ADAS Sensor Requirements for Eco Driving*

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Sensors used for Autonomous Driving (AD) and Advanced Driver Assistance Systems (ADAS) offer opportunities to improve fuel economy. We examined additional requirements which contribute to achieving fuel efficient driving. In consideration of vehicle electrification, we selected as the study target vehicle a hybrid car equipped with a regeneration function. We examined the relation between the fuel saving effect and sensor performance using both this vehicle and a simulation tool.

Key words :

CO_2 Emissions, ADAS, Hybrid Vehicle

Introduction

There have been fuel-saving application proposals which control vehicle speed, charge-discharge or driving route[1)-4)]. However, only few studies deal with integration of multiple applications or sensor requirements. In addition, the test conditions such as road environments, vehicle speed profiles and vehicle types are limited. While integrating multiple applications could cause a trade-off problem, it has a possibility to improve fuel economy significantly. In this research, we quantify the fuel-saving effect and sensor performance based on the integrated application. Fuel economy is calculated by utilizing a test vehicle and a simulation tool under multiple vehicle types, roads and vehicle speed profiles to explore different sensor requirements from conventional ones for ADAS.

First, we list up fuel-saving applications from previous researches to select promising applications (ECO ACC, Battery management). Then, we combine them into one application. After that, it is implemented into the simulation tool to clarify the relation between fuel-saving effect and sensor performance. Lastly, necessary sensor performance is derived based on improving fuel economy.

Method

Benchmark of Eco Application

Fuel-saving applications using ADAS sensors are extracted from papers and patents. Table 1 describes the list of them. The major control variables are vehicle speed, charge-discharge amount and driving route. Among them, we choose ECO ACC and battery management as the applications to be examined, since they can improve fuel economy significantly. In addition, they only need widely-used autonomous

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sensors. In this paper, we discuss the trade-off problem and fuel efficiency of the integrated application.

Table 1 Sensors for eco driving

ECO-Application	Control variable	Main sensing contents	Main sensors
ECO Driver Assist	Vehicle speed	Traffic sign , limit speed	Camera, ADAS locator
ECO ACC	Vehicle speed	Preceding vehicle	Lidar / radar
Cooperative ACC	Vehicle speed	Multiple preceding vehicles	Lidar / radar,V2V
ECO lane change	Route/path	Surrounding vehicles, lane	Camera,radar,V2V
Green wave system	Vehicle speed	Traffic signal , intersection	V2X
ECO routing	Route/path	Map info. , traffic stream	Car navigation
Battery management	Amount of charge	Road geometry (slope, curve)	ADAS locator

Eco ACC

ECO ACC improves fuel economy by vehicle speed control with utilizing Pulse & Glide (PnG) method. The vehicle speed profile of PnG is shown in Fig. 1. PnG is a driving method repeating the acceleration phase with high engine power around the "sweet spot" of the engine (Pulse) and a deceleration phase with "coasting" (Glide). Here, "sweet spot" means the engine driving point achieving the maximum efficiency and "coasting" means freewheel driving with engine off. Generally speaking, constant-speed driving is known as the way of improving fuel economy, because it does not lose energy through braking and accelerating. However, PnG can be more efficient method under the same average speed. The reason is that driving at constant vehicle speed is relatively low efficiency, because engine power is too low to achieve "sweet spot" without acceleration resistance. On the other hand, in the case of PnG, engine efficiency can be improved by acceleration with high engine power around the "sweet spot" until the vehicle speed reaches the set upper limit and decelerates with engine off.

