The Study on the Framework on Collision Risk Warning System Using Loop Detector and Vehicle Information

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ABSTRACT

Current safety warning systems generally operate based on the information from sensors attached to individual vehicles. This vehicle-sensor based system can only estimate the collision potential situation in close proximity of a subject vehicle, and it requires additional communication technologies such as Vehicle-to-Vehicle (V2V) and Vehicle-to-Infrastructure (V2I) communication technologies in order to obtain a wide range of information. The device requirements for such technologies will lead to the price increase of the collision warning system. So, in this study, we propose the collision warning system that utilizes the information from the fusion of loop detector data and smartphone data. The proposed collision warning system can be directly applied without any additional cost, because the databases of loop detector and smartphones are available to be used. The developed system is tested by simulating a real vehicle trip based on the NGSIM data and comparing its results to vehicle-sensor based system and infrastructure information based system. It was found that the newly proposed collision risk warning system can show the similar performance with the V2V-based collision warning system.

INTRODUCTION

The typical collision warning systems have utilized individual vehicle information such as relative-speed information to process its own collision risk. This does not utilize information obtained from other vehicles or infrastructure. As Vehicle-to-Vehicle (V2V) communication related technology such as Dedicated Short-Range Communication (DSRC) and Global Positioning System (GPS) developed, however, sharing information of collision risk between vehicles became possible (Elbatt et al., 2006). In addition to this development, WLAN infrastructure on the road will facilitate the development of vehicle to infrastructure (V2I) communication. (Wang et al., 2008)

V2V and V2I communication based collision warning systems have some limitation. First, V2V collision warning system assesses information collected by sensors equipped in vehicle and estimates the collision risk of the subject vehicle relative to the surrounding vehicles and propagates the information (Yeo et al., 2010). V2V communication based system can be also used for autonomous driving based on the prediction of future traffic state (Tak and Yeo, 2013). However it has its shortcomings in that the vehicle sensors may not perform well concerning accuracy, latency and reliability. For instance, the GPS may sometimes create results with error of too large a distance that the collision risk will be meaningless. An absence of sensors in vehicles on the road may create large errors as well (Elbatt et al. 2006). Another disadvantage is that the system performance will be significantly decreased if there are disruptions in communication between vehicles, for example blockage of transmission due to physical obstacles (Wang et al. 2008).

Second, V2I collision warning system covers information not only from the vehicles, but also from the roadside infrastructure on the driving environment (Milanes et al., 2012, Yeo et al., 2013). Though this system could greatly improve the collision warning system, the lack of extensive coverage of infrastructure on the road challenges its feasibility. It still remains a long-term plan for the government to support extensive installation of the necessary infrastructure on the road (Tan et al., 2006; Palazzi et al., 2007). Considering the weaknesses of above systems, this paper proposes a hybrid system, which will utilize the information from the loop detector on the roadside and the subject vehicle's in-vehicle information. This way the system will not depend on the information transmission with other vehicles, which is the crucial shortcoming of the V2V system.

In addition, this paper proposes a new Safety Surrogate Measure (SSM), a parameter that reflects the possibility of collision. Unfortunately, the currently used SSMs have limitations in predicting the safety of individual vehicle and of roads in real life application. One limitation is that they do not represent performance characteristics of each vehicle, such as different braking or accelerating capability. Instead they implement the average value for these characteristics, which may create errors in measuring the safety. Another limitation is that the existing SSM fail to measure the change in the degree of safety as the vehicle accelerates or decelerates. For example, in the accelerating or decelerating process, the time it takes to reach the maximum braking rate changes and this must be considered in calculating the collision risk. In other words, the risk will be underestimated while accelerating. Therefore, this paper tests the performance of a new SSM, called Deceleration-based Safety Surrogate Measure (DSSM), which reflects the human driving behaviors. This will consider different behaviors of drivers by applying variable acceleration and deceleration rates of each individual.

