Transportation Research Part C 74 (2017) 22–33

Contents lists available at ScienceDirect

Transportation Research Part C

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

Crash prediction with behavioral and physiological features for advanced vehicle collision avoidance system

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ARTICLE INFO

Article history:
Received 25 September 2015
Received in revised form 19 June 2016
Accepted 10 November 2016

Keywords:
Crash prediction
Driving behavior
Fixation
Physiological measures
Discriminant analysis

ABSTRACT

Real-time crash prediction is the key component of the Vehicle Collision Avoidance System (VCAS) and other driver assistance systems. The further improvements of predictability requires the systemic estimation of crash risks in the driver-vehicle-environment loop. Therefore, this study designed and validated a prediction method based on the supervised learning model with added behavioral and physiological features. The data samples were extracted from 130 drivers' simulator driving, and included various features generated from synchronized recording of vehicle dynamics, distance metrics, driving behaviors, fixations and physiological measures. In order to identify the optimal configuration of proposed method, the Discriminant Analysis (DA) with different features and models (i.e. linear or quadratic) was tested to classify the crash samples and non-crash samples. The results demonstrated the significant improvements of accuracy and specificity with added visual and physiological features. The different models also showed significant effects on the characteristics of sensitivity and specificity. These results supported the effectiveness of crash prediction by quantifying drivers' risky states as inputs. More importantly, such an approach also provides opportunities to integrate the driver state monitoring into other vehicle-mounted systems at the software level.

1. Introduction

1.1. Crash prediction for vehicle collision avoidance system

Traffic accidents cause more than one million deaths per year worldwide (WHO, 2013). It is imperative to conduct the beforehand interventions by forecasting impending on-road crashes. For this reason, a series of new systems have been implemented in mass-produced vehicles, to decrease the possibility and severity of traffic accidents. One widely used active-safety technology, Vehicle Collision Avoidance Systems (VCASs) are designed to predict an imminent crash, provide warnings to drivers or take autonomous actions (Seiler et al., 1998). Experimental studies and market feedbacks have evidenced the effectiveness of VCASs to improve driving safety, as well as drivers' subjective appraisals (Hoffenson et al., 2013; Itoh et al., 2013; Maltz and Shinar, 2007; Jamson et al., 2008).

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http://dx.doi.org/10.1016/j.trc.2016.11.009
0968-090X/

Methodology of crash prediction is the fundamental component of VCASs, as well as other real-time driver assistance systems. The vast majority of crash predictions are based on the data collected continuously from vehicular radars or motion sensors (Wu et al., 2014; Milanés et al., 2012; Kiefer et al., 2005; Seiler et al., 1998). This data covers various vehicle dynamics (e.g. velocity) and distance metrics (e.g. Time-to-Collision, TTC), which are then processed by the algorithms embedded in an on-board electric circuit. The algorithms estimate the risk level or collision possibility, and decide whether, when and how to conduct the beforehand interventions (e.g. warning or braking).

Accuracy and timeliness are always the key performances for crash prediction, with the first priority to be considered (Wu et al., 2014; Wang et al., 2008; Itoh et al., 2013; Abe and Richardson, 2006). On one hand, prediction with low accuracy means that the VCAS designers have to balance the chances of a 'miss' or a 'false alarm'. Missing an impending collision is always unacceptable risk for drivers who use VCAS. Thus, to decrease the chances of a miss with limited accuracy, the false alarm rate is relatively increased. Jamson et al. (2008) have suggested that the false alarms would reduce drivers' trust in VCAS, as well as the long-term system usage. More importantly, false alarms could also impair drivers' propensity for effective responses to the correct predictions. On the other hand, prediction with low timeliness means the time duration could be insufficient for drivers to react to the approaching hazards. Previous studies have recommended that the warnings of collision to drivers should be presented at least 4 s prior to the approaching conflicts, and this time interval should be increased probably as the velocity increases (Werneke and Vollrath, 2013; Yan et al., 2015). Therefore, the increasing prevalence of VCAS raises an issue of how to develop crash prediction methods with better predictability.

