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Current Technologies in Vehicle Safety

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Abstract

Road crashes are a worldwide contemporary problem, responsible for significant personal and societal injuries and material lost. In recent years, electronic equipment showed a high increase of participation in the control and driver assistance of vehicles. This phenomenon is associated with a growth in complexity and sophistication of functional requirements of safety devices installed in vehicles. This paper describes new safety electronic systems available in modern vehicles and technological trends in this field. It is remarked that there is concern about the adaptation of drivers to the enhanced safety offered by modern vehicles, and that observable benefits could be different according to the development condition of different countries.

Keywords: ITS, crashes, road safety equipment

1. Introduction

Road crashes are a worldwide and multidisciplinary contemporary problem, responsible for significant personal injuries and material lost (DOT-NHTSA, 2007). According to a World Health Organization report, road traffic injuries are expected to take a third place in the rank order of disease burden by the year 2020 (WHO, 2004). Attempting to reduce road crashes occurrence and consequences, research have primarily focused in drivers' and pedestrians' behavior (Beede & Kass, 2006; Bianchi & Summala, 2002; Nasar, Hecht, & Wener, 2008), infrastructure enhancements and vehicular safety systems (Alonso, Vidal, Rotter, & Muhlenberg, 2008; Andelin et al., 1989; Chatzigiannakis, Grammatikou, & Papavassiliou, 2007; Chen & Wang, 2007; Sattel & Brandt, 2008). In recent years, electronic equipments showed a great increase of participation in the vehicular control and driver assistance. This

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phenomenon is associated with a growth in complexity and sophistication of functional requirements of safety devices installed in vehicles. This paper describes new safety electronic systems currently available in modern vehicles and it also points technological trends in this field.

2. Description of technologies

2.1. Passive Safety Systems

Passive systems protect the driver, passenger, and more recently, pedestrians, when crashes occur. They don't avoid crashes but reduce the consequences of crashing instead. Examples are enhanced seat belts, air bags, protection bars, and shock absorbing vehicle structure. Since the present work is focused on electronic safety systems, pure mechanical components like protection bars will not be discussed.

The National Highway Traffic Safety Administration of the U.S. Department of Transportation, the European Community and the Australian government develop programs oriented to the assessment of new cars. These programs, respectively, *New Car Assessment Program* (NHTSA, 2009), *European New Car Assessment Program* (ENCAP, 2009), and *Australian New Car Assessment Program* (ANCAP, 2009), rate vehicles through controlled crash and rollover tests, determining crash worthiness and rollover safety. The evaluation of injuries to passengers uses sophisticated dummies equipped with force and acceleration sensors (Guizzo, 2007). Recently, children restraints and pedestrian protection under impacts have been introduced (ANCAP, 2009; ENCAP, 2009; NHTSA, 2009). In general there is significant correlation between the crash test scores and injury risks observed in real life impacts, showing that crash tests are an effective tool to analyze passive protection (Lie & Tingvall, 2000).

2.1.1. Seat Belt Pretensioners

Nowadays, seat belts are three-point anchoring systems provided with pretensioners, locking the belt during an impact. The pretensioners can be mechanical, electrical, pyrotechnic or active. The first pretensioners were mechanical, built with an inertial wheel with a pendulum that moves under the big deceleration of a crash, locking the belt. The electrical pretensioners use electronic accelerometers instead of the mechanical pendulum to detect crashes. The pyrotechnic pretensioners are an evolution of electrical pretensioners that use electrically triggered explosives to tighten the seatbelt during a crash event. The most recent pretensioners are active pretensioners, called Active Control Retractors (EDN, 2008; Kurutas, Elsasser, Schramm, & Hiller, 2006). These systems are based on electronic accelerometers combined with fast electric motors to tighten the seat belt in case of strong decelerations. They have the advantages of being the only reversible system and where the tightening force can be proportional to the deceleration suffered by the vehicle. It should be remarked that only the two last pretensioner types are true pretensioners, the first ones are just limiting devices that avoid unrolling and extension of seatbelt during impacts. The pyrotechnic and active pretensioners help to keep the occupants in proper position during crashes, reducing injuries due to rapid inflation of airbags and also reducing the energy necessary to the airbags to protect them.