The most ideal condition to prevent vehicle collision is to install sensors with V2V technology in every vehicle to provide CWS with most information possible. However this is currently impossible due to the high cost and low market share of the technology. On the other hand, information from vehicle and infrastructure are readily available but are not be fully implemented due to the lack of algorithms for collision warning. This research attempts to (1) develop a measure for warning collision in V2V environment, (2) suggest a framework for CWS using information from vehicle and loop detector, and (3) assess the possibility of application in real life by comparing its risk estimation capability and reliability of V2V technology.

COLLISION WARNING SYSTEM BASED ON SAFETY SURROGATE MEASURE

Deceleration-Based Safety Surrogate Measure. We propose a new SSM called Deceleration-based Safety Surrogate Measure (DSSM), whose equation is as follows:

Stopping location of leader vehicle ≥ Stopping location of following vehicle

$$x_{n-1}(t)-\frac{v_{n-1}(t)^2}{2\cdot b_{max,\, n-1}}-s_{n-1}+\frac{1}{2}\cdot\left[v_{n-1}(t)+\frac{(a_{n-1}(t)+b_{max,\, n-1})}{2}\cdot\frac{(a_{n-1}(t)-b_{max,\, n-1})}{L_{n-1}}\right]\cdot T_{n-1}$$

$$\geq x_n(t)+[v_n(t)+v_n(t+\tau)]\cdot\frac{\tau}{2}-\frac{v_n(t+\tau)^2}{2\cdot b_n(t)}+\frac{1}{2}\cdot\left[v_n(t)+a_n(t)\cdot\tau+\frac{(a_n(t)+b_{max,\, n})}{2}\cdot\frac{(a_n(t)-b_{max,\, n})}{L_n}\right]\cdot T_{n-1} \quad (1)$$

From the equation (1), the DSSM of the two vehicles is calculated based on the maximum braking capability of the following vehicle as below:

$$b_n(t)=b_{max,\, n-1}\cdot\frac{[v_n(t)+a_n(t)\cdot\tau]^2}{\left[2\cdot K\cdot b_{max,\, n-1}+v_{n-1}(t)^2\right]}<0 \quad (2)$$

$$DSSM=\frac{b_n(t)}{b_{max.n}} \quad (3)$$

As mentioned above, DSSM ultimately evaluates the collision risk based on the maximum deceleration to avoid a collision. If all information of the subject vehicle is available, applying this to the analysis will increase the reliability of the collision risk. If the subject vehicle has no information or if assessment of multiple vehicles in a certain interval is needed, the average value will be used for the risk assessment.

Framework for the Collision Warning System. This paper suggests two different frameworks for CWS. First is the loop detector-based system, which uses the information only from the loop detector to calculate the collision risk of a certain interval of a road. Second is a hybrid system to use the information from both loop detector and subject vehicle to calculate the collision risk of each vehicle.

