Utilizing ACC Radar Data to Signal Trailing Drivers of Forward Decelerations.

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ABSTRACT

ACC radar systems gather valuable data about the speed of forward vehicles, and then utilize that information to best regulate the spacing between those forward vehicles and the ACC host. However, such radar-gathered data can also be useful to help prevent rear-end collisions involving the host vehicle. Embedded in that data is information revealing decelerations of forward vehicles that holds particular value to any driver that might be trailing the host vehicle – especially if their vision is screened by the bulk of the host vehicle.

In this paper, a hybrid stop lamp system is proposed whereby ACC radar data gathered by a host vehicle is automatically conveyed to the trailing driver utilizing a new light element integrated with the host vehicle’s stop lamp system. Such an ‘intelligent brake light’ (i-B.L.) system allows trailing drivers to effectively ‘see’ the braking status two vehicles in front of them instead of just one, thus providing them with an extra 0.7 to 1.3 seconds of braking time.

This paper will introduce the hybrid ACC/i-B.L. concept, study the functional, the technical, and the aesthetic options for integrating such a new light with conventional stop lamps and discuss the regulatory obstacles that would need to be overcome for testing and implementing.

INTRODUCTION

Adaptive Cruise Control (ACC) radar systems gather valuable data about the speed of forward vehicles, and then utilize that information to best regulate the spacing between those forward vehicles and the ACC host. However, such radar-gathered data can also be useful to help prevent rear-end collisions involving the host vehicle. Embedded in that data is information revealing decelerations of forward vehicles that holds particular value to any driver that might be trailing the host vehicle – especially if their vision is screened by the bulk of the host vehicle. Drivers trailing a large SUV or truck have little view to the open road. With current brake light design, such drivers are essentially ‘blind to the road’, relying on the brake lights directly in front of them for their information. When downstream stoppages rapidly occur, the driver of a truck or SUV has to hope that trailing drivers will observe their brake lights and have sufficient time to stop. But with the technical advances and expanded use of ACC, there is an opportunity to make great strides in reducing the annual 1.2 million injuries and $18 Billion dollars in property damage caused by rear-end collisions. This can be accomplished by introducing a new radar controlled stop lamp - possibly integrated with a vehicle’s Center High Mounted Stop Lamp (CHMSL) – that receives deceleration data from an ‘always on’ ACC radar.

Operating both on highways and city streets, the hybrid system would have the following advantages:
1. Being radar-activated, the reaction time of the host driver is taken out of the signaling sequence and thus provides warning to trailing drivers 0.7 – 1.3 seconds earlier than conventional stomp lamps. At freeway speeds, this gives an extra 60-100 feet of extra stopping distance.

2. Such a light would give trailing drivers ‘vision’ to the braking status two cars ahead of them instead of just one.

3. Technology exists for such a system, and can be implemented by a single manufacturer without depending on any modifications to other vehicles (such as is required for collision avoidance systems relying on inter-vehicular communication). For vehicle models that already offer ACC, the cost for such a brake light adaption is minimal.

4. The design of the new light element can easily be standardized and integrated into existing CHMSL or stop lamp clusters without significant aesthetic compromises.

DEFICIENCIES IN CONVENTIONAL STOP LAMP SYSTEMS

In rapidly moving dense traffic, the effectiveness of conventional stop lamps are often marginalized because information about forward braking emergencies travels upstream at a slower rate than the speed at which the information is needed by upstream drivers to initiate braking and avoid a collision. This is especially apparent when the forward vehicle is a large SUV or truck that completely obstructs a trailing driver’s view to the forward road forcing that trailing driver to rely entirely on the status of the stop lamps in front of him or her for braking cues.

The stop lamp system in vehicles today, first introduced over a century ago, may be the best collision avoidance device yet invented, but as roadways have become more congested and vehicle speed has increased, three inherent deficiencies have become apparent.