2.1.2. Seat Belt Load Limiters

Another new feature of seatbelts are load limiters. During a collision, a seatbelt can inflict damage to the user due to the force to keep him/her in place. The idea of a load limiter is to release the belt a little when a great force is applied to it. The simplest form of load limiter is a fold sewed into the belt webbing. When the tension is too high the stitches break allowing the belt to extend a little bit. More advanced load limiters are based on torsion bars embedded in the retractor mechanism.

2.1.3. Airbags

Airbags were introduced in the automotive industry in the mid-1970s by Ford and General Motors, and Mercedes-Benz in 1980 (Chan, 2007; Mertz, 1988). They are occupant restraints consisting of a nylon bag designed to inflate rapidly in case of collision. Airbags prevent drivers and passengers from striking windshield, steering-wheel and other vehicle parts during collisions. The impact condition is detected by an Airbag Control Unit (ACU), based on data acquired from sensors like accelerometers, wheel speed sensors, and brake pressure sensors.

In case of impact, a solid gas generator propellant is activated, inflating the bag instantly. Just after that, the gas dissipates through tiny holes in the bag, deflating the bag, thus allowing occupants to move. All this process occurs in approximately 1/25 second after collision detection.

The quick and strong airbag inflation may injury vehicle occupants, particularly if they are out of position (OOP). Here, out of position refers to conditions like children and adults sitting too close to the airbags or being thrown forward due to severe deceleration or missing or wrong seatbelt usage. A particular OOP condition is carrying an infant at frontal passenger seat in a mounted child seat, also too close to the airbag.

Because of this many vehicles already have a control to manually disable the passenger airbag when carrying infants at passenger side. In order to avoid the side-effect injuries, new technologies and mathematical models have been developed to adapt the airbag inflation to the severity of collision, the size and posture of the occupant, and belt usage. The mathematical models are very complex and represent the airbag expansion and interaction with occupants, in general based on finite elements or analytical expressions (Khan & Moatmadi, 2008).

Some work have been also developed using image analysis to identify occupants and their position and size in order to adjust the airbag to them (Farmer and Jain, 2007; Schreiber & Luo, 2007; Trivedi et al., 2004).

2.2. Active Safety Systems

Active systems, named Driver Assistance Systems (DAS), execute actions or give drivers information in order to avoid or compensate their errors. Examples of active systems are anti-lock braking systems, forward collision warning systems, and lane departure warning systems.

DAS are supplementary systems designed to help drivers in the tasks of vehicle stabilization, maneuvering and navigation. They can trigger actions of vehicle control, e.g. breaking, but the commands issued by the driver always override their actions. In this sense, DAS offer a support for the driver without restricting his/her actions. DAS are electronic devices, which bring comparative advantages over human beings in some tasks of the control of a vehicle: (i) they are not susceptible to fatigue, (ii) act in a uniform way either at stressing or normal conditions, and (iii) they can quickly process a large amount of information simultaneously.

2.2.1. Anti-lock Braking System

An anti-lock braking system (ABS, from the German Antiblockiersystem) is a system that prevents the wheels on a vehicle from locking while braking. The ABS simplifies the breaking action in panic cases, removing from the driver the task of managing the trade-off between break pressure and wheel slipping. The first systems were developed for avionics (Madison & Riordan, 1969), and due to cost restrictions and technological developments needed for massive application they were introduced in commercial automobiles by the end of 1980s. The operation principle of ABS is based on the analysis of the wheels angular speeds and subsequent control of individual brake pressure in order to keep slip ratio near the peak of wheel adhesion coefficient. The result is shorter breaking distance and better stability in most cases (Xin, Yuanyuan, & Xiufang, 2008).

2.2.2. Electronic Stability Control

Electronic Stability Control (ESC) is a recently introduced electronic system that improves the safety of a vehicle by detecting and preventing skids. Other names given by automotive industry for ESC are Electronic Stability Program (ESP), Dynamic Stability Control (DSC), Vehicle Dynamics Control (VDC), Vehicle Stability Control (VSC) and Vehicle Stability Assist (VSA).

ESC works by monitoring steering and vehicle direction. It compares the driver's intended direction, by measuring steering angle, to the vehicle's actual direction, obtained from sensing lateral acceleration, vehicle horizontal rotation (yaw), and individual wheel speeds. When ESC detects loss of steering control, it brakes automatically, helping the vehicle to keep direction.

