DEVELOPMENT OF A METHODOLOGY AND THE TEST TOOLS FOR THE EVALUATION OF PEDESTRIAN DETECTION SYSTEMS

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ABSTRACT

Pedestrian detection systems are expected to provide a relevant impact in the decrease of vulnerable road user casualties and injuries. Currently, different safety functions are under development and some of them have reached the market. In order to promote the wide spread of these functions and to standardize as much as possible the performance requirements, consumer organizations are also working in the development of test and assessment protocols

As a contribution to the current activities done by car manufacturers, research centers and consumer testing organizations, the research described in this paper will address some specific questions, including:

- The development of a crashable representative pedestrian test target, in terms of sensor detection
- The definition of the walking movement characteristics of pedestrians and implementation of these characteristics in the test target
- The development of a complete test facility for pedestrian detection tests
- The validation of the test target as a test tool for pedestrian detection systems
- The evaluation of representative test scenarios for pedestrian detection systems
- The estimation of the benefits of using test targets with walking movement capabilities for the better pedestrian recognition

As a result, the paper will present the developed pedestrian test target and further indications for the implementation of pedestrian detection tests.

All these questions are currently a challenge for the definition of new test procedures in the field of pedestrian detection systems.

The results of this paper will be useful for the current development of pedestrian detection systems and further development of test targets suitable for ADAS testing.

INTRODUCTION

Most accidents with pedestrians are caused by the driver being in-alert or misinterpreting the situation. Vulnerable road users, pedestrians and cyclists, have a greater risk of injury in any collision with a vehicle. For this reason pedestrian detection systems coupled with driver warnings and/or autonomous emergency braking actions are recommended to facilitate accident avoidance or reduction of the impact speed.

As described in [1], some OEMs have started to provide autonomous emergency braking systems (AEBs), which provide longitudinal assistance. In parallel to the appearance of these systems into the market, consumer testing organizations, manufacturers, engineering companies and research centers are interested in the development of test and assessment methodologies allowing the evaluation of the safety level that these systems. It is accepted that a key aspect for the success of these systems and the associated safety benefit is the information to the consumer. In order to develop a test and assessment procedure for the evaluation of Autonomous Emergency Braking systems, several initiatives have been set up: ASSESS [2], AsPeCSS [3], AEB Group [4], vFSS [5], ADAC [6]. Some of these initiatives are supported by public authorities while others are independent.

Each of these initiatives is proposing a methodology for the evaluation of autonomous emergency braking systems, including:

- The identification of relevant test scenarios and test cases

– The standardization of a representative test target representing a real pedestrian
– The definition of evaluation criteria for the performance of AEBs

This paper focusses in the development of the tools for evaluating pedestrian detection systems. Therefore, first step was to identify the most relevant accident scenarios and their derived test scenarios for pedestrian detection systems. According to [7], the most representative situation in pedestrian accidents is the crossing scenario, where a vehicle is driving in straight road while a pedestrian is crossing the road in front. Examples of these scenarios are shown in Figure 1. Different parameters can modify the configuration of these scenarios, such as obstructions and approaching direction of the vehicle.

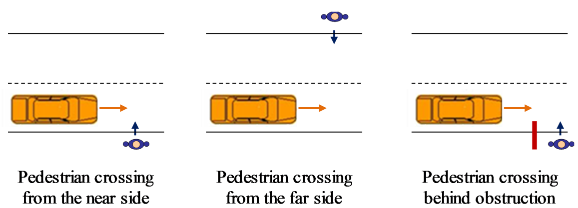


Figure1. Most typical test scenarios representing pedestrian accidents

The tools proposed in this paper should, at least, be able to reproduce these situations in a controlled environment. Additional situations might include pedestrian walking along the road and vehicles turning in a crossing.

Pedestrian test target geometry

Once the test scenarios were been identified, a test target representing pedestrian was developed. Most of the pedestrian detection systems use camera sensors to determine that the obstacle in front of the vehicle is a pedestrian. For this reason, the geometry of the pedestrian test target should match in shape and size of real humans.

The two sizes chosen in this particular case are:
– 50%ile adult male, total height 1800 mm
– 6 years old child, total height 1200 mm

A lot of activities have been addressing these issues: [3], [4] and [5]. These two sizes were chosen in order to match the decisions in other activities.

The CAD data for these 2 sizes was obtained from:
– ATD Hybrid III 50th Male Dummy, FEM model for LS-Dyna
– ATD Hybrid III 6 yo Child Dummy, FEM model for LS-Dyna

This CAD data was modified in order to match other criteria, such as walking posture and hanging mechanisms.

