC system named V-ACC (Visibility-ACC) is proposed. This ACC modifies the following distance according to the size of the target vehicle.

(3) The new sensor fusion system is employed in this V-ACC system to detect the height and width of the target vehicle.

(4) The height and width detection is demonstrated and the advantage of proposed ACC is confirmed by using a test vehicle with real sensor system.

Possible directions for future research include:

(1) More various types of the target vehicle and drivers should be examined.

(2) Further factors of an appropriate following distance should be also concerned in ACC system. Especially, other visibility factors such like illumination or weather condition such as rain or mist should be examined.

(3) The effect of the occlusion (blocked vision) should be more precisely examined. For example: blind corner and appropriate host vehicle velocity, lateral movement of the host vehicle behind a large car, etc.

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