Mechatronics xxx (xxxx) xxx–xxx

Contents lists available at ScienceDirect

Mechatronics

journal homepage: www.elsevier.com/locate/mechatronics

Heavy vehicle collision avoidance control in heterogeneous traffic using varying time headway☆

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ARTICLE INFO

Keywords:
Collision avoidance control
Time headway
Rear end collision
Heterogeneous traffic
Advanced driver assistance systems
Heavy road vehicle

ABSTRACT

A rear-end collision avoidance system (RECAS) could reduce accidents by assisting drivers during emergencies through autonomous braking. If the decision to intervene is made too early, the intervention can become a disturbance to the driver and if the decision is made too late, the safety benefits of the system will be reduced. Hence, proper threat assessment is important to make a decision for intervention in a RECAS. In this study, a new threat assessment measure using a varying time headway has been proposed to develop a rear-end collision avoidance algorithm (RECAA) for heavy commercial road vehicles in heterogeneous traffic. The proposed varying time headway depends on the type of lead vehicle, host vehicle load conditions, road conditions and relative longitudinal speed. The developed RECAA was implemented in a hardware-in-loop experimental setup that is equipped with the vehicle dynamic simulation software, IPG/TruckMaker® and tested for vehicle following scenarios using different types of lead vehicles and host vehicle loading conditions. The results showed that the proposed varying time headway improved the RECAA by activating the host vehicle's brake system at different time instants based on the type of lead vehicle and thereby preventing the unintended early brake intervention of RECAS.

1. Introduction

The increase in the number of motor vehicles coupled with the slower expansion of the road network has brought many challenges such as traffic congestion and increase in road accidents and fatalities [1]. A long-term solution to reduce road accidents and fatalities is the development of an intelligent vehicle that senses its surrounding environment, navigates on its own and takes fast decisions to maneuver in a safe manner [2]. The development of an advanced driver assistance system (ADAS) would address the immediate need for increased driver assistance to reduce accidents, while contributing to the long-term development of autonomous and intelligent vehicles. In fact, the European Accident Research and Safety Report 2013 by Volvo showed that nearly 90% of road accidents were due to driver's inattention [3]. Various studies showed that the accidents due to driver error could be reduced by nearly 40%–50% by installing ADASs in vehicles [4,5]. Nowadays, various governments have started implementing stringent norms related to vehicle safety and these have made the commercial market for ADASs grow at a rapid rate. A report by Future Market Insights [6] estimated that the ADAS market is expected to register a 16%–18% compound annual growth rate (CAGR) during the period 2014–2020. The details of a few ADASs are provided in Table 1 [7].

The German in Depth Accident Statistics provided information about the braking behavior during accidents and it was reported that emergency braking happened only in 1% of accidents and in all other cases, only a partial braking was made [8], implying the ineffective/insufficient driver action during these accidents. In this context, a rear-end collision avoidance system (RECAS) is a driver assistance system that would help the driver during an emergency to prevent or reduce the severity of rear-end accidents. It has been reported that, during the year 2014, 20.5% of accidents in the United States involving large trucks were rear-end collisions [9]. During the year 2015, heavy commercial vehicles (HCVs) accounted for 33.9% of 146,133 road accident fatalities in India [1], and it is safe to surmise that this high number could be reduced by better driver assistance. A study by the center for automotive safety research, Australia, estimated the benefit-cost ratio (BCR) of introducing forward collision avoidance technology in HCVs as 2.7–9.8, whereas the BCR for introducing such systems in a passenger car is less than one [10]. Motivated by these factors, this study focused on developing a rear-end collision avoidance algorithm (RECAA) for HCVs.

An important step in the collision avoidance process is threat

☆ This paper was recommended for publication by Associate Editor Prof Junmin Wang.

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https://doi.org/10.1016/j.mechatronics.2017.11.010
Received 25 October 2016; Received in revised form 20 March 2017; Accepted 22 November 2017
0957-4158/

Table 1
Advanced driver assistance systems.

ADAS	Description	Current status
Lane departure warning	It provides a warning to the driver if the vehicle drifts across the lane so that the driver can take corrective action. This system ensures that a vehicle does not leave its lane accidentally.	These systems are already implemented in passenger card and HCVs [11].
Lane keeping assist	It takes corrective actions with the help of steering actuator to maintain the vehicle in the lane without any driver inputs.	These systems have been introduced in passenger cars [12].
Adaptive cruise control (ACC)	It monitors the longitudinal speed of the lead vehicle and adjusts the longitudinal speed of the host vehicle to maintain a safe distance from the lead vehicle.	Nowadays ACC is a common feature in premium cars [13].
Intelligent headlamp control	It is designed to help drivers see the road and its surroundings in front better in darkness. This advanced driver assistance technology allows the headlights to move side to side as the steering wheel is turned by the driver for better illumination of the roadway.	This feature is available in passenger cars as well as in HCVs [14].
Emergency brake assist	It helps to reduce the severity of high speed collisions in the event of driver's inattention. These systems are meant to slow the vehicle to mitigate the damage during accidents and thereby prevent/reduce fatalities.	This system along with the electronic stability control system is available in passenger cars and HCVs [15].
Blind spot detection	It assists drivers by detecting the objects in the vehicle's vicinity and provides warnings.	This system is mostly introduced in HCVs because of its dimensions. It is also available for cars [16].
Intelligent speed adaptation (ISA)	It helps the driver to adjust the speed based on the location and thereby avoiding accidents due to over speeding.	As of now, these systems are based on fixed speed limits. Research is going on include dynamic speed limits [17].
Hill descent control	It assists the driver to descend steep gradients at a pre-determined speed. This system typically controls the brakes to automatically slow the vehicle when required.	These systems are available for passenger cars and still in development phase for HCVs.
Rear cross traffic alert system	It is designed to provide warnings when other vehicles enter the backing path while reversing. These systems work only when the vehicle is backing perpendicular to a roadway.	These systems are available for passenger cars [16].