1. First and foremost, conventional stop lamp systems require the host driver to activate them. If a forward stoppage occurs, conveyance of the need to stop is delayed by the driver’s reaction time. If that driver is distracted by the view, passengers, or a cell phone, then this delay may be significantly longer, further reducing the time a trailing driver has to react to their stop lamp signal.

2. Secondly, once conventional brakes have been applied and the stop lamps activated, no new braking information can be conveyed to trailing drivers. Thus, on a steep downgrade, where trucks and other vehicles may have their brakes applied for an extended period, forward drivers have no means by which they can signal trailing vehicles about any pending braking emergencies. A similar problem occurs on all roadways if the driver of the lead vehicle rests their left foot on the brake pedal. In these situations, trailing drivers must observe a reduction in the gap separating the two vehicles to deduce that the forward driver has increased the intensity of their braking.

3. Thirdly, conventional stop lamps only indicate the braking status of the host vehicle – without the possibility of providing information about the traffic flow forward of the host vehicle. In today’s dense traffic, with inter-vehicular distances often shorter than the necessary safe stopping distance, most braking events involve at least three vehicles: a lead, middle, and trailing vehicle. Ideally, to increase the likelihood that a trailing driver is given sufficient advance notice of a braking event to allow them proper distance to stop, that driver would be made aware of the braking status of both the middle and the lead vehicles simultaneously.
Each of these deficiencies contribute to increased rear-end collisions statistics. And, unfortunately, drivers today are often faced with traffic situations where more than one of these deficiencies becomes a factor. But now, advances in radar technology leading to the decreased cost and widespread use of ACC there is an opportunity to modernize the century old stop lamp technology and construct a hybrid ‘intelligent brake light’ (i-B.L.) system that alleviates those stated deficiencies.

SYSTEM DESCRIPTION

The proposed hybrid ACC/i-B.L. system consists of two main components: a front mounted radar like that already incorporated into many vehicles for their ACC, and a new rear-mounted light element integrated with the host vehicle’s existing stop lamp system as shown schematically in Figure 1.

![Figure 1 – Host vehicle (middle) with ACC radar signal in yellow and i-B.L. signal in red.](image)

The ACC system radar remains active at all times while the vehicle is in motion – even if the auto-braking and accelerating features of the ACC are de-activated or put on standby. ACC radar monitors the speed of the forward vehicle and upon detection of significant decelerations – perhaps in excess of a 0.2g minimum threshold - automatically activates the new i.B.L. element to alert the trailing driver of the pending slowdown. The system functions as if the forward vehicle’s stop lamps were added to the rear of the host vehicle. Such a system piggybacks on the intuitive understanding of conventional stop lamps, but now informs the trailing driver of the braking status two cars in front of them instead of just one - (Figure 2).

![Figure 2 – Illustrating a trailing driver’s view to a forward vehicle’s stop lamps.](image)

Because a hybrid ACC/i-B.L. system removes the host driver from the operating loop, and because the signal is communicated to the trailing driver almost instantaneously, the trailing driver will be notified of the need to brake a minimum of 0.7 - 1.3 seconds faster than they could otherwise. If the forward deceleration is such that only a speed reduction is required, then signaling that driver early keeps their attention on the road and makes it less likely that they will allow themselves to be distracted until they see the lights turn off and the flow return to normal speed.
REGULATORY ISSUES

All vehicles sold in the United States must comply with the Federal Motor Vehicle Safety Standard (FMVSS). Vehicle lighting is controlled by Section 108. The proposed hybrid ACC/i-B.L. system is not in compliance with these standards, for in paragraph S5.1.3, it is stated that brake lamps are prohibited from turning on if the [host] vehicle is not actively decelerating. Therefore, the proposed brake light modification would require a change in these standards.

Such a change has, of course, been accomplished before with the introduction of the CHMSL in 1986. And with modification to the lighting regulations, several companies have now released vehicles equipped to convey a flashing Emergency Stop Signal. The proposed hybrid ACC/i-B.L. system would require a similar revision to the standards that can realistically only be pursued by a major auto manufacturer or group like the SAE. Road testing of any such device is allowed by auto manufacturers via exemption part 555.

