

Development and Evaluation of a Distance Control Assist System with an Active Accelerator Pedal

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ABSTRACT

A Distance Control Assist System (DCA) aiming at facilitating the driver maintaining a following distance to a lead vehicle in congested traffic was developed. The DCA imposes active force to the driver's foot to urge him or her to release the accelerator pedal as well as decelerates automatically when the host vehicle comes too close to a lead vehicle. This paper introduces the system description and a field test conducted to evaluate effectiveness of the DCA. As a result of the field test, comparison of the driver performances between with and without the DCA showed that numbers of braking by the drivers were decreased, and comparison of NASA-TLX scores showed subjective workload was reduced by the DCA. These results suggested that the DCA can contribute to mitigation of the driver's workload while following situations.

INTRODUCTION

With advance of sensing and vehicle control technologies, various driver-assistance systems have become available. Adaptive Cruise Control Systems (ACCs) are one of such driver-assistance systems to lessen the driver's workload in cruising and in following to a lead vehicle. ACCs maintain the vehicle speed set by the driver while detecting no lead vehicle by radar. When a lead vehicle is detected, ACCs control the host vehicle's speed to maintain a following distance to the lead vehicle. Some ACCs now have additional functionalities, such as low-speed following [1] in stop-and-go situations during congested traffic and controlling

the host vehicle's speed before and during curves in collaboration with a navigation system [2]. ACCs can mitigate the driver's workload mostly in smooth traffic conditions with small speed fluctuations. However, they may not be able to alleviate the driver's workload in congested traffic conditions with large speed changes. In such conditions, the driver needs to change control settings of the ACC, intervene into control of the ACC, or even override the ACC many times.

A new driver-assistance system called Distance Control Assist System (DCA) could help the driver control a distance between the host vehicle and a lead vehicle was developed. The DCA (1) gives push back force to the accelerator pedal to help the driver lift the accelerator pedal then press the brake pedal, and (2) controls the host vehicle's deceleration when the driver does not press the accelerator pedal in the situation where the host vehicle approaches to a lead vehicle closely. The DCA has been designed so that it can alleviate the driver's workload even in traffic conditions where ACCs have difficulties to reduce the driver's workload effectively. This paper explains the system description and reports an experimental study for assessing the effectiveness of the DCA.

SYSTEM DESCRIPTION

PURPOSE OF SYSTEM

ACCs may not be able to reduce the driver's workload effectively under congested traffic conditions where a distance to a lead vehicle is varied frequently, because

the driver needs to change system setting, cancel or override the ACC often. A DCA developed, assists deceleration control so that the driver can focus acceleration control. The distinctive feature of the DCA lies in the function of lifting the accelerator pedal up when the DCA determines that a following distance to a lead vehicle is becoming too short, although the driver has an authority to override the DCA in case that he or she has a clear intention to accelerate. The functionality of the DCA to lift the accelerator pedal up can let the driver know that it is appropriate to release the accelerator pedal then press the brake pedal. This function may lead to workload alleviation even in congested traffic conditions as well as reduction of potentially hazardous circumstances in which the host vehicle comes too close to a lead vehicle.

SYSTEM COMPONENTS

Figure 1 shows main components of the DCA. The main controller operates the active accelerator pedal or the active booster with a following distance to a lead vehicle measured by the laser radar sensor installed in the front bumper. The active accelerator pedal has an actuator to push back its pedal for the purpose of urging the driver release the accelerator pedal or hit the brake pedal. When the accelerator pedal is pushed back but the driver presses the accelerator pedal with clear intention to accelerate, the actuator stops pushing back its pedal according to priority of the driver's control. The active booster makes the host vehicle decelerate after the driver releases the accelerator pedal. A Visual indicator and a buzzer mounted on the instrument panel present status of the DCA and warn the driver when the host vehicle comes too close to a lead vehicle. The driver has an authority to activate the DCA by using the main switch on the steering wheel.



Figure 1 Main Components of the DCA

SYSTEM FUNCTIONALITY

Case 1. Too Close to Lead Vehicle

If the driver releases or is not pressing the accelerator pedal, the DCA automatically applies the brakes to help the driver control a distance to a lead vehicle (Figure 2).

Case 2. Braking is Required by Driver (When Lead Driver Slows Down, etc.)

If a lead vehicle slows down and the DCA determines that braking by the driver is required, a visual indicator and a buzzer prompt the driver to take an action. The accelerator pedal also lifts up to assist the driver in switching to the brakes (Figure 3).

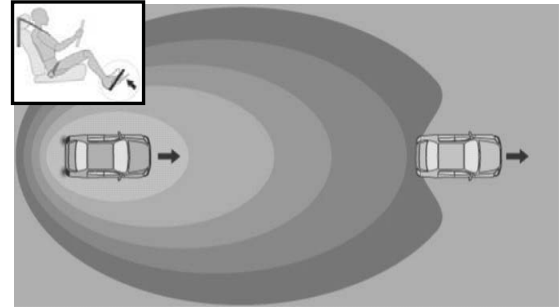


Figure 2 Activation Case 1

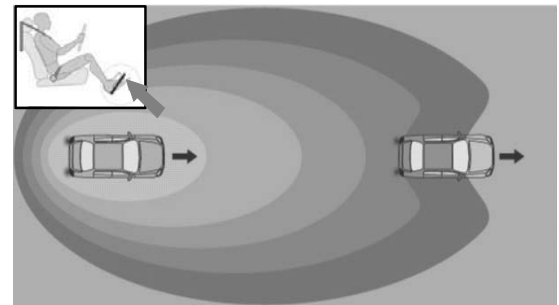


Figure 3 Activation Case 2

FIELD TEST EVALUATION

PURPOSE OF FIELD TEST

A field test was conducted to evaluate the effectiveness of the DCA. The DCA is designed to help the driver control a distance between the host vehicle and a lead vehicle under traffic volume conditions in which frequent acceleration and braking are needed. However the DCA may also be useful under calm and stable traffic conditions in which ACCs work well. In the field test, the effectiveness of the driver assistance function was evaluated by measuring vehicle states, driver behaviors and subjective workload assessment.