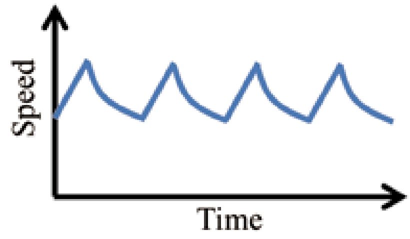


Fig. 1 Pulse & Glide speed profile

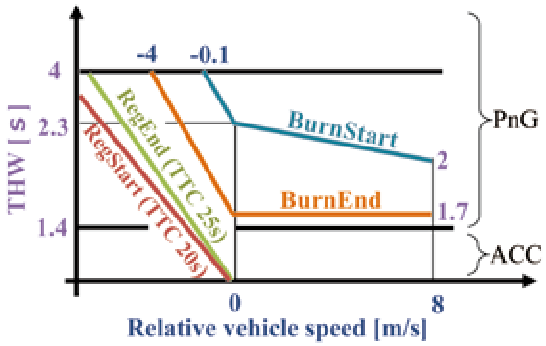


Fig. 2 Control map of PnG with ACC

As this research focuses on the clarification of sensor requirements, a simple control system is adopted. State of the control consists of Pulse, Glide and deceleration which is switched depending on THW (Time Head Way: defined as following distance divided by vehicle speed), relative vehicle speed (defined as subtract ego vehicle speed from preceding vehicle speed) and TTC (Time To Collision: defined as following distance divided by relative vehicle speed).

Control strategy is as follows (see also Fig. 2):

- When the state is positioned in the upper right of "BurnStartLine", the vehicle accelerates (pulse).
- When the state is positioned in the lower left of "BurnEndLine", the vehicle decelerates (glide).
- When the state is positioned between "BurnStartLine" and "BurnEndLine", the vehicle holds previous control phase, that is, if the vehicle was accelerating in the previous step, it continues acceleration.
- When the state is positioned in the lower left

of "RegStartLine", the vehicle decelerates with regeneration. This control phase lasts until the state comes in the upper right of "RegEndLine".

The regeneration power is designed not to give uncomfortable feelings to drivers in the sensory evaluation. When THW is bigger than four second, the vehicle performs PnG at the allowable vehicle speed. The upper limit of the allowable vehicle speed is the ACC target speed and lower limit is 0.9 x the ACC target speed. On the other hand, when THW is lower than 1.4 second, the vehicle speed is decided based on conventional ACC strategy. The reason is because the driving feeling cannot be accepted by drivers.

Battery Management

Battery management means controlling SOC with looking ahead based on the information about congestion, driving route and so on. The application considered in this research is "preconditioning of the battery state of charge" (P-SOC) to improve fuel economy at a long downhill road, one of the typical usage of battery management. In this scene, if the vehicle drives at constant vehicle speed, it needs braking with regeneration and SOC reaches the upper limit. Therefore, some portion of potential energy cannot be regenerated. In the case of P-SOC, the battery energy is consumed by the motor before downhill to avoid prohibiting of regeneration because of full charge (Fig. 3).

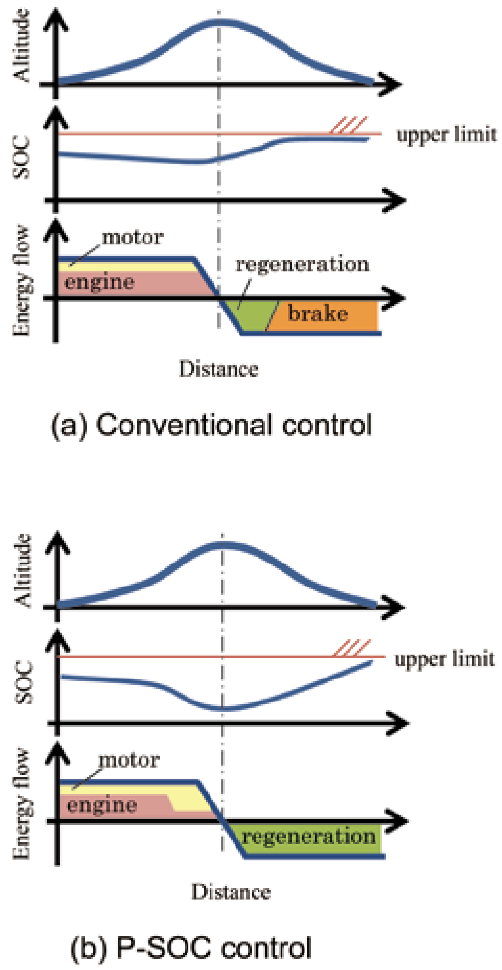


Fig. 3 Conceptual diagram of P-SOC

The algorithm of P-SOC is as follows:

(1) Assuming that the vehicle drives a certain distance at constant vehicle speed from the current position, battery SOC profile is estimated to judge whether it exceeds the upper limit.

