Complex World Safety:

Detection of Run Off Road Scenarios Using Inertial Sensors

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Abstract

Run off road events occur frequently in real life and may result in severe consequences for the vehicle occupants. In the United States, single vehicle roadway departure crashes accounted for about 20% of all police-reported crashes. In Germany, 33% of all fatal crashes were run off road crashes. In Sweden since 2003, single car crashes was the most common type when it comes to fatal accidents.

There are numerous reasons for leaving the road, and the sequence of events that the car is subjected to is different in most scenarios. Complex vehicle kinematics and occupant kinematics together with occupant retention have been identified as important mechanisms of occupant injury. The complex vehicle kinematics affects the occupant posture at impact, which has influence on the injury tolerances and increases the likelihood of impacts to the vehicle interior.

This paper investigates how information from the standard set of sensors already present in the vehicle can support detection strategies and algorithm modifications for run off road scenarios in the airbag control module. It also proposes enhanced protection principles for such events.

New full scale test methods, defined based on analysis of real world crash events, were used to collect sensor data and to understand the benefits of different protection principles. The full scale test methods cover run off road into a ditch, run off road from a higher elevation to a lower elevation, and run off road into a rough terrain area, with crash test dummies used to represent the vehicle occupants.

Introduction

According to the World Health Organization (WHO), about 1.3 million people die every year in traffic crashes across the world, and up to 50 million sustain nonfatal injuries (WHO, 2013).

The United Nations (UN) has described the current situation as a safety crisis, and in 2010 proclaimed a "Global Plan for the Decade of Action for Road Safety 2011-2020", encouraging safety development efforts within the whole road transportation system for all countries and regions around the world (UN, 2010). On a national level, the most well-known effort is Vision Zero, formulated by the Swedish National Road Administration and accepted by the Swedish Parliament in 1997 (Johansson, 2009).

Several other countries and organizations have followed this example by adopting similar visions. As an example, in 2007 Volvo Car Corporation declared a vision (Volvo Cars Vision 2020) to design cars that should not crash. In the shorter perspective, the aim is that by 2020 no-one should be killed or injured in a new Volvo car. Continuous research and enhancement of safety in and around the cars is essential for achieving a safer driver environment and a collision-free future. In this aim Volvo Car Corporation cooperates with authorities and other parties in the automotive industry (Eugensson et al., 2011).

In order to meet these visions, it is essential to understand and address all different types of real world scenarios. For instance, run off road events are not addressed in standardized test methods today. Run off road events occur frequently and may result in severe consequences for the vehicle occupants. In the United States, single vehicle roadway departure crashes accounted for about 20% of all police-reported crashes (Wang and Knipling, 1994). In Germany, 33% of all fatal crashes were run off road crashes (Statistisches Bundesamt, 2011). In Sweden since 2003, single car crashes was the most common type when it comes to fatal accidents (Hillerdal, 2011).

There are numerous reasons for leaving the road (Hillerdal, 2011; Najm et al., 2002). The sequence of events that the car is subjected to is different in most scenarios. Based on real world data, Jakobsson et al. (2014) identified important occupant protection mechanisms such as impacts to interior structures and vertical loading on the occupant through the seat, as well as keeping the occupant in a favourable position. Complex vehicle kinematics due to the run off road environment, occupant kinematics and occupant retention affect the occupant posture which, depending on the impact, influences the occupant injury consequences in a run off road crash (Jakobsson et al., 2006 and 2014).

Restraint systems are evaluated based on extensive crash testing as well as real world follow-up. The crash scenarios that today's restraint systems are required to identify and take appropriate action for typically come from legal requirements (e.g. FMVSS 208, ECE R/94, ECE R/95), consumer rating requirements (e.g. US-NCAP, EU-NCAP, C-NCAP) and insurance requirements (e.g. Allianz). Such crash scenarios tend to be single crash events and do not necessarily cover more complex scenarios in the real world where activation of restraints could be of importance as well. Hence, in order to take steps towards meeting the safety visions, it is necessary to go beyond the standardized evaluation methods.

The aim of this paper is to present Volvo's Complex World Safety functionality, including the rationale and the means of evaluation. Adding the Complex World Safety detection algorithms and activation logic to the restraint system will make an important contribution to the overall ambition to reduce injuries in traffic.

