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Context-aware system for pre-triggering irreversible vehicle safety actuators

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ABSTRACT

New vehicle safety systems have led to a steady improvement of road safety and a reduction in the risk of suffering a major injury in vehicle accidents. A huge leap forward in the development of new vehicle safety systems are actuators that have to be activated irreversibly shortly before a collision in order to mitigate accident consequences. The triggering decision has to be based on measurements of exteroceptive sensors currently used in driver assistance systems. This paper focuses on developing a novel context-aware system designed to detect potential collisions and to trigger safety actuators even before an accident occurs. In this context, the analysis examines the information that can be collected from exteroceptive sensors (pre-crash data) to predict a certain collision and its severity to decide whether a triggering is entitled or not. A five-layer context-aware architecture is presented, that is able to collect contextual information about the vehicle environment and the actual driving state using different sensors, to perform reasoning about potential collisions, and to trigger safety functions upon that information. Accident analysis is used in a data model to represent uncertain knowledge and to perform reasoning. A simulation concept based on real accident data is introduced to evaluate the presented system concept.

1. Introduction

It is estimated that on the world's roads 20–50 million people suffer injuries each year by traffic collisions. This trend will worsen according to World Health Organization (WHO) predictions so that by 2030, traffic fatalities will be the fifth most common cause of death in the world (World Health Organization, 2013). Unfortunately, most accidents are caused by human error, and the reasons are typically related to incorrect judgment (e.g. distance to preceding vehicle) or lack of driver attention (Bayless et al., 2012). The primary goals of the vehicle safety research of today, therefore, is the complete avoidance of traffic accidents. Failing this, a secondary goal should be the optimal protection of the vehicle passengers and Vulnerable Road Users (VRUs) (i.e. pedestrians). In this respect, the automobiles sense of 'sight' and its exteroceptive sensors, can play an increasingly important role. Intelligent Vehicles (IV) are able to perceive and model their environment and correctly recognize potential dangers. Today, a special focus is on the investigation of methods to activate pre-crash triggered safety applications in order to increase the vehicle crash performance and the passenger protection.

Research activities in the past years show benefits of new occupant restraint systems which are deployed immediately prior to a collision. Contemporary passenger safety systems combine air bags and three-point-automatic seat-belts to reduce the passengers risk of injury. For a proper generation of the triggering decision, vehicle dynamics, peripheral intrusion and occupants positions are measured and evaluated (Feser et al., 2006; Chan, 2000; Rölleke and Köhler, 2001). In comparison, novel systems which have to be triggered shortly before a vehicle crash can provide a larger cushion volume. In special load cases occupant loads can be reduced by up to 20% on average (Wohllebe et al., 2006; Gstrein and Sinz, 2009). This will offer occupants new interior concepts and profoundly changed sitting positions. External airbags and structure-airbag concepts (i.e. synthetic pressure hoses which are filled with gas before an impact) can extend the vehicle's crumple zones to provide additional energy absorption of impacts (Hakki and Hakki, 2008; Chung et al., 2014; Löffler and Quedenbaum, 2014; Unselt et al., 2015). The introduction of pre-crash measures not only makes sense for occupant protection, but is also an important element in upcoming actuator technology to protect VRUs (Mishra, 2012; Choi and Kim, 2010). Fig. 1 outlines the chronological sequence of

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Abbreviations

c	stiffness
m	mass
J_z	momentum around z-axis
$\mathbf{L}$	angular momentum
$\mathbf{I}$	Impulse
τ	trajectory
$\mathcal{R}$	risk
$\mathbf{x}$	state vector
$\mathbf{r}, x, y$	distance
$v, \dot{x}$	velocity
$a, \ddot{x}$	acceleration
ψ	heading angle
$\dot{\psi}$	yaw rate
$\boldsymbol{\omega}(t)$	angular velocity
ΔV	change in velocity
OLC	occupant load criterion
Cs	crash severity
k	restitution coefficient
$\mathbf{IP}$	impact point
α	impact angle
CG	center of gravity
d	y-distance between $\mathbf{IP}$ and CG
l	length
w	width
$\mathbf{S}$	crash constellation
OL	collision overlap
μ	expected value
TS	triggering strategy
NF	no fire
CF	can fire
MF	must fire
TTC	time to collision
t_{algo}	computing time
T_S	sample time
t_F	triggering time
t_l	system latency
F_β	weighted average of precision and recall
σ	variance
$\mathbf{R}$	noise covariance matrix
$\mathbf{P}$	a posteriori error covariance matrix
f	probability density function

