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Collision mitigation and vehicle transportation safety using integrated vehicle dynamics control systems

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HIGHLIGHTS

- Integrated vehicle dynamics control systems for collisions improvement.
- Development of a new dynamics/crash mathematical model for vehicle collisions.
- Development of a new occupant-based lumped mass-spring-damper mathematical model.
- Vehicle response and occupant behaviour are captured and analysed accurately.

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ABSTRACT

The aim of this paper is to investigate the effect of vehicle dynamics control systems (VDCS) on both the collision of the vehicle body and the kinematic behaviour of the vehicle's occupant in case of offset frontal vehicle-to-vehicle collision. A unique 6-degree-of-freedom (6-DOF) vehicle dynamics/crash mathematical model and a simplified lumped mass occupant model are developed. The first model is used to define the vehicle body crash parameters and it integrates a vehicle dynamics model with a vehicle front-end structure model. The second model aims to predict the effect of VDCS on the kinematics of the occupant. It is shown from the numerical simulations that the vehicle dynamics/crash response and occupant behaviour can be captured and analysed quickly and accurately. Furthermore, it is shown that the VDCS can affect the crash characteristics positively and the occupant behaviour is improved.

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1. Introduction

Vehicle dynamics control systems (VDCS) exist on the most modern vehicles and play important roles in vehicle ride, stability, and safety. For example, anti-lock brake system (ABS) is used to allow the vehicle to follow the desired steering angle while intense braking is applied (Bang et al., 2001; Yu et al., 2002). In addition, the ABS helps reducing the stopping distance of a vehicle compared to the conventional braking system (Celentano et al., 2003; Pasillas-Lépine, 2006). The active suspension control system (ASC) is used to improve the quality of the vehicle ride and reduce the vertical acceleration (Alleyne and Hedrick, 1995; Yue et al., 1988). From the view of vehicle transportation safety, nowadays, occupant safety becomes one of the most important research areas and the automotive industry increased their efforts to enhance the safety of vehicles. Seat belts, airbags, and advanced driver assistant systems (ADAS) are used to prevent a vehicle crash or mitigate vehicle collision when a crash occurs.

The most well-known pre-collision method is the advance driver assistant systems (ADAS). The aim of ADAS is to mitigate and avoid vehicle frontal collisions. The main idea of ADAS is to collect data from the road (i.e., traffic lights, other cars distances and velocities, obstacles, etc.) and transfer this information to the driver, warn the driver in danger situations and aid the driver actively in imminent collision (Gietelink et al., 2006; Seiler et al., 1998). There are different actions may be taken when these systems detect that the collision is unavoidable. For example, to help the driver actively, the baking force can be applied in imminent collision (Jansson et al., 2002), in addition, the brake assistant system (BAS) (Tamura et al., 2001) and the collision mitigation brake system (CMBS) (Sugimoto and Sauer, 2005) were used to activate the braking instantly based on the behaviour characteristics of the driver, and relative position of the most dangerous other object for the moment.

Vehicle crash structures are designed to be able to absorb the crash energy and control vehicle deformations, therefore simple mathematical models are used to represent the vehicle front structure (Emori, 1968). In this model, the vehicle mass is represented as a lumped mass and the vehicle structure is represented as a spring in a simple model to simulate a frontal and rear-end vehicle collision processes. Also, other analyses and simulations of vehicle-to-barrier impact using a simple mass spring model were established by Kamal (1970) and widely extended by Elmarakbi and Zu (2005, 2007) to include smart-front structures. To achieve enhanced occupant safety, the crash energy management system was explored by Khattab (2010). This study, using a simple lumped-parameter model, discussed the applicability of providing variable energy-absorbing properties as a function of the impact speed.

In terms of the enhancing crash energy absorption and minimizing deformation of the vehicle's structure, a frontal structure consisting of two special longitudinal members was designed (Witteman and Kriens, 1998; Witteman, 1999). This longitudinal member system was divided into two separate systems: the first, called the crushing part, guarantees the desired stable and efficient energy absorption; the other, called the supporting part, guarantees the desired stiffness in the transverse direction. For high crash energy absorption and weight efficiency, new multi-cell profiles were developed (Kim, 2002). Various design aspects of the new multi-cell members were investigated and the optimization was carried out as an exemplary design guide.

The vehicle body pitches and drops at fontal impact are the main reason for the unbelted driver neck and head injury (Chang et al., 2006). Vehicle pitch and drop are normally experienced at frontal crash tests. They used a finite element (FE) method to investigate the frame deformation at full frontal impact and discussed the cause and countermeasures design for the issue of vehicle body pitch and drop. It found that the bending down of frame rails caused by the geometry offsets of the frame rails in vertical direction during a crash is the key feature of the pitching of the vehicle body.

The effect of vehicle braking on the crash and the possibility of using vehicle dynamics control systems to reduce the risk of incompatibility and improve the crash performance in frontal vehicle-to-barrier collision were investigated (Hogan and Manning, 2007). They proved that there was a slight improvement of the vehicle deformation once the brakes were applied during the crash. A multi-body vehicle dynamic model using ADAMS software, alongside with a simple crash model was generated in order to study the effects of the implemented control strategy.

Their study showed that the control systems were not able to significantly affect the vehicle dynamics in the offset barrier impact. In addition, it was found that in offset vehicle-to-vehicle rear-end collision, the ABS or direct yaw control (DYC) systems can stabilize the vehicle. However, these control systems affected each other and cannot work together at the same time.

The behaviour of a vehicle at high-speed crashes is enhanced by using active vehicle dynamics control systems (Elkady and Elmarakbi, 2012). A 6-degree-of-freedom (6-DOF) mathematical model was developed to carry out this study. In this model, vehicle dynamics was studied together with a vehicle crash structural dynamics and a validation of the vehicle crash structure of the proposed model was achieved. Four different cases of VDCS were applied to the model to predict the most effective one. An extension to this study, an occupant model has been developed and the effect of VDCS on the occupant kinematics has been analysed (Elkady and Elmarakbi, 2012).

The main aim of this research is to investigate the effect of the VDCS on vehicle collision mitigation, enhance vehicle crash characteristics, and improve occupant biodynamics responses in case of 50% vehicle-to-vehicle offset crash scenario. For that purpose, different seven cases of VDCS are applied to the vehicle model, there are three new cases which are not mentioned in the previous publications.

2. Methodology

A vehicle frontal collision can be divided into two main stages, the first one is a primary impact, and the second one is a secondary impact. The primary impact indicates the collision