(2) If the excess occurs, the excessive energy is discharged by increasing motor power by the time when the regeneration is started.

Therefore, the item detected by the sensor is a slope profile in the range from the current position to the destination. Here, it is assumed that the battery capacity is a fixed value.

Application unification

In this research, both ECO ACC and P-SOC are executed to verify the additional sensor requirements under the condition that these two applications are integrated. Since the battery cannot charge or discharge at Glide phase, the control variables of each applications (ECO ACC: vehicle speed, P-SOC: SOC) are not independent. Therefore, the control strategy at Glide phase is designed as follows: gliding is executed as much as possible within the range of the following distance to the preceding vehicle and the constraint of the target vehicle speed. The reason of this idea is because gliding is an efficient way to use kinetic energy directly, while charge-discharge generates energy loss in the process of conversion from kinetic energy to electric energy. The control inputs of the integrated application are shown in Table 2.

Table 2 Input of application

Input	Application destination	Assumed ADAS sensor	Examination item
Ego vehicle speed	PnG, P-SOC	-	-
Set speed for ACC	PnG, P-SOC	-	-
Relative distance	PnG	Radar, lidar	Detection range
Relative speed	PnG	Radar, lidar	Detection range
SOC	P-SOC	-	-
Slope profile (Road resistance)	P-SOC	ADAS locator	Detection range

In this research, fuel economy improvement is simulated to examine the requirements of the preceding vehicle and the slope profile detection range. Driving force should be determined based on road surface abrasion, air resistance, slope and energy loss at the powertrain system. However, in this research, variables other than slope, which is the major influential factor, are regarded as fixed values for the sake of simplicity.

Simulation

In order to clarify the difference caused by vehicle specifications, two vehicle models are used. Table 3 shows the vehicle specifications. The vehicle data, such as engine efficiency and battery capacity which are necessary for simulation is obtained from public information and vehicle testing results.

Table 3 condition of vehicle

	C-Segment vehicle	E-Segment vehicle
Weight	1500 kg	2100 kg
Engine displacement	1.8 L	3.5 L
Battery capacity	0.3 kWh	0.5 kWh

Driving force to maintain constant vehicle speed (F[N]) is calculated based on the road load shown in Fig. 4 and slope:

$$F = F_{flat} + Mg\sin\theta$$

Here, F_{flat}: road load, M: vehicle inertia weight [kg], g: gravity acceleration [m/s^2] and θ:slope[deg] respectively.

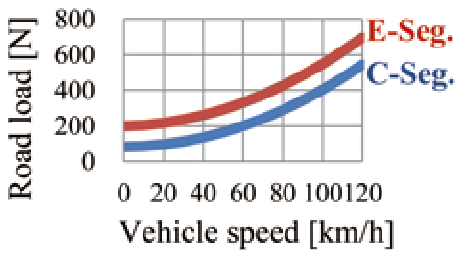


Fig. 4 Road load on flat road

Table 4 shows the road condition used for simulation to examine the requirements of detection range. In order to simulate fuel economy on the actual roads, the vehicle speed profile of the preceding vehicle is measured under the condition that the vehicle drives on public roads with ACC. Fig. 5 shows the profile of slope and altitude of two public roads used for simulation.

Table 4　Simulation condition

Examine requirements	Slope detection		Preceding vehicle detection
Condition name	Tomei	Chuo	Approach
Route (Slope data)	TOMEI EXPRESSWAY Toyota IC to Komaki JCT	CHUO EXPRESSWAY Komaki JCT to Toki IC	Flat road
Distance	29 km	24 km	5.6km
Set speed limit (Legal speed)	100 km/h	80 km/h	100km/h
Preceding vehicle speed	Actual driving data (77 km/h in average)	Actual driving data (75 km/h in average)	50km/h, 1500m ahead of the ego vehicle
Detection range of slope	Variable (from 0 to 8000 m)	Variable (from 0 to 8000 m)	Constant (8000 m)
Detection range of preceding vehicle	Constant (200 m)	Constant (200 m)	Variable (from 150 to 800m)