Over-steering occurs when an abrupt steering maneuver is done in an attempt to keep vehicle control during a critical driving situation. As a vehicle begins to over-steer, the tire slip angles at the rear wheels increase rapidly. If those angles are left uncorrected, the vehicle yaw rate increases until it spins out of control. The ESC system senses the onset of instability and automatically applies the outside front brake, producing a counter moment to stabilize the vehicle.

Under-steering occurs when a vehicle fails to respond sufficiently to driver steer input on a curve and the front of the vehicle slides to the outside of the road. In that case, the ESC system applies the inside rear brake in an attempt to bring the vehicle back in line with its original intended direction. ESC systems can also reduce engine power until control is regained (Green & Woodrooffe, 2006).

2.2.3. Lane Departure Warning

A Lane Departure Warning (LDW) or Lane Departure Prevention (LDP) system warns the driver about drifting off the lane. In general, LDW is based on analysis of images taken by cameras or infra-red sensors installed in front of the vehicle. Drifting from intended trajectory can be detected from lane crossing recognition in image analysis (Lee, Kwon, & Lee, 1999; McCall & Trivedi, 2006; Zhou, Xu, Hu, & Ye, 2008), or from steering wheel torque sensors, identifying loss of driver control (Minoiu Enache, Netto, Mammar, & Lusetti, 2008).

LDW systems can just warn the driver about the lane departure with acoustic, light, or steering wheel vibration alarms, or they can take control of the steering wheel in case of loss-of-control detection. Driver's action always overrides the automatic control, allowing intentional lane departure, for example, in case of sudden collision avoidance maneuver.

2.2.4. Forward Collision Warning

Forward Collision Warning (FCWs) warns the driver about the risk of imminent collision. A Collision Avoidance System (CAS) acts actively by breaking the car when a dangerous situation is detected. Both FCW and CAS use forward-looking radar systems, images from camera, or laser scanners to monitor obstacles in front of the vehicle. The system computes the risk of collision based on the distance between the vehicle and obstacle, approximation speed, weather conditions, road slope and estimated break performance (Ferrara & Paderno, 2006; Jansson & Gustafsson, 2008; Sattel & Brandt, 2008; Vahidi & Eskandarian, 2003). A particular case of collision avoidance relates to pedestrian detection.

Recently, effort have been directed to the detection of pedestrians and estimation of their behaviour in order to predict the risk of collision between vulnerable road users (e.g., pedestrian, bicyclists, two wheelers) and vehicles (De Nicolao, Ferrara, and Giacomini, 2007; Gandhi and Trivedi, 2007). These pedestrian detection systems are in general based on information acquired from cameras and laser scanners, using features like shape, color texture, motion analysis, and background subtraction, with the support from probabilistic techniques as Kalman filters, Hidden Markov Models and Particle Filtering (Alonso et al. 2007; Munder, Schnörr, and Gavrila, 2008).

2.3. Other Safety Systems

Dynamic Steering Response (DSR) system changes the rate of hydraulic or electric power steering system to adapt it to vehicle's speed and road conditions. This provides easier and faster responses when parking or driving slowly in urban areas and less sensitive steering when driving at high speeds. Adaptive break lights that flash in case of emergency breaks also are an additional safety resource (Li & Milgram, 2008). The lights warn the follower driver if the vehicle in front stops abruptly. LEDs (Light Emmiter Diodes) are replacing conventional incandescent bulbs in brake lamps due to their longer service life and resistance to vibration. Another advantage is that these devices achieve peak intensity at around 200ms faster than conventional lights. This quicker response gives driver extra reaction time in the event of an unanticipated braking in the vehicle in front, contributing to reduce the crash risk.

2.4. Vehicular Networks

In recent years the automotive industry has equipped the cars with advanced electronic systems, which gather information from several sources, like wheels rotation speed, tire pressure, steering wheel position, brake pressure, distance to obstacles, fuel consumption, and temperature. Although these systems offer relatively complete information of vehicle's state, they neither interact with other vehicles nor with road infrastructure.