Walking posture

However, shape and size are not the only parameters required by camera sensors to classify the test target as a real human. Walking posture is a key attribute. Figure 2 shows the postures along the whole walking cycle. [8] has been working a lot in this aspect and the proposal is to use the posture between the MSw and TSw steps.

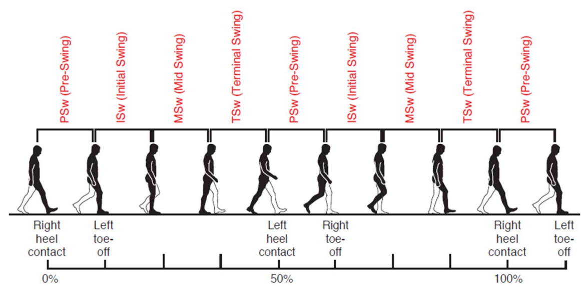


Figure2. Human postures in different walking steps, as proposed in [8]

Walking movement

The CAD data for the pedestrian test targets should have been modified in order to represent the proposed walking posture. In this particular case, it was decided to develop a test target with moving articulations able to reproduce the whole walking cycle.

Discussions with some sensor suppliers, suggested that a test target with moving articulations would better represent a real human during its walking activity. This would result in a better system performance. According to their input, the movement of the lower extremities allows a better classification of the test target as a real human. By this:
1. Algorithms can be developed to detect and classify objects which are more representative to real humans.
2. Algorithms can be developed to distinguish static objects which are not representing real humans.

Sensor and algorithm suppliers also indicated that, while current systems do not require test targets with moving articulations in order to classify the target as a pedestrian, they would allow the development of a new generation of systems.

In order to address this possibility, the walking movement of real pedestrians was analyzed. As an example, Figure 3 provides the flexion of hip and knee during the whole walking cycle.

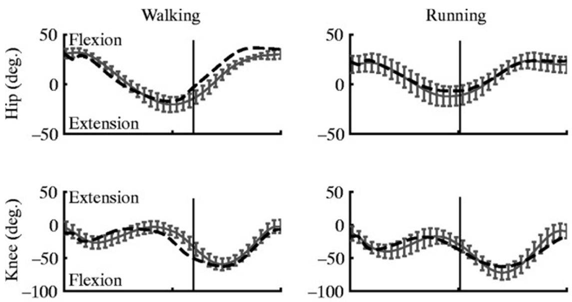


Figure3. Hip and knee flexion during walking and running [9]

In order to implement these flexion angles, the pedestrian test target was fitted with articulated knees and hips, which could be commanded mechanically by wires. An external 4-cam mechanism was designed to reproduce the movement shown in Figure 3.

Crashability of the test target

Pedestrian test targets are intended to reproduce real humans in test scenarios which should be detected by the AEB systems under test. In case of system failure, the test target will be overrun by the vehicle. In order to allow continued testing, the test targets must be crash-forgiving and do not damage the vehicle under test.

For this reason, most of the test targets are built with light materials, which should provide a low density combined with some compressibility capabilities. In this particular case, a low density polyethylene foam was used to reproduce the body of the pedestrian, which covered the aluminum structure used to reproduce the walking movement.

As in some of the test scenarios under proposal, the driving speed of the vehicle reaches up to 60 km/h, the objective was to allow impacts at 60 km/h with no damage for the vehicle under test and the pedestrian test target. FEM simulations where used to assess the crashworthiness of the adult and child pedestrian test targets. Figure 4 shows 3 time steps of these simulations.

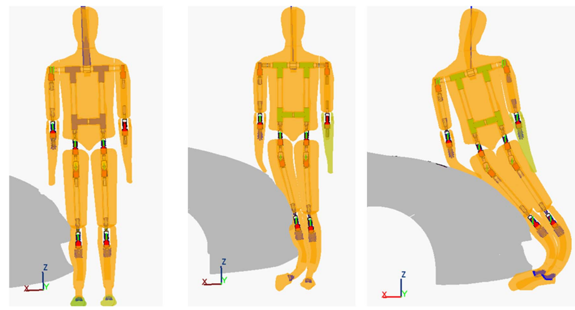
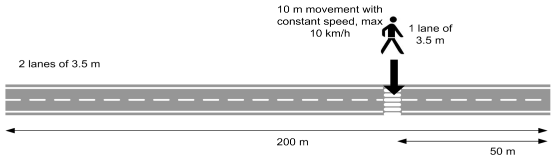


Figure4. Simulation of the 50%ile pedestrian test target during impact

The initial simulations suggested that in order to ensure no damage in crashes at a high speed, the mass of the test target should be limited to 15 kg maximum. Additionally, strong effort was made in order to ensure the crash performance of the articulations during the impact. Initially, rotational joints in Y-axis of the test target where used to allow the articulation of the extremities. Additional joints in X-axis where included to allow deformation of the articulations during the impact. This allowed some deformation of the articulation during the impact with no breakage.