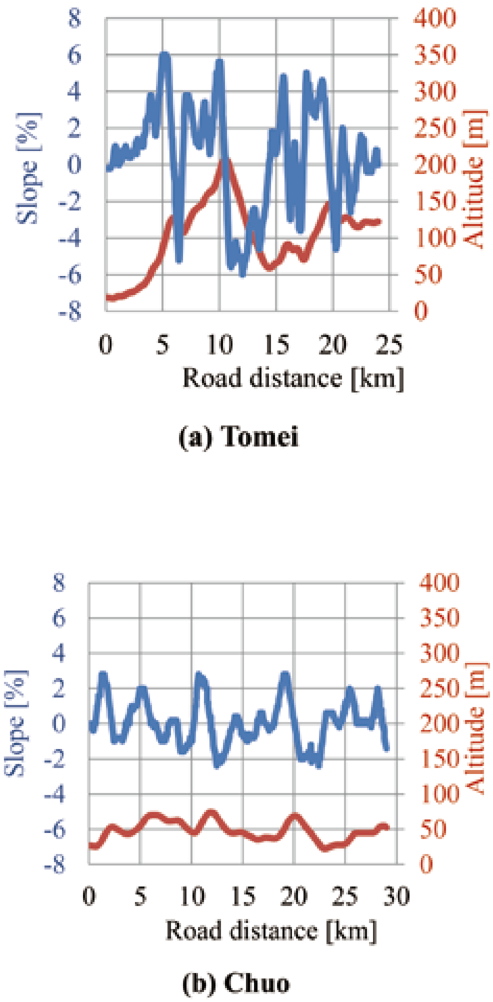


Fig. 5　Road geometry profile

The requirements of the preceding vehicle detection range is not enough by utilizing the simulation condition for slope detection shown in Table 4, because the ego vehicle always follows the preceding vehicle. Thus, another simulation condition(“Approach”) is introduced to examine the preceding vehicle detection range. “Approach” is the situation where the ego vehicle approaches the low speed preceding vehicle which is regarded to have the largest influence on detection performance. The specific simulation condition is that the preceding vehicle is driving at 50kph, which is the lower limit of highways in Japan, and 1500m ahead of the ego vehicle.

Result

Fig. 6 shows the result of the simulation. The graphs show the fuel economy when PnG and P-SOC are activated simultaneously compared with the one of the conventional ACC with a preceding vehicle detection performance up to 200m. When the slope detection performance is variable, the fuel economy does not improve in the case of “Tomei”, while it is effective in the case of “Chuo”. As “Chuo” includes a 4km of continuous downhill, the fuel-saving effect saturated with the slope detection performance of 4km. In addition, in “Tomei” and “Chuo”, assuming that the ego vehicle follows the preceding vehicle, it is found out that the vehicle detection performance does not affect fuel economy. This is because the vehicle follows the preceding vehicle with the following distance of 50m all the time.