Allowing vehicles to communicate with other vehicles and with infrastructure opens a new set of applications directed to traffic safety and flow control. Thus, vehicular networks have emerged as a hot topic in vehicular technology research. With Vehicle-to-Vehicle (V2V) and Vehicle-to-roadside (V2R) communication it is possible to have safer and more efficient roads. V2V and V2R allow for negotiation between vehicles at a crossing, avoiding collisions (Cooperative Collision Avoidance – CCA), notification of incidents along the route, communication with traffic lights, therefore optimizing switching times according to vehicular flow, notification of wrong-way driver on the road, collision warning on curved roads, and many others (Biswas, Tatchikou, & Dion, 2006; Ernst, 2006; Huang & Tan, 2006; Sung, Yoo, & Kim, 2007; Yang & Recker, 2008).

The pedestrian and other vulnerable road users protection based in these emerging technologies is emphasized in a global context, motivating research programs in many countries. It should be observed that in low-income countries the problems are often different form those found in high-income countries. In general, the measures needed to low-income countries begin with the necessity of improvement of the infra-structure design, mainly pedestrian-vehicle separation, speed control and measures to increase pedestrian visibility to drivers, aspects already solved in developed countries (Gandhi and Trivedi, 2007).

2.5. Driver Coaching

Other important safety equipment is an onboard computer that monitors driver's behavior, recording speeds, accelerations, route traversed, motor rotation and temperature, and gage usage. This equipment is usually used in truck fleets, and data is collected and analyzed giving reports about drivers' performance and some traffic violations (Stanton, Walker, Young, Kazi, & Salmon, 2007).

2.6. Black boxes for cars

Driven by the lack of uniform scientific crash data needed to make vehicle and highway transportation safer and reduce fatalities, the Institute of Electrical and Electronics Engineers (IEEE) has created a universal standard for motor vehicle event data recorders (MVEDR), similar to those that monitor crashes on aircrafts and trains (Kowalick, 2004).

The IEEE standard 1616 "Motor Vehicle Event Data Recorders" specifies minimum characteristics for tamper and crash-proof devices for all types and classes of highway and roadway vehicles. The adoption of this kind of devices will provide automotive industry with reliable data to enhance designs, avoiding fraudulent claims for the insurance business, helping government to promulgate standards and rules, and supporting behavioral research of human factors and man-machine interactions.

3. Conclusion

The availability of cheap and powerful processors enabled the development of a new generation of on-board safety systems. Nowadays top line cars have dozens of processors working in parallel, dealing with hundreds of Mb of information.

In general the new systems have proved to be effective in protecting passengers or reducing the risk of crashing. New cars offer better control and more protection to passengers and pedestrians. For example, Forward Collision Warning systems can be helpful since approximately 70% of highway road crashes are caused by not keeping braking safety distance between vehicles (Chen & Wang, 2007). Volvo and ChooseESC show demonstration of the improvement in stability of control in videos available at their sites (ChooseESC, 2008; Volvo, 2008).

However, many scientists are worried about the global effectiveness of advanced safety systems. Drivers could adapt their behavior to safer cars, compensating the higher level of protection offered (Summala, 1996).

Studies had shown some level of adaption and compensation for enhanced vehicle security (Sagberg, Fosser, & Saetermo, 1997) but the balance is that the new technologies contribute to safer traffic. Currently the most known crash test evaluation organizations strongly recommend the utilization of electronic stability control (ANCAP, 2009; ENCAP, 2009), corroborated by studies that indicate the effectiveness of this kind of protection in reducing crashes (Erke, 2008; Green & Woodrooffe, 2006; Lie, Tingvall, Krafft, & Kullgren, 2005; Page & Cuny, 2006).

Finally, the technologies that support the construction of safer vehicles also enable the creation of new devices dedicated to law enforcement, like electronic controls for speed, gap between vehicles, traffic lights, intersection crossing and traffic flow management. Thus, beyond offering safer cars, the new technologies allow the construction of more controlled and efficient traffic environments. However, it should be taken into account that the benefits brought by the emerging technologies for vehicular safety may be not uniform in all countries. For instance, in low-income countries the basic infrastructure issues still aren't solved (pedestrian-vehicle separation, speed control, pedestrian visibility), thus the reduction of fatalities observed in developed countries due to the introduction of new safety devices in the cars may not be reproduced with the same proportion in underdeveloped countries.

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