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Study on the framework of hybrid collision warning system using loop detectors and vehicle information

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A B S T R A C T

Safety warning systems generally operate based on information from sensors attached to individual vehicles. Various types of data used for collision risk calculation can be categorized into two types, microscopic or macroscopic, depending on how the sensors collect the information of traffic state. Most collision warning systems use only either of these types of data, but they all have limitations imposed by the data, such as requirement of high installation cost and high market penetration rate of devices. In order to overcome these limits, we propose a collision warning system that utilizes the integrated information of macroscopic data and microscopic data, from loop detectors and smartphones respectively. The proposed system is evaluated by simulating a real vehicle trip based on the NGSIM data. We compare the results against collision warning systems based on macroscopic data from infrastructure and microscopic data from Vehicle-to-Vehicle information. The analysis of three systems shows two findings that (a) ICWS (Infrastructure-based Collision Warning System) is inadequate for immediate collision warning system and (b) VCWS (V2V communication based Collision Warning System) and HCWS (Hybrid Collision Warning System) produce collision warning at very similar timing, even with different behavior of individual drivers. Advantages of HCWS are that it can be directly applied to existing system with small additional cost, because data of loop detector are already available to be used in Korea and smartphones are widely spread. Also, the computation power distributed to each individual smartphone greatly increases the efficiency of the system by distributing the computation resources and load.

1. Introduction

Safety on the road is one of the principle issues that have to be improved, and a recent analysis of car accidents found that the principal causal factor is driver's inattention and excessively close distance between vehicles (Knipling et al., 1993; Rumar, 1990). After development of damage-reducing devices, such as safety belts and ABS system, followed many efforts that help prevent accidents or mitigate the consequences of accidents, such as Advanced Driver Assistance Systems (ADAS) (Lindgren and Chen, 2006). Among those systems, Forward Collision Warning System (FCWS) and Forward Collision Avoidance System (FCAS) are the most extensively prototyped and tested for the most critical and intuitive need for preventing accident in the field of transportation research (Kiefer et al., 2005; Lee et al., 2002; Lindgren and Chen, 2006; Parasuraman et al., 1997; Polychronopoulos, 2004; Wang and Cheng, 2008).

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In the FCWS, various types of data used for collision risk calculation can be categorized into two types – microscopic data and macroscopic data – depending on how the sensors collect the information of traffic state. Microscopic data can be defined as the data representing the characteristics of individual vehicles, such as velocity of leader vehicle and following vehicle, and macroscopic data can be defined as the data representing the information of a group of vehicles as a whole, for example the average velocity of the vehicles on a road section. Previous collision risk calculation methods have focused on either of these data types, which are described in the following.

Forward Collision Warning System initially has used microscopic data to give a warning signal to the driver when detecting a possibility of impending collision with the preceding traffic (Hirst and Graham, 1997; Lee et al., 2002). The system generally uses in-vehicle distance sensors such as Lidar, and Radar to continuously measure the spacing and speed difference with leader vehicles. Then, it estimates the collision risk based on measurements such as Time-To-Collision and alarms the driver of a possible accident when the measurement value drops below a certain threshold predefined by the system (Parasuraman et al., 1997; Shladover and Tan, 2006; Vogel, 2003).

Though FCWS could improve safety and reduce negative effects caused by the accidents on the road, this system is subjected to some major drawbacks. First, it only detects vehicle in immediate vicinity due to the limited range and field-of-view (FOV) of the sensor. This limited sensing capability may overlook a possibility of an accident that originates from outside of the range of the sensor, which is especially dangerous if the system is overly trusted by the drivers. Second, FCWS with sufficient accuracy for stable service is expensive at the stage of current sensing technology. Even though vehicles can be detected in a longer distance with available technology, these kinds of sensors may lead to an increase of cost. Third, FCWS that uses data from in-vehicle sensors calculates the collision risk only with vehicles ahead. This system may underestimate or overestimate the collision risk, for instance in multi-vehicle crash situation that involves multiple vehicles in front of subject vehicle. The limited accuracy and applicability of the collision warning system based only on in-vehicle sensors then call for a need to develop a system that integrates information outside the individual vehicle in a cost-effective manner.

To overcome the weaknesses of FCWS, a collision warning system that uses information of individual surrounding vehicles in a wider range was developed by adopting various communication technologies, such as Global Positioning Systems (GPS) and Dedicated Short-Range Communication (DSRC) technologies (ElBatt et al., 2006; Jiang et al., 2006; Lee et al., 2001; Varaiya, 1993). This system is generally called Cooperative Collision Warning System (CCWS) or Vehicle-to-Vehicle Communication based Collision Warning System (VCWS) and shares microscopic data between vehicles (ElBatt et al., 2006; Girard et al., 2001; Sengupta et al., 2007; Shladover and Tan, 2006). Status information like location, velocity, and acceleration is periodically broadcasted between neighboring vehicles and the system calculates the collision risk of its own. VCWS provides a robust system with sufficient warning accuracy regardless of the road geometry because it can well detect a stopped or slowly moving car even at blind curve. Also, it uses equipment such as radio and GPS, which are cheap compared to the in-vehicle sensor used in FCWS.

However, VCWS also has its shortcomings in that the vehicle sensors may not achieve consistent accuracy and reliability from latency of the data acquisition. For instance, GPS may sometimes create results with large error in dense building area, where the collision risk estimation might be meaningless. The system performance will be significantly degraded if there are difficulties in communication between vehicles, for example, blockage of transmission due to physical obstacles (Wang and Cheng, 2008). Another disadvantage is that the usefulness of communication-based FCWS highly depends on its market penetration rate. With less vehicles broadcasting information to the other vehicles, it cannot provide warning for the imminent dangers at all time. Unfortunately, achieving a high level of adoption of this technology in the near future seems very difficult at the current market trend. Lastly, this system only considers information from the close vehicles. Though the field of view of sensors in VCWS has improved, VCWS still cannot cover enough range and may overestimate or underestimate the crash probability and severity because the collision risk on highway are influenced by the traffic state of even larger road section about 1.2 miles (Song and Yeo, 2012; Yeo et al., 2010).

Another approach to calculate the collision risk is to use the macroscopic data of traffic. It is rare to find a collision warning system using macroscopic data but researchers have studied the relationship between macroscopic information from infrastructure sensors and crash rate (Milanés et al., 2012; Zeng et al., 2012). This system is based on the finding that average speed difference between two adjacent loop detectors shows correlation to accident frequency and collision risk depending on the traffic state of road section (Chung et al., 2010; Golob et al., 2004; Li et al., 2012; Song and Yeo, 2012; Xu et al., 2011; Yeo et al., 2012). Therefore, it uses information from the roadside infrastructure to evaluate the collision risk for each road section based on the macroscopic data collected from the infrastructure (e.g. loop detector) and transmits the collision risk to drivers. However, this system does not produce a collision risk measured for each individual user but only gives the warning signal at the aggregated level of service for the each road section. This system therefore fails to consider the variability of individual drivers on the road, which is critical in the accuracy of collision warning service.

Despite their advantages, collision warning systems based on either microscopic or macroscopic data have critical challenges in a practical application. These systems fail to consider the traffic state of the road and the variability of individual drivers at the same time or require a great expense for the installation of device and high market penetration rate to guarantee the high accuracy. To overcome the weaknesses of the above-mentioned systems, this paper proposes a hybrid system, which utilizes both macroscopic data from infrastructure (e.g. loop detectors) and microscopic data from individual vehicle (e.g. smartphones). This research is highly motivated by the wide spread of smartphone with high market penetration and the fact that information can already be freely transmitted between infrastructure and each vehicles via