Human Body Behavior as Response on Autonomous Maneuvers, Based on ATD and Human Model*

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Abstract: In the near future, active safety systems will take more control over the vehicle driving, even up to introducing fully autonomous vehicles. Nowadays, it is expected that the active safety systems will aid avoiding collisions much more efficiently than human drivers. These systems can protect not only the passengers, but also other road users. To mitigate collision, certain maneuvers (e.g., sudden braking, lane change, etc.) need to be done in a reasonably quick time. However, this may lead to low-g energy pulses. The latter fact, may cause unexpected and, in some cases, unwanted occupant body motion resulting even in OOP (out of position) postures. New patterns of occupant reactions in such cases are, to some extent, confirmed experimentally [1-3]. This paper evaluates the limits of standard ATDs (anthropometric test devices) and chosen human models in well established maneuver scenarios. Obtained results are compared with experimental data available in the literature. Drawbacks identify new challenges for the near future simulation based safety engineering. One scenario with combined conditions of emergency braking during lane change has been used as an example of OOP posture after maneuver.

Key words: Active safety systems, passive safety systems, autonomous maneuvers, human body behavior.

1. Introduction

In the near future, active safety systems will take more control over the vehicle driving, even up to introducing fully autonomous vehicles. It is expected that the active safety systems can avoid collisions much more efficiently than humans. These systems can protect not only the passengers, but also other road users. To mitigate collision, certain maneuvers need to be done. It is important to keep in mind, that the passengers are unaware of autonomous maneuvers.

More passengers than drivers are casualties in collisions [4]. There may be a few reasons for such a result. In order to be prepared for the collision, driver can instinctively protect himself by performing certain actions. Driver can prepare themselves for the collision by activating the muscles and taking the correct position. Passengers can only be prepared, if they know

about the collision. Driver observes the road and knows earlier about the possibility of the collision, while the passenger usually does not do this, and their chances to prepare for the collision are smaller.

In the future, autonomous vehicles and small urban cars may change this pattern [5, 6]. It is possible that occupants will be more often unaware of the impending collision, and will not prepare themselves for the crash. In such a situation, possibility of the out of position placement for the passive safety systems is higher.

2. Maneuvers

The maneuvers selected for the tests are: emergency braking from speed 50 km/h to 0, lane change with velocity 50 km/h and acceleration from 0 to 50 km/h. Scenarios are based on the tests procedures for active safety systems:

- AEBS (autonomous emergency braking system) of Euro NCAP [7];
- ACC (adaptive cruise control) system of ISO [8];
- LKA (lane keep assistance) of ISO [9];
- LCA (lane change assistance) of ISO [10] and

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eValue [11];

- LSF (low speed following) of ISO [12];
- Full speed range adaptive cruise control of ISO [13];
- LDW (lane departure warning) of NHTSA [14] protocols.

Scenarios have been built in the PreScan environment. Tests are prepared on both straight road and bend road. The trajectory of the lane change maneuver was simulated by the Bezier Curve.

3. Methods

The acceleration of the host vehicle is the output from the simulations of selected PreScan scenarios. The selected car is Audi A8 equipped with the model of Simple Dynamics and the Path Follower controller [15]. This combination allows to check the accelerations affecting the car. The mass and movement of the car's occupants have been omitted.

Some of the scenarios consist of combined conditions, e.g., emergency braking, involved (caused) by VRU (vulnerable road user) protecting system during lane change performed by the driver (complex scenario).

The accelerations from the PreScan simulation are applied to the ATD (anthropometric test device) and human model in MADYMO environment. MADYMO model is a simplified car with the possibility of movement in X and Y directions and rotation around Z axis. In all simulations, body behavior has been calculated for the driver occupant with three-point seat-belt used.

There is no ATD dedicated for low-g acceleration (Table 1) and movement in both X and Y directions, but for the simulations, authors used Hybrid III, EuroSID-2 Q and USSID. Also, a PHM (passive human model) has been used in simulation.

3.1 AEBS: ADAC B3 Test—Braking 50-0 km/h

In ADAC, B3 test for AEBS car is traveling with constant speed 50 km/h while obstacle vehicle travels

on the same lane with much lower velocity. Host car

Table 1 ATDs and human model limitations.

Model	Side load	Front load
Hybrid III	x	High-g
EuroSID2	High-g	x
USSID	High-g	x
Human model	High-g, Low-g	High-g, Low-g

applies AEBS autonomous braking (Fig. 1) when it approaches to the target car (Fig. 2).

3.2 AEBS: ADAC B5 Test—Braking 100-0 km/h

B5 test of ADAC for AEBS system is similar to the B3, but the host vehicle travels with higher velocity of 100 km/h (Fig. 3).

3.3 LKAS: ISO 17361:2007 Left Departure on Straight Road with Velocity 75 km/h

During LKAS test from ISO 17361:2007, car travels with constant velocity 75 km/h (Fig. 4). Vehicle changes lane to the left on distance 60 m (Fig. 5).

Fig. 1 Acceleration in longitudinal direction of the host vehicle in ADAC test B3.

Fig. 2 Emergency braking of the AEBS in ADAC tests.