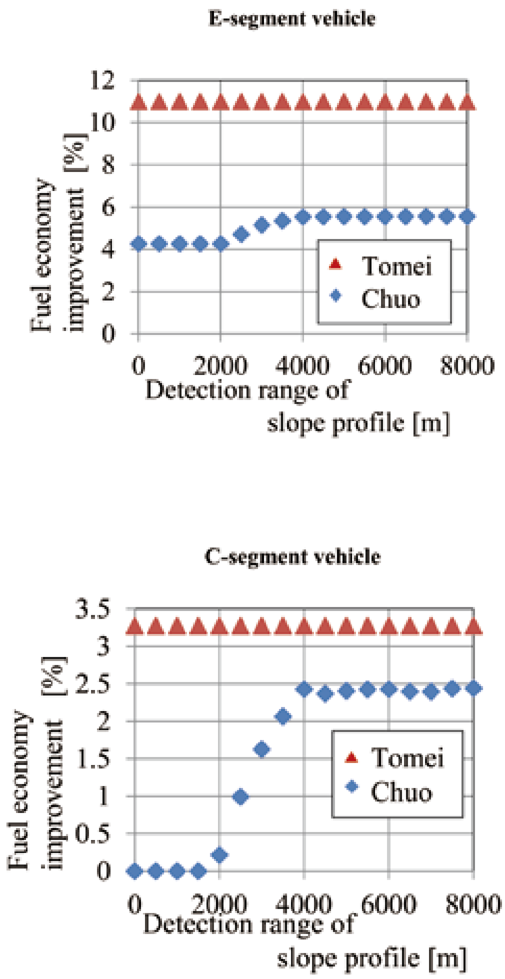


Fig. 6　Relation between sensor range and improvement of fuel efficiency

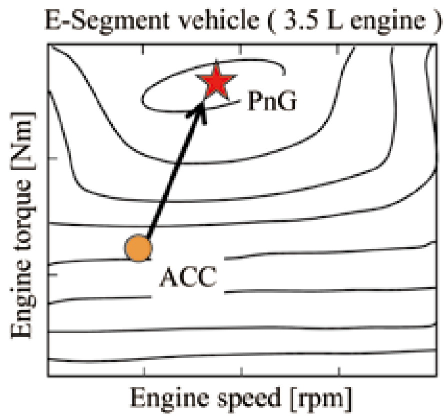
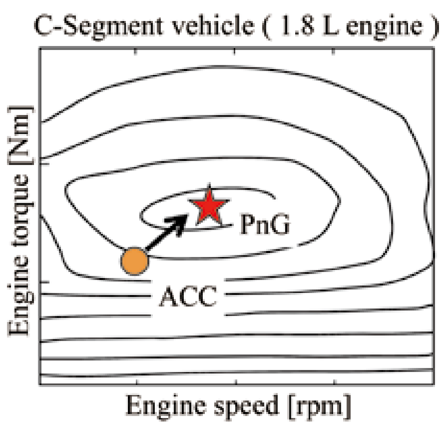
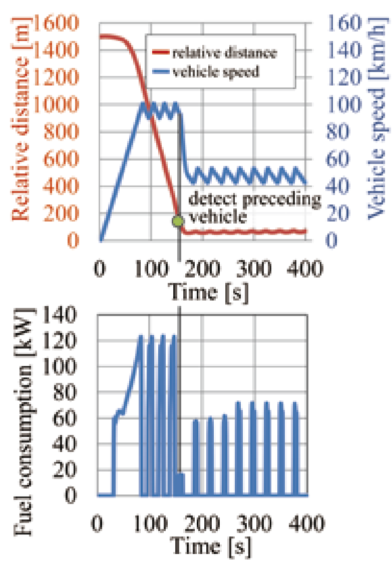


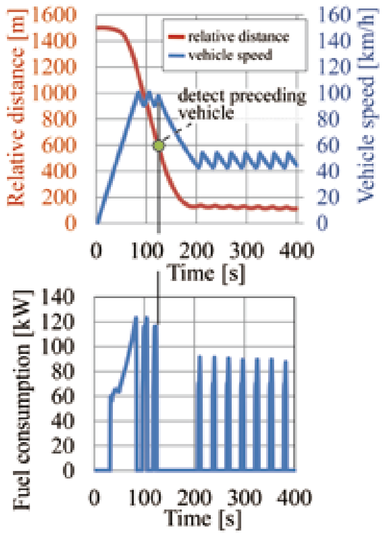
Fig. 7　Schematic view of engine efficiency map



The fuel economy improvement for E-segment is bigger than the one for C-segment. Fig. 7 explains the reason. Since the engine "sweet spot" power of E-segment vehicle is high, it is difficult to drive by utilizing the high engine efficiency driving points with less vehicle speed change well seen at highway. Therefore, by using PnG method, the engine efficiency can be improved a lot. On the other hand, as the engine "sweet spot" power of C-segment vehicle is low, the engine can be driven efficiently without using PnG method, which leads to smaller fuel economy improvement. However, as the battery capacity of C-segment vehicle is smaller than the one of E-segment vehicle, the fuel economy improvement of P-SOC becomes larger compared with the one of E-segment vehicle in the case of "Chuo".



(a) Detection range = 150 m



(b) Detection range = 600 m

Fig. 8 Engine and vehicle behaviour at Approaching to low speed vehicle

Fig. 8 shows the result of approaching to a low speed vehicle scene. In this verification, the vehicle and engine behaviors are compared under the condition that the preceding vehicle detection performance is 150m and 600m. The detection performance when preceding vehicle detection performance is 600m can improve fuel economy by reducing fuel injection earlier than the one when preceding vehicle detection performance is 150m. In this 400 seconds driving, the detection performance of 600m can improve fuel economy by 13% compared with the one of 150m. There are no difference between 600m and 800m, because 600m is enough to judge fuel cut timing for approaching preceding vehicle.