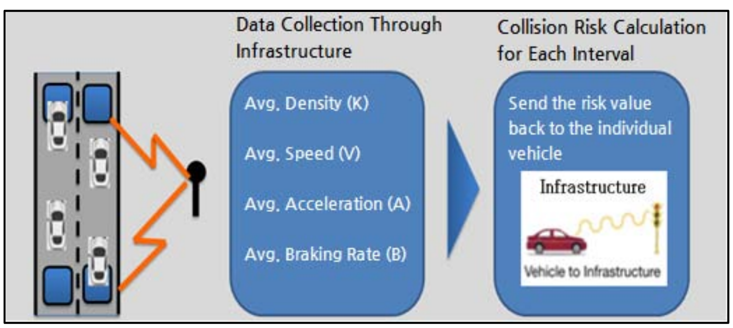

Figure 1. Data Collection Through the Loop Detector and Risk Calculation

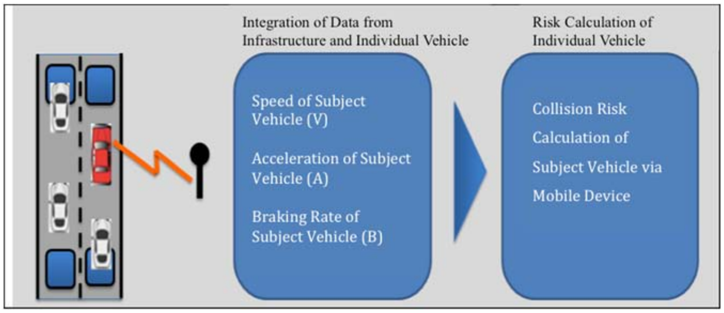

Figure 2. Risk Calculation of Individual Vehicle

Figure 1 and 2 above show the two frameworks with the required data and processes, with the loop detector-based and hybrid systems, respectively. As shown in Figure 1, the basic information collected from loop detector is density, speed and flow. By using DSSM with these values, one can calculate collision risk between loop detectors. Also in Figure 2 shows the hybrid model of integrating information from loop detector and subject vehicle. The average value of the collision risk from the loop detector is combined with the information of the subject vehicle, to achieve its own tailored individual collision risk. Due to the development of smart phones and automobile technologies, this hybrid system could be applied in real life, present time. For example, smart phone and navigations in automobiles produce information of acceleration and speed of the vehicle.

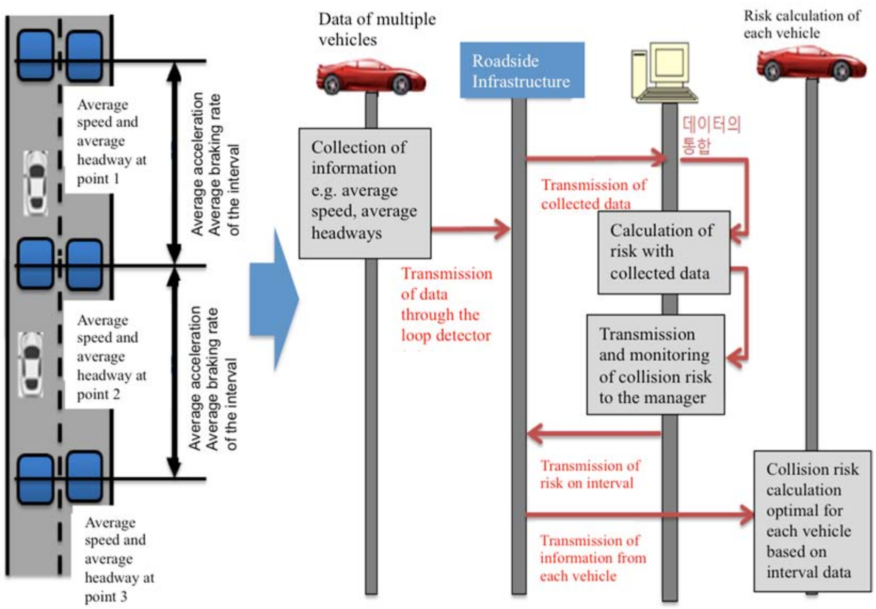

Figure 3. Data Flow of the Hybrid System

Figure 3 shows the data flow of the suggested CWS. In each point of the road, the loop detector measures the average data, which then results in the collision risk of each interval. To calculate the collision risk of one interval, three loop detector measurements are required. This is then sent to individual vehicle, which substitutes its own information such as speed, acceleration, braking capacity to assess its own collision risk with increased accuracy.

Contents of the Collision Warning System. The suggested CWS in this paper may provide the necessary information optimally, following the driver's demand and consequences. Information used in the CWS, when exposed to only a portion of the drivers on the road, may create unstable traffic flow by distorting the behavior of the receiver drivers. Therefore it is most effective when the information is supplied to all drivers on the road to prevent any accident. For instance, an infrastructure installed on guardrail may show alerting lights based on loop-detector information to all the drivers on the road.