Fig. 3 Acceleration in longitudinal direction of the host vehicle in ADAC test B5.

Fig. 4 Acceleration in lateral direction of the host vehicle in LKAS ISO 17361:2007 test on straight road with departure to the left.

Fig. 5 Lane change to the left performed by the host vehicle in LKAS test.

3.4 LKAS: ISO 17361:2007 Right Departure on Straight Road with Velocity 75 km/h

Test is very similar to the left departure, but behavior of occupant in the car can change, as seat belts and car

interior are unsymmetrical. Car travels with constant velocity 75 km/h. Vehicle changes lane to the right on distance 60 m (Fig. 6).

3.5 Complex Scenario—Braking during Lane Change

Complex scenario represents a real life road situation (Fig. 9). A pedestrian enters the road behind cars, in such a way, that driver cannot see him. As the person is already in field of VRU warning, car autonomously brakes but in the same time driver wants to avoid collision by lane change. As a result, two accelerations affect the occupant: longitudinal (Fig. 7) as the result of braking, and lateral (Fig. 8) from lane change.

Fig. 6 Acceleration in lateral direction of the host vehicle in LKAS ISO 17361:2007 test on straight road with departure to the right.

Fig. 7 Longitudinal acceleration of the vehicle in complex scenario.

Fig. 8 Lateral acceleration of the vehicle in complex scenario.

Fig. 9 Emergency braking caused by the VRU system during lane change executed by the driver.

4. Results

The main factor for evaluation occupant safety changes is head motion during maneuvers, as distance between airbag and head just before crash may result in OOP. Simulations with PHM have uncertain results, because it has no muscle activation and is very flexible. For standardized tests, only the ATDs results have been presented. PHM is presented for complex scenario, and represents maximal human body movement.

4.1 AEBS: ADAC B3 Test—Braking 50-0 km/h

During test, ATDs moved forward. Hybrid III moved 0.142 m, EuroSID2 0.176 m and the USSID 0.234 m (Fig. 10).

4.2 AEBS: ADAC B5 Test—Braking 100-0 km/h

During test, ATDs moved forward more in comparison to test B3, but it is not proportional to the

velocity change, also USSID had smaller movement than in previous test, what can be result of different braking profile. Hybrid III moved 0.156 m, EuroSID2 0.188 m and the USSID 0.225 m (Fig. 11).

4.3 LKAS: ISO 17361:2007 Left Departure on Straight Road with Velocity 75 km/h

In scenarios with lane change, the lateral displacement is measured. For the lane change to the left, distances are: Hybrid III 0.157 m, EuroSID2 0.15 m, USSID 0.126 m (Fig. 12).

4.4 LKAS: ISO 17361:2007 Right Departure on Straight Road with Velocity 75 km/h

Behavior of the occupant during right departure is different than during the left. Displacements are much bigger than in left case. It can be result of car interior. ATDs move: Hybrid III 0.27 m, EuroSID2 0.323 m, USSID 0.313 m (Fig. 13) what is sometimes more than twice distance of left case.

Fig. 10 ATDs maximal displacements in AEBS B3 test.

Fig. 11 ATDs maximal displacements in AEBS B5 test.

Fig. 12 ATDs maximal displacements in LKAS left departure test.

Fig. 13 ATDs maximal displacements in LKAS right departure test.

4.5 Complex Scenario—Braking during Lane Change

In complex scenario, the result of longitudinal and lateral accelerations is displacement of occupant head in both directions. Head moved forward more than to the side. For the ATDs, longitudinal displacements were: Hybrid III 0.225 m, USSID 0.233 m, EuroSID2 0.25 m. Lateral displacements were: Hybrid III 0.125 m, USSID 0.056 m, EuroSID2 0.066 m. PHM was much more flexible and moved 0.411 m forward, and 0.113 m to the side.

4.6 Summary

All test scenarios show some trend in ATD and human model behavior. ATDs are too stiff, on the other hand, the human model is too flexible. However, the simulations show some differences in model behavior with pre-crash low-g acceleration and lateral impact [16].

Fig. 14 ATDs and PHM maximal displacements in complex scenario.

Fig. 15 Comparison of the ATDs and PHM responses to the combined low-g braking and lane change.

The pre-crash maneuvers may move the occupant's body to the OOP. Combined conditions show the influence of the autonomous maneuver on the occupant's position. Every test shows occupant's movement to the side during lane change and to the front during emergency braking (Fig. 15), which can lower airbag efficiency. The movement of ATD shows one of the smallest possible displacements of the occupant in comparison to volunteer reactions [3] while PHM shows one of the biggest.

5. Conclusions

The body movement may affect the efficiency of the passive safety systems, as the occupant can move to the OOP. Simulations compared with volunteer results show the need for more tests, but also justify the reasonableness of research on efficiency of active and passive systems interaction. Based on the research, a new methodology of the occupant movement measurement needs to be created in different conditions. Moreover, it has to be compared with Active Human Model [17]. The forecasting of the collision should be combined with passive safety systems to increase the efficacy of both protections. There is a need for the comparison of the behavior of the aware and unaware occupant during maneuvers.

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