Discussion

Slope profile detection

The result reveals that the detection range of the slope profile to optimize fuel economy improvement is determined depending on the distance of downhill road that the vehicle drives. In order to verify the necessary detection range on public roads, we extract driving routes with large height differences from 8000km of highways in Japan to illustrate the relation between difference of elevation and its road distance shown in Fig. 9.

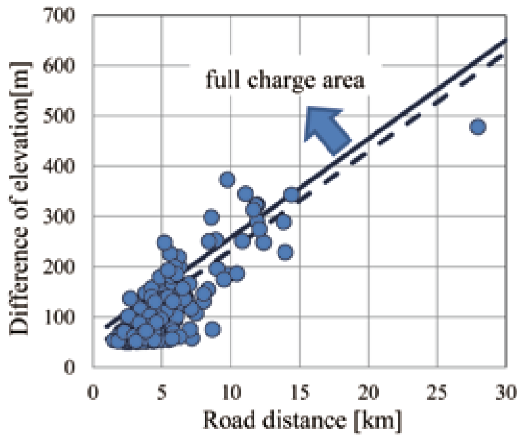


Fig. 9 Relation between Difference of elevation and its road distance

The slant line represents the regeneration energy with half capacity of the battery when driving at constant vehicle speed of 80 kph (the solid line: E-segment vehicle (0.25kWh), the dotted line: C-segment (0.15kWh)).

The reason why the half capacity of the battery is considered here is that the SOC is regulated around the center of feasible area by major control strategies. Thus, the point in the upper left of these lines indicate that some portion of potential energy cannot be regenerated in many cases by using the conventional control strategy.

Based on this Figure, if the sensor can detect at least 15km, the maximum fuel economy improvement can be gained in the Japanese highways. This requirement is expanded from the performance (about 8km in general) of the conventional ADAS locators.

However, if the vehicle specification such as battery capacity is different, the energy lines shown in Fig. 8 move vertically. The requirement of the detection range also varies depending on the routes. Therefore, it is a future issue to refine the requirements by estimating the trend of future battery capacity and collecting route information worldwide. In addition, route detection remains as a problem. If the vehicle fails to predict a future driving route, fuel economy is deteriorated due to charging with the engine output to compensate battery energy shortage or losing regeneration energy under the battery full-charge condition. While the correct route prediction is highly probable on the highways, where the route change does not occur until the vehicle reaches the next interchange, it is low probable in the urban area due to a lot of intersections and branches. The cooperation with a car navigation system will be necessary, as well as the adoption of a method to learn routes where the drivers use frequently such as commuting routes to predict them.

Preceding vehicle detection

The simulation result reveals that the detection range of 600m is required under the special condition, approaching a preceding vehicle at a distant place while fuel efficient driving is possible even with the detection performance of the conventional ADAS sensor (100m) in the scene where the vehicle follows a preceding vehicle. As it is not realistic to realize the detection range of 600m with autonomous sensors in the actual roads where curves and slopes exist, it shall be required to apply radio communication technologies such as V2V and V2I to maximize fuel economy improvement. Another scene affecting sensor requirements that is not mentioned in this paper is a cut-in scene. If the ego vehicle can predict that another vehicle driving in the next lane cuts in several seconds later, unnecessary acceleration and deceleration can be omitted. This strategy will be achieved by detecting the directional indicator flash of the vehicle changing lanes with an onboard camera. Since the timing of cut-in depends on the driver habits, it is a future issue to design the vehicle speed control strategy in consideration of the uncertainty.

Conclusion

This paper clarifies the relation between the sensor performance and fuel economy by actuating two applications, PnG and P-SOC, under the multiple simulation conditions.

The simulation results reveal that the detection range of both slope profile and the preceding vehicle needs to be expanded (slope profile detection range: 8km -> 15km, preceding vehicle detection range: 150m -> 600m).

As they are just examples under the several test conditions, it is a future issue to verify the sensor requirements in all the possible scenes on the actual roads.

In addition, we will also verify the sensor requirements for different specifications of powertrain components, since they influence the requirements (for example, the battery capacity).

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