Validation of the test targets

The test targets were tested at Applus IDIADA premises located in Santa Oliva, Spain. The crossing pedestrian facility consists in a 2 lanes straight road with an acceleration length of 200 m and a braking length of 50 m. A portal test rig is installed, with a total crossing distance of 25 m. A controlled trolley slides through the cross beam of the portal and pedestrian test targets can be hung from this trolley. Figures 5 and 6 provide a view of the facility.



Figures5 and 6. Pedestrian crossing facility available at Applus IDIADA premises

With this facility, tests can be executed in controlled conditions. The position of the pedestrian can be controlled with ± 1 cm accuracy. The movement can be real-time synchronized with the movement of the oncoming car via a D-GPS with ± 2 cm accuracy.

This test setup was used to validate some of the characteristics of the pedestrian.

Test target geometry and walking movement - The cam mechanism for commanding the articulations of the pedestrian was installed in the trolley. The walking movement of the adult male and the child were tested with different vehicles. The test targets were correctly recognized as pedestrians. Figure 7 provides a view of the walking movement of the test target.

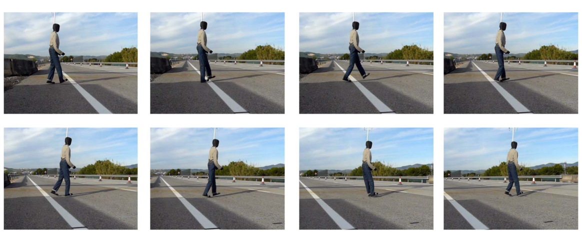


Figure7. Walking movement of the adult pedestrian test target

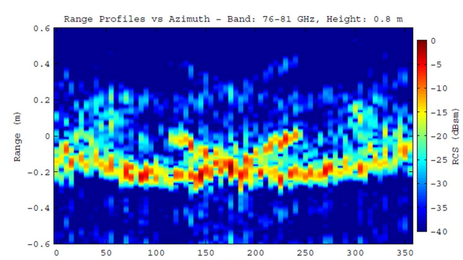
Crashworthiness – During the tests, the test targets were impacted at different speeds, up to 50 km/h. Impacts at high speeds resulted in minor damages to the vehicle under test. The test targets withstood the impacts correctly. The X-axis joints allowed the deformation of the extremities with no damage. After some impacts, the test targets had to be re-adjusted, due to degradation of the mechanism.

RADAR signature – Within this paper, shape, size and posture of the pedestrian test target have been discussed in order to ensure the correct classification of the target by camera sensors. State of the art systems use data fusion of the camera sensors combined with other sensors such as radar or lidar in order to better perform. Both radar and lidar issues have been identified by [8].

According to them, the performance of the target for lidar sensors can be mainly controlled by the clothes used. For this reason, during all the test activities, the clothes proposed by [8] were used.

Additional activities were implemented for radar sensors, under the frame of the AsPeCSS project. An object reflects a limited amount of radar energy. In order to quantify this phenomenon, several pedestrian test targets were delivered to [10], in order to measure radar signature. Radar cross section (RCS) is a measure of how detectable an object is with a radar. A larger RCS indicates that an object is more easily detected. Real humans and test targets were measured in different conditions. This paper includes only the measurement results relevant for the developed target.

Figures 8 and 9 show the RCS measurements of a standing adult and the test target in the 76 – 81 GHz band. Additional measurements in the 23 – 28 GHz band were also implemented and available in [10].