Evaluation methods

Based on run off road safety research, a set of real world representative run off road crash test methods were developed (Jakobsson et al., 2014, and Figures 1-3). The aim was to address key injury mechanism aspects in standardized test set-ups, and to gather information on vehicle kinematics in addition to occupant kinematics and loadings. Crash test dummies are used as human representation in the tests. Data is gathered from reference accelerometers and gyros mounted in the test vehicle, as well as from control modules and data bus traffic in the vehicle.

Figure 1: Ditch scenario

Figure 1 shows an example of a Ditch scenario recreated at the Volvo Cars Safety Centre. The vehicle is launched at 80 km/h and drifts into a ditch with an approach angle of 12°. The ditch is 0.8 m deep, with a slope of 30%, and ends in an embankment.

Figure 2: Airborne scenario

Figure 2 shows an example of an Airborne scenario recreated at the Volvo Cars Safety Centre. The test vehicle is launched at 50 km/h at a 90° angle across a road edge, introducing a phase of free flight. The height difference is 0.8 m, resulting in a hard impact at landing.

Figure 3: Rough Terrain scenario

Figure 3 shows an example of a Rough Terrain scenario recreated at the Volvo Cars Safety Centre. The test vehicle is launched at 80 km/h, perpendicular to the road edge, into a rough terrain environment. The rough terrain causes a bumpy ride, producing substantial lateral vehicle motions (rolling motions) in combination with vertical and longitudinal vehicle motions.

Restraint system design implications

Comparing run off road crashes to on-road crashes, overall occupant injury risks are generally higher in run off road crashes and significant differences in injured body regions were seen (Jakobsson et al., 2014). The numerous different run off road situations, the variety of off-road sequences and possible impact types, with secondary impacts including impacts to rocks, trees etc. as well as roll over and turn over events, emphasize the complexity of addressing run off road safety and pose special challenges to the restraint design. These challenges are beyond what is evaluated in standardized crash test methods, such as regulatory and rating tests.

Impacts to interior structures and vertical loading on the occupant through the seat are highlighted as important occupant protection mechanisms. The complex vehicle kinematics due to the run off road environment, occupant kinematics and occupant retention affect the occupant posture which, depending on the impact, influences the occupant injury consequences in a run off road crash.

The test methods presented in this paper illustrate some of the important potential injury mechanisms in run off road events. Vertical loading through the occupant can occur as a result of an airborne event (Figure 2), due to interaction with the vehicle undercarriage during the event by e.g. an impacting to an embankment (Figure 1), as well as in a rollover event when the car lands on its wheels. During such an event, the human tolerances are influenced by the occupant's sitting posture. An upright spine can withstand higher vertical loads than when flexed; hence it is essential to reduce the vertical loads transferred into the body as well as to help keep the occupant in an upright sitting posture through these types of events.

Another important potential injury mechanism concerns impacts to interior structures. The relatively high occurrence of upper extremity, chest and head injuries (Jakobsson et al. 2014) stresses the importance of occupant posture at impact and movements of extremities due to complex and diverse pre-impact sequences. The Rough Terrain scenario (Figure 3), which simulates a bumpy ride producing substantial lateral vehicle motions (rolling motions) in combination with vertical and longitudinal vehicle motions, and the initial lateral slope part of the Ditch scenario (Figure 1) are two examples of situations which are challenging from a restraint perspective.

By controlling occupant posture and upper extremity and head positions and movements during these complex events, protection can be enhanced. Means to do so could include seat belt pretensioning or activation of airbags and other devices designed to help control occupant posture, in addition to built-in energy absorption in the seat or other parts of the interior designed for the needs for the complex events. In order to make use of restraints that need activation, it is essential to build knowledge about detection of the event as such. The run off road crash test scenarios presented in this paper form an important part in this.

Detection algorithms and activation logic

A typical restraints control module (SRS ECU) in a vehicle contains crash algorithms that are calibrated to meet the requirements for crash detection and timely activation of protection components (e.g. seat belt pretensioners and airbags) for that particular vehicle. Sensor data gathered from full scale crash tests and CAE simulations is taken as input to the calibration process, wherein algorithm parameters are tuned in multiple simulation loops. The input data set typically includes both scenarios where activation of one or more protection components is required (Fire tests), and scenarios where there shall be no activation of protection components (No Fire tests).