assessment. In literature, different approaches have been used for threat assessment, out of which, two major approaches are time-based [18–21] and distance based [22–25]. Two frequently used time-based measures are time-to-collision (TTC) and time headway. TTC is defined as the ratio of the distance between the front of the host vehicle (a vehicle in which the RECAS is fitted) and the rear of the lead vehicle (a vehicle that is traveling in front of the host vehicle) to the relative longitudinal speed between these two vehicles [20]. A few studies have also used relative acceleration along with the distance and relative longitudinal speed between the vehicles for calculating TTC [26]. TTC specifies the time available for the host vehicle before it collides with the lead vehicle. A second time-based measure is the time headway, which is calculated as the distance between the two vehicles divided by the host vehicle longitudinal speed [27]. Time headway is defined as the time elapsed between the rear of the lead vehicle passing a point on the roadway and the front of the host vehicle passing the same point considering the prevailing longitudinal speed of the host vehicle. A few distance-based measures such as the projected minimum distance [28] and predicted minimum distance [29] were used for threat assessment. A few deceleration-based approaches were also used for developing a RECAA. One important deceleration-based approach is the required deceleration measure, which is defined as the constant deceleration required for the host vehicle to avoid a potential collision with the lead vehicle [30,31]. Even though different approaches have been discussed in the literature, each method has its own advantages and limitations. In case of the TTC based approach, TTC tends to infinity as relative longitudinal speed becomes zero during vehicle following. In order to avoid this ambiguity, Inverse TTC (ITTC) was proposed [32]. The time headway based approach does not consider the longitudinal speed of the lead vehicle, and hence would not be able to differentiate a stationary and a moving lead vehicle. The advantages of distance based measures over time-based measures are described in [29]. In most distance based approaches, the maximum deceleration of the host vehicle and the lead vehicle was assumed to be constant [22–25]. In reality, the host vehicle's maximum deceleration depends on loading and road conditions, and different types of lead vehicles have different braking characteristics in heterogeneous traffic. Motivated by these factors, a new distance-based approach using varying time headway has been proposed in this study for threat assessment in heterogeneous traffic. The varying time headway depends on the type of lead vehicle, host vehicle loading conditions and road conditions. It also varies with time based on the longitudinal speed of the host vehicle and the lead vehicle.

In countries with heterogeneous traffic, various types of vehicles such as cars, buses, trucks, three-wheeled vehicles and two-wheeled vehicles share the road space. In homogeneous traffic, all vehicles at the equilibrium state have zero acceleration, the same speed and the same distance headway; in the case of heterogeneous traffic flow, all vehicles still have zero acceleration and the same speed, but their distance headways vary for different vehicles [33]. This is due to the fact that different vehicles have different maneuverability, acceleration and braking characteristics. In transportation research, various studies have been performed to analyze the interaction between cars and trucks [34–37]. Sarvi [38] studied the driving behavior of HCVs and compared it with passenger cars and found a significant difference in the following behavior of HCVs compared with passenger cars. Aghabayk et al. [39] studied the effect of heterogeneous traffic on traffic flow and found that the presence of heavy vehicles in traffic resulted in longer reaction times, larger space and time headways. Sayer et al. [37] showed that passenger car drivers followed light trucks at shorter distances than other passenger cars. Ye and Zhang [40] studied vehicle specific time headway and found that the headway when a truck followed a car was larger than when a car followed a truck. Tordeux et al. [41] studied the vehicle following behavior and found that the time gap decreased with increase in longitudinal speed for all vehicle types. They also found that trucks maintained larger time gaps with other vehicles. In case of RECAS, the highly heterogeneous traffic found in many developing countries provides significant challenges to its successful implementation. The time headway used for homogeneous traffic may not be suitable for heterogeneous traffic and may result in false warnings and unintended early interventions in normal driving. Hence, in this study, a new varying time headway was developed for use in heterogeneous traffic. This would allow for the automatic intervention of CAA by considering the type of lead vehicle and operating conditions such as vehicle loading conditions, relative longitudinal speed, brake system specifications and road adhesion conditions. This study explored the characteristics of four kinds of vehicle following such as HCV-following-car, HCV-following-HCV, HCV-following-Light commercial road vehicle (LCV) and HCV-following-2/3 wheeler.

In literature different controllers have been proposed for brake control. Gerdes proposed a sliding mode controller for brake system control for Intelligent Vehicle Highway System (IVHS) and platooning