DESIGN OPTIONS

With the above significant regulatory issues not withstanding, design objectives for any proposed modification can still be defined. Space on the rear of most vehicles is already cluttered with lights – stop lamps, rear-position lamps, optional fog lamps, and CHMSL, with flashing lights for the turn signal indicators, hazard warnings, and rapid decelerations; introducing a new element must therefore be done with much care. There are four clear objectives that need to be satisfied:

1. The design must have intuitive understanding and must not cause miss-interpretation of conventional stop lamp signals.
2. The design must be easily standardized.
3. The design must not significantly compromise the aesthetic options for conventional stop lamp cluster composition.
4. The design must be inexpensive to implement.

One design that appears to favorably meet each of these requirements is the integration of the radar-controlled element into the center of the existing CHMSL as shown in Figures 3 and 4. Such a configuration can easily be defined and standardized, e.g. "An equilateral triangle with sides 2.5 inches in length oriented with point down" (perhaps 3.5” on a side for trucks). The new light is positioned where it is most visible – together with the CHMSL. Working in tandem with the CHMSL, it gives an intuitive understanding of its operation – if either lamp is activated it conveys knowledge that forward braking is occurring, activation of the CHMSL means that the host vehicle is braking, while activation of the i-B.L. lamp means that the vehicle forward of the host is braking. It has no impact on the design of the vehicle’s other lamps. The modification would involve a relatively minor expense.
Figure 3 – A radar-controlled i-B.L. stop lamp (middle) optionally integrated with an existing CHMSL.

Figure 4 – The CHMSL/i-B.L. stop lamp (beneath arrow) integrated into an existing vehicle.

Other alternative designs studied for the i-B.L. stop lamp element are shown in figures 5 & 6 below.

Figure 5 – Optional design for a ring shaped light element concentric to the standard lamp element.
i-B.L. EMERGENCY STOP MODE

Some manufactures have added an emergency stop signal option to either the rear stop lamps or the hazard lamps. These lamps flash at a frequency of 4 Hz when passenger vehicles decelerate faster than 6 m/s^2 to better convey the emergency to a trailing driver. Consistent with that feature, it is proposed that the i-B.L. stop lamp flash at a similar frequency when the ACC radar detects an equivalent deceleration of the forward vehicle. It should be noted that such a signal is provided to the trailing driver independently of and in advance of any braking actions taken by the host driver. Significantly, in an emergency braking situation, the i-B.L. flashing signal would be seen by the trailing driver at least 0.7 seconds ahead of the emergency stop signal noted above.

TIME-MOTION STUDY OF A REAR-END COLLISION

A common rear-end collision occurs on the freeway when a forward vehicle (FV) begins to brake, a large host (or middle) vehicle (HV) that blocks the forward view and whose driver is possibly distracted then brakes, and then a third trailing tailgating vehicle - who cannot see the brake lights of the forward vehicle - must quickly react but does not have sufficient stopping distance in front to avoid the collision. Such a sequence can serve as a good model for demonstrating the benefits of the ACC/i-B.L. system.

Figure 7 below illustrates the path of the three vehicles for scenarios where a host vehicle is and is not equipped with ACC/i-B.L.
Figure 7 – Graph illustrating vehicle paths leading to a typical rear-end collision with and without i-B.L.

Timing sequence if host vehicle is Not ACC/I-B.L. equipped:

(1) FV begins braking; (2) elapsed time for HV to react; (3) HV begins braking; (4) brake lights reach HV, but distraction causes 0.4 second delay; (5a) elapsed time for HV to react; (6a) HV begins braking; (7a) collision.

Timing sequence if host vehicle is ACC/i-B.L. equipped:

(1) forward vehicle begins braking; ACC radar detects FV deceleration; after 200ms processing time i-B.L. stop lamp activated; (5b) elapsed time for HV to react; (6b) HV begins braking; (7b) safe stop.