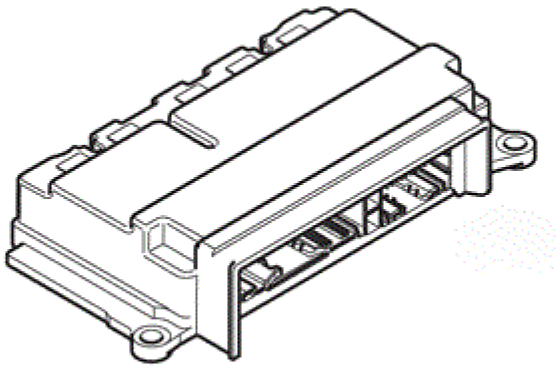

Figure 4: SRS ECU

Volvo's restraints control modules (SRS ECUs, Figure 4) are equipped with a set of sensors (accelerometers and gyros) that meet the sensing needs of the crash algorithm. The sensors also provide data to other functions in the vehicle, e.g. ESP.

A major challenge is to address all relevant real world crash scenarios and take action to help protect the vehicle occupants accordingly. Volvo's Complex World Safety functionality is an important step towards addressing crashes beyond the standardized crash test methods. There are two main aspects of Volvo's Complex World Safety algorithms.

Firstly, data from the already existing sensors in the vehicle's restraints control module (SRS ECU) is used, along with information from the vehicle bus. Thus no additional hardware is needed.

Secondly, the algorithms are able to detect new run off road scenarios (Ditch, Airborne, and Rough Terrain) which may be followed by a secondary impact or lead to radical vehicle motions.

If a run off road scenario is detected, a reversible seat belt pretensioner is activated, provided the occupant is belted. The reversible pretensioner has two force levels, which are used depending on the estimated severity of the scenario (i.e. medium force in low severity events, high force in high severity events). Once the run off road scenario has ended, as determined by global acceleration level, the belt is released.

In case of a sufficiently severe secondary impact in the course of a run off road scenario, e.g. to a tree, an embankment or another obstacle, the traditional restraint system will function normally and activate protective devices such as pyrotechnical seat belt pretensioners or airbags if needed.

The Complex World Safety algorithms have been validated in full scale run off road tests, using the methods outlined above. Vehicle kinematics similar to run off road scenarios may also be experienced in real life, e.g. during sporty driving on the road or off-road driving. Therefore, additional driving tests (misuse tests) have been performed, in order to assess the robustness of the algorithm methods and the calibration.

Discussion

Run off road crashes are complex and require a wide approach, addressing the whole sequence of the event, and a large variation of situations. In order to address this category of events as a whole, technology developments are needed in a number of areas including detection algorithm and activation logic development, active safety technology, restraint system design and tuning of seat and interior structure designs, as well as post-crash technology.

This paper presents developments in detection algorithms and activation logic, specifically applied using pretensioning of seat belts. This is an important step for occupant protection in run off road events. The pretensioning will help restrict the head and upper extremities movements during the event, thus reducing exposure to impacts to the interior that could potentially cause injuries. The pretensioning will also help keep the occupant in a safe and upright position, which is essential for increasing human tolerances to potential vertical loads during the event.

The seat belt pretensioner could be pyrotechnical (irreversible) or electrical (reversible). Use of a reversible seat belt pretensioner is advantageous, since such a component can be activated multiple times without need of replacement.

The Complex World Safety algorithms will be introduced into Volvo production vehicles in 2015, along with reversible seat belt pretensioners. Adding the Complex World Safety detection algorithms and activation logic to the restraint system will make an important contribution to the overall ambition to reduce injuries in traffic, as well as towards meeting Volvo Cars' Vision 2020.

Conclusion

Volvo's Complex World Safety functionality enables further improved restraint performance by detecting and activating restraints in important and complex situations such as run off road scenarios. New full scale vehicle test methods, based on analysis of real world crash events, have been used to collect sensor data and to understand the benefits of different protection principles. The test methods cover run off road into a ditch, run off road from a higher elevation to a lower elevation, and run off road into a rough terrain area.

Data from the standard sensors already present in the vehicle's restraints control module (SRS ECU) supports new detection algorithms and activation logic for run off road scenarios. These will be introduced into production vehicles in 2015, along with reversible seat belt pretensioners, and will further help protecting vehicle occupants in complex run off road scenarios.

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