Figure 4 shows the example of the hybrid system, which alerts the driver of his own collision risk calculated from the loop detector and in-vehicle information. When the loop-detector-based system is used together with the hybrid system, it will reduce the possibility of unstable traffic flow that may rise from certain drivers without the collision risk alarm. At the same time, this will increase the safety of the vehicles with hybrid system installed.

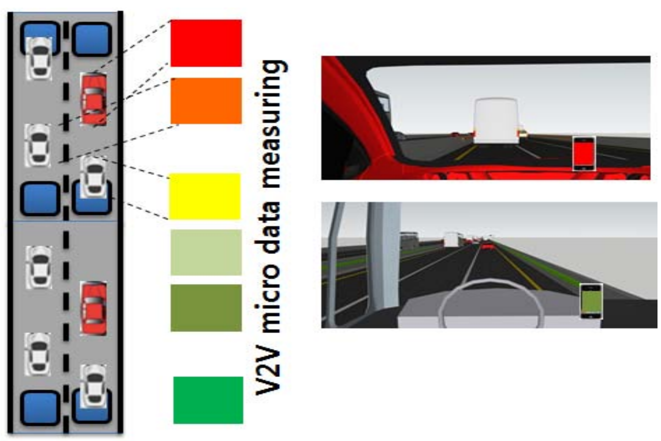

Figure 4. Example of the Hybrid System Contents

METHODOLOGY

The most ideal system to calculate the collision risk is the completely installed V2V system operating real time, though this is currently infeasible because of the cost and market share of the vehicles. In this research, we assess the reliability of the loop detector-based CWS and hybrid CWS, under the assumption that the V2V system produces the most ideal collision risk.

The required data for each system is as follows. The loop-detector-based system analyzes the collision risk by using the average data gathered over a certain time period, where V2V system applies information from each and every vehicle. In case of the hybrid system, a limited set of individual vehicle information is used. In the assumption that data is not attainable from surrounding vehicles directly, the system use the average values form the loop detectors for surrounding vehicle's information and detail information of the subject vehicle. In order to compare the collision risk of the V2V, loop detector-based, and the hybrid system, the data from V2V and hybrid system have been converted to the average collision risk values over 30 seconds.

The results of V2V and hybrid system were analyzed based on the two criteria – detection capability of dangerous situations and the accuracy of the overall system. First, the detection capability of dangerous situations means the ratio of subject vehicle detecting danger under V2V to under the hybrid system. This ratio is calculated based on the Table 1. In this table, 'true' means detecting a danger and 'false' means detecting no danger, when the subject vehicle is evaluated for its risk every 0.1 second. If a system shows many 'true' values, the vehicle is under more dangerous situations where as many 'false' values mean that the vehicle is relatively safe. The detection capability of dangerous situations is calculated as A/(A+C). Second, the accuracy of the overall system evaluates the agreement between V2V and hybrid. Based on the Table 2, the accuracy is calculated as (A+D)/(A+B+C+D).

Table 1. Detection Capability of Dangerous Situations

		V2V Future Technology	
		True	False
Hybrid	True	A	B
System	False	C	D

DATA

In order to assess the reliability of the hybrid system, NGSIM data is used. NGSIM data is collected on the I-80 highway in California, the United States, which provides information, such as speed of individual vehicle, acceleration, distance between vehicles, length of the vehicle, in interval of 0.1 second. With this data, the collision risk using both V2V and hybrid system was calculated. As well, the NGSIM data was converted to what loop detectors would have measured, calculating the collision risk the loop-detector-based system.

RESULTS

Figure 5 represents calculated collision risks of three cases using the V2V, loop-detector-based, and hybrid system. As shown, the loop-detector-based system either overestimates or underestimates the collision risk, and has a different trend compared to the V2V system. Contrarily, the hybrid system shows similar results as well as a similar trend to that of the V2V system. It can be predicted that the collision warning based on the hybrid system will bring benefits to the individual drivers as the V2V system would bring.