If the host vehicle is ACC/i-B.L. equipped, then the trailing vehicle can learn of the need to brake at the same time as the host vehicle - even before the host driver if the host is distracted. An attentive trailing driver can brake in parallel with the host vehicle maximizing his breaking distance, and avoiding the accident. Such braking is only possible if he is given the advance notice that ACC/i-B.L. provides.
ALTERNATIVE TECHNOLOGIES: ACC WITH STOP & GO

An emerging technology that can control the speed of a host vehicle through the full speed range is called ACC with Stop & Go. In such systems, the forward radar is kept operational while traveling in the Stop & Go mode, or until the host disengages it. With the detection of the deceleration of a forward vehicle, the system initiates braking which instantly activates the host vehicle’s stop lamps, providing the same instant warning to the trailing driver that the proposed ACC/i-B.L. would. Accordingly, wouldn’t that make the i-B.L. lamp redundant?

Interestingly, the Dutch Ministry of Transport funded an extensive field study - presented at the 2008 IEEE Intelligent Vehicle Symposium (1, 2) - that analyzed driver behavior when they were using vehicles equipped with ACC. It is particularly relevant to this argument. They make two important observations and deductions from their extensive field study:

1) A majority of drivers transition out of ACC as soon as the traffic density reaches 20-40 veh/km/lane.
2) Over 40% of drivers transitioned out of ACC due to their desire to accelerate and close the gap in front of them. 72% of those reduced their time-headway (THW) to less than 1 second - meaning they were entering an ‘aggressive’ drive mode by choice. Significantly, they reduced their THW into a range deemed 'unsafe' and into a range where no auto manufacturer would allow their system to operate in and still assume responsibility for the increased likelihood of collisions.

This limit to the utilization of ACC is perhaps stated best in their conclusions:

"ACC systems should be seen exclusively as safety-comfort-enhancing, [for] as traffic conditions approach the road capacity, drivers will likely inactivate the system and rely on their own driving capabilities."

As this study clearly shows, when traffic density gets heavy - at times when advance warnings are needed the most - drivers transition out of their ACC. No auto braking means no brake light will be activated and no advance warning will be given to the trailing driver. The host driver is put back in the loop adding their 0.7 -1.3 seconds of reaction time into the delay before warning is given. This problem does not occur with the proposed hybrid ACC/i-B.L. system.

Further, when a driver of a vehicle equipped with ACC Stop & Go applies their brakes, this negates the possibility of conveying any further information about the forward traffic. Like the examples given earlier, when vehicles brake while traveling down a long grade, or as a driver of a vehicle rests their free foot on the brake, the activation of the stop lamp masks any possibility of conveying new braking emergencies.

ACC/i-B.L. FOR CITY DRIVING

One of the benefits of the hybrid ACC/i-B.L. system is that it is equally valuable in city driving. Trucks, delivery vans, and big SUV’s block the forward view on city roads just as they do on freeways and highways. And while vehicle speeds are usually less on city roads, braking emergencies occur more suddenly due to increased distractions and the unpredictability of pedestrians. Conveying data about the sudden braking of vehicles two ahead of a driver is perhaps the best method for reducing common rear-end collisions.
CONCLUDING REMARKS

There will be a time in the future when collision avoidance systems become sophisticated and reliable enough for even the most reluctant of drivers to surrender control of their vehicle to electronic decision-making. However, until such time there remains a critical need to improve the conveyance of traffic data and braking emergencies to today’s drivers so that they may plot their own best course for avoiding accidents. Existing ACC radar already collects the needed data and the i-B.L. stop lamp system is a simple solution that can deliver the information. The proposed hybrid ACC/i-B.L. system, operating in tandem with conventional stop lamps, maximizes the rate at which forward braking information is conveyed and minimizes the likelihood that trailing drivers will become involved in rear-end collisions.

REFERENCES


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DEFINITIONS/ABBREVIATIONS

ACC Adaptive Cruise Control
CHMSL Center High Mounted Stop Lamp
FV Forward Vehicle
HV Host Vehicle
I-B.L. Intelligent Brake Light
NHTSA National High and Safety Administration
TV  Trailing Vehicle