a vehicle collision and demonstrates the basic idea to pre-trigger irreversible vehicle safety actuators. State-of-the-art systems measure and assess the vehicle's acceleration and structure-borne sound to make a safe triggering decision. Compared to today's restraint triggering, the proposed approach in this paper only uses exteroceptive sensor observations to detect unavoidable collisions and to assess the crash severity in order to trigger restraint systems shortly before collision. This paper discusses requirements and a system concept to activate vehicle safety systems just before an unavoidable collision and is structured as follows: Section 2 addresses related work and identifies the central challenges. Section 3 introduces a context-aware system for pre-triggering and discusses possible methods to predict a collision as well as defines requirements. Section 4 addresses crash severity and vehicle accident analysis. In Section 5 a model is presented to predict the crash severity and to trigger safety actuators. The evaluation of the described methodology based on real accident data is presented in Section 6. Finally, in Section 7 conclusions are drawn and the further research direction is described.

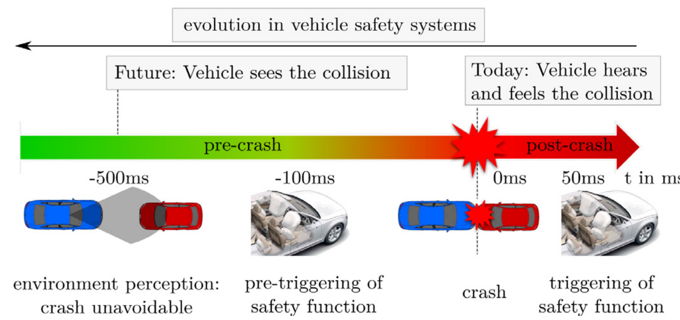

Fig. 1. Basic concept for pre-triggering irreversible vehicle safety actuators.

2. Related work

This section puts this work into the context of relevant literature. Active restraint systems like air-bags and seat-belts are triggered to reduce the vehicle occupants risk of injury when an accident occurs. To cushion the occupant motion best during a vehicle accident, air-bags have to be triggered and inflated extremely rapidly after the collision occurs. Beyond that it is not only a decision if or not an activation is necessary but also which actuator and at what time it has to be triggered. A typical state-of-the-art sensing concept consists of pressure sensors in the vehicle passenger doors to detect side collisions and acceleration sensors in all spatial directions at the transmission tunnel (near to the vehicles center of gravity) as well as two acceleration sensors in the vehicle front.

Different studies show that triggering of safety actuators (i.e. smart air-bags) shortly before a collision can significantly reduce the injury risk and severity of the vehicle occupant. In order to predict a certain crash severity, information from the vehicle environment has to be collected and analyzed.

Mühlfeld et al. (2013) present an approach to trigger driver-adaptive pre-crash systems via statistical behavior modeling with the focus on system performance and user acceptance. The proposed methodology analyses past situations to calculate a driver individual activation threshold. The presented approach estimates the criticality of an oncoming collision for pre-crash triggering, but does not take into account a possible crash severity. Cho et al. combines exteroceptive sensor and longitudinal accelerometer measurements to improve the integrity of airbag deployment decisions (Kwanghyun Cho, 2011). The presented approach only uses Radar sensor measurements as an additional input where the deployment decision is mainly based on the in-crash deceleration measurement.

A methodology to estimate optimal trigger times of an adaptive frontal restraint system for an oncoming collision can be found in (Wallner et al., 2009; Eichberger et al., 2009). An algorithm is presented, which calculates force levels with acquired parameters by combining three separate models (vehicle model, collision model and occupant model). The collision and occupant model uses a spring mass system to calculate the maximum and mean acceleration of the occupant. As input parameters, the models use the collision speed, mass and stiffness of the colliding vehicle. The investigation considers straight frontal collisions with full overlap and determine the stiffness according to different sets of mass categories. However, it is not described how the mass and collision speed can be acquired or predicted.

Rao et al. proposes an architecture consisting of a vision system and a Radar or Lidar sensor to trigger external airbags (Rao et al., 2005). Measurements from a Radar and Lidar sensor are used to determine the relative velocity and distance to the potential collision opponent. This information is then fused with the collision opponents classification (it can distinguish between pedestrians or vehicles) provided by the vision system in order to deploy the