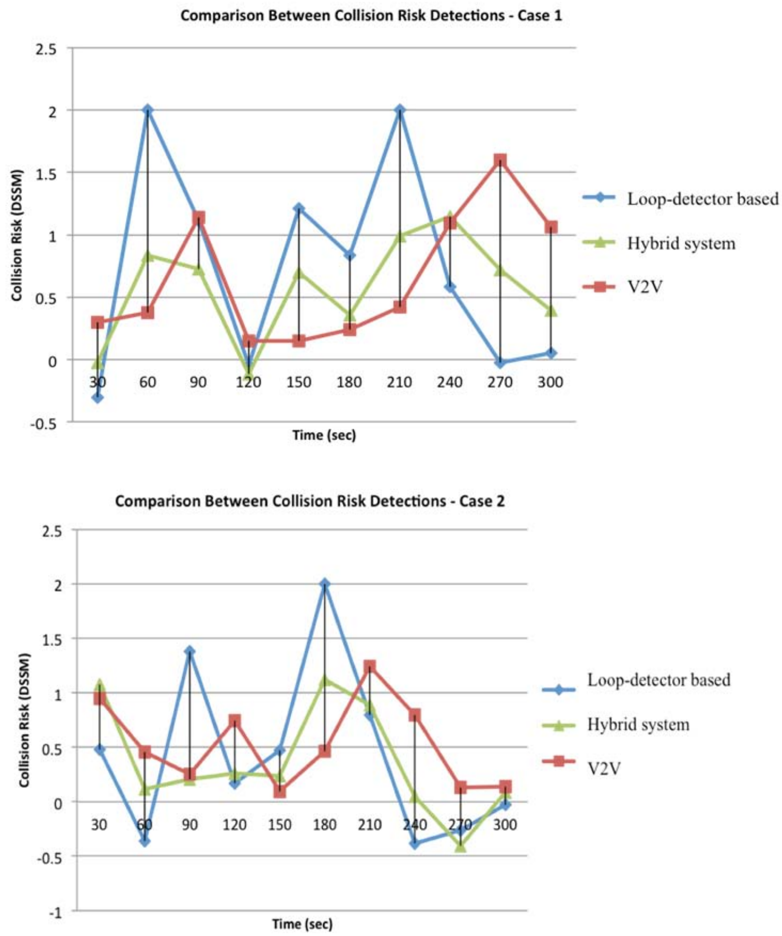

Figure 5. Comparison Between Collision Risk Detections of Case 1 and Case 2

Table 2 lists the collision risk assessment capability and accuracy of the hybrid system, comparing to the V2V results. The hybrid system shows a 72%, 79%, and 75% accuracy in case 1, 2, and 3, respectively. Especially, the hybrid system has strength in the risk assessment capability, which shows an average of 90% detection of the risky conditions. Therefore, this hybrid system is likely to calculate the risk at 90% to the V2V system without installing any additional equipment or development, solely based on the currently available devices such as the loop detector and smart phone.

Table 2 Collision risk assessment capability and accuracy of the hybrid system

	Collision Risk Assessment Capability	Accuracy
Case 1	94%	72%
Case 2	87%	79%
Case 3	90%	75%

CONCLUSION

This paper proposes a system of predicting the collision risk before an accident with the traffic parameters available from loop detectors and in-vehicle devices. From the results, the hybrid system shows approximately 90% prediction capability of the V2V system, the most ideal but infeasible collision warning system. Further study may compare the V2V based system and proposed hybrid system based on the micro level driving pattern and vehicle trajectory data. And we will investigate a system to increase the reliability of the collision risk calculation even further by applying more than one subject vehicle in the hybrid system, which will estimate closer to that of V2V.

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