EXPERIMENTAL DESIGN

The experiment has 2 x 4 factorial design, mapping onto (system usage) x (road type). Both factors are designed as within-subject factors.

(1) System Usage

For the system usage, we have distinguished driving with the DCA and without the DCA to clear the effectiveness of driver assist from the DCA. In driving with the DCA, the participant drove by letting the DCA

be active. In driving without the DCA, the participant drove by letting the DCA be inactive.

(2) Road Type

A test route was selected so that it includes various types of traffic volume conditions from congested to smooth traffic, with reference to number of traffic and travel speed in daytime by the road traffic census [3]. The test route was divided into four sections as shown in Table 1.

Section 1 was 8.6 kilometers in length, mainly divided one lane road comprising an ordinary national road and suburban roads. The ordinary national road was always congested. Section 1 included some hills, curves, traffic light signals, and intersections. The average travel speed was 18.2 km/h and the slowest among four sections.

Section 2 was a toll expressway of 17.9 km in length, mainly consisted divided three lanes and flat. Driving under section 2 was usually calm and stable. The average travel speed was 80.3 km/h and the highest among four sections.

Section 3 was an arterial high-standard highway of 10.0 km in length, of mainly divided three lanes, including merges and junctions without traffic light signals. It was known as the most congested road in Japan daytime. The average travel speed was 45.5 km/h, higher than section 1 and slower than sections 2 and 4.

Section 4 was an urban expressway of 16.2 km in length, of mainly divided two lanes. The road traffic census presented 1092 vehicles were traveled per an hour and the average travel speed was 73.4 km/h in section 4. Driving under section 4 was calm and stable usually as same as section 2.

CONTROLLED CONDITIONS

Three conditions (A)-(C) were controlled in the experiment.

(A) Order of Using DCA

Participants were divided into two groups with respect to order of the DCA usage.

Group 1: Half participants drove without the DCA during outbound leg (section 1->2->3->4), with the DCA during inbound leg (section 4->3->2->1) on first day. On second day, they drove with the DCA during outbound leg but drove without the DCA during inbound leg.

Group 2: Rest half participants drove with the DCA during outbound leg, without the DCA during inbound leg on first day. On second day, they drove without the DCA during outbound leg but drove with the DCA during inbound leg.

(B) Driving Time

Driving time was divided into two slots, morning session and afternoon session. Each participant ran same time slot of two days in order to avoid potential influence of different traffic condition due to the time of day. Half participants drove in morning sessions and the rest drove in afternoon session.

(C) Preferred Following Distance

Recruiting participants needs to be done carefully, because the DCA works differently depending on a following distance to a lead vehicle, and thus, the DCA may be used differently depending on the driver's preference of a choice of following distance to a lead vehicle. The DSQ (Driving Style Questionnaire) and the WSQ (Workload Sensitivity Questionnaire) [4,5] developed by the Research Institute of Human Engineering for Quality Life [6] were used to estimate the participant's preference on a choice of the following distance to a lead vehicle in his or her daily driving.

The DSQ is known as a scoring method of driving style. It shows eight aspects, which are related with drivers' attitude, preference and mind to driving from eighteen questions. The WSQ is known as a scoring method of workload sensitivity of drivers. It shows ten aspects which are related workload sensitivity of drivers from thirty eight questions. The authors found that selection of pre-set headway distance of ACC might be affected with the driver's preference on a choice of following distance to a lead vehicle in daily driving [7]. In addition, the driver's preference on a choice of following distance might be negatively correlated to following 4 aspects of the DSQ and the WSQ: 'Preparatory maneuvers at traffic signals', 'Confidence in driving skill', 'Impatience in driving', and 'Active reaction to other vehicles'

For the field test evaluation, thirty candidates were chosen. They were asked to answer the DSQ and the WSQ questionnaires. An average score x_i of the four aspects described in previous paragraph were clarified for each participant i . The Dist. Index (preferred Distant Index) was defined for each participant by Eq. 1, where x_{av} denotes the mean of published 500 drivers' average score [7] of the four aspects and s.e. denotes the standard error of all x_i ($i=1-30$).

$$\text{Dist. index (i)} = (x_i - x_{av}) / \text{s.e.} \quad (\text{Eq. 1})$$

Thirty candidates were divided into three groups (Short, Medium and Long group) by his or her dist. Index. The candidates who belonged to the upper 25th percentile of the dist. index distribution were assigned as the Short group might prefer short following distance to a lead vehicle in daily driving. The candidates, who belonged to the middle 50th percentile of the dist. Index distribution, were assigned the Medium group. The candidate who belonged to the lower 25th percentile of the dist. index distribution, they were assigned the Long group might prefer long following distance to a lead vehicle in daily