From a systemic perspective, the VCAS is a close-loop control system including drivers' human factors. As illustrated in Fig. 1(a), the vehicular sensors collect continuous data from the vehicle and surrounding traffic environment; algorithms estimate the current risk level; other devices generate intervention. In this architecture, the driver conducts behavioral responses to compensate for the crash risk according to the driver's perceived risk level and VCAS feedbacks. However, the current VCAS and its crash prediction rarely consider the relation between drivers' states and crash possibilities. Therefore, to further increase the predictability of crash involvements, one promising approach is to systemically estimate the situational risk of vehicle, traffic environment and driver.

1.2. Assessments of drivers' risky states

The previous studies have extended our understanding of the drivers' risky states as related to crash involvements, and also found abundant measurements to assess these states. These findings allowed us to address the feasibility to estimate drivers' risks continuously via various behavioral and physiological measures.

At the behavioral level, drivers' risky propensities could be reflected by their behavioral features, which are also determined by the road geometries (e.g. curve or straight) and driving scenarios (e.g. free-driving or hazardous situation). Jun et al. (2011) found that drivers' longitudinal controls via GPS data was significantly correlated with their accident records.

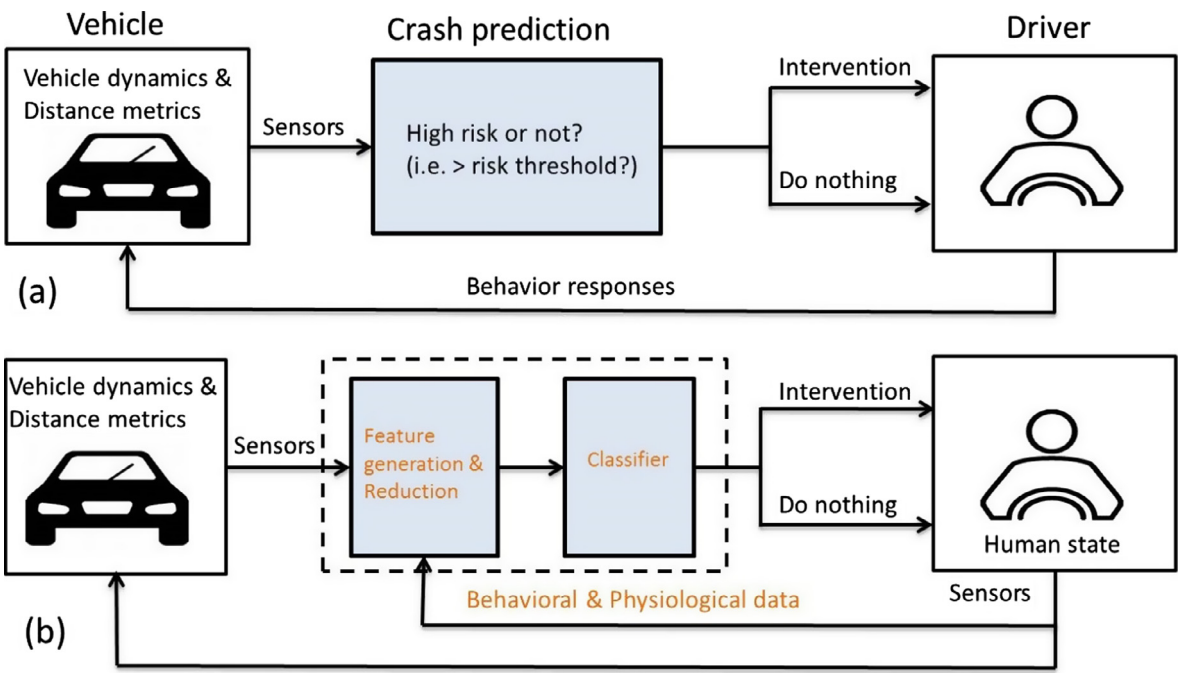

Fig. 1. Architectures of VCAS without/with behavioral and physiological monitoring.