Adult#2 Shirt

Frequency/Azimuth Average RCS (dBsm)

Band (GHz)	76-77	77-78	78-79	79-80	80-81	76-81
Height=0.8m	-6.57	-7.70	-6.87	-6.62	-6.55	-6.86

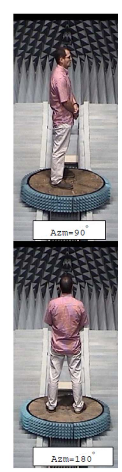
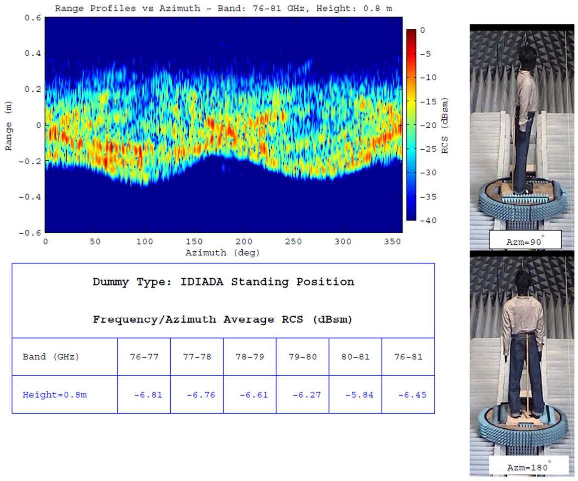


Figure8. Real standing human RCS signature in the 76 – 81 GHz band [10]



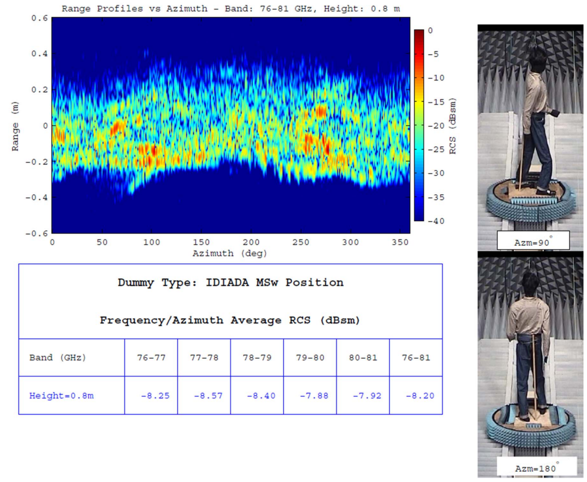
Dummy Type: IDIADA Standing Position Frequency/Azimuth Average RCS (dBsm)						
Band (GHz)	76-77	77-78	78-79	79-80	80-81	76-81
Height=0.8m	-6.81	-6.76	-6.61	-6.27	-5.84	-6.45

Figure9. Standing pedestrian test target RCS signature in the 76 – 81 GHz band [10]

Before the measurements were implemented, initial thoughts suggested that the test target might provide an excessive RCS, as it had a metal structure inside. However, the measurements showed that the RCS of the test target is slightly lower when compared to real humans.

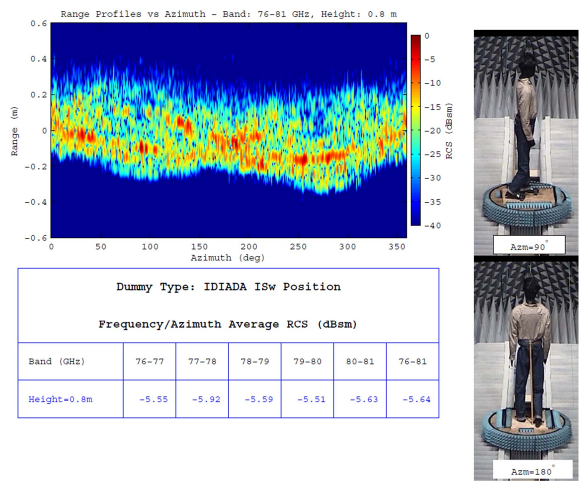
After this result, additional efforts were required in order to better match RCS of real humans. Fortunately, this was a relatively easy task, as RCS can be easily increased by adding reflective material. If RCS had been excessively high, the task would have been more complex, as shielding strategies with radar absorbers are not very efficient.

Effect of RCS signature in walking posture - Taking the opportunity brought by [10], the effect of the walking posture in the RCS signature was investigated. Figures 10 and 11 show the differences in the MSw and ISw positions of the walking cycle. It can be noted that RCS strongly depended on the posture of the pedestrian. Therefore, it could be stated that walking movement should be considered when implementing pedestrian detection tests in vehicles fitted with RADAR sensors.



Dummy Type: IDIADA MSw Position Frequency/Azimuth Average RCS (dBsm)						
Band (GHz)	76-77	77-78	78-79	79-80	80-81	76-81
Height=0.8m	-8.25	-8.57	-8.40	-7.88	-7.92	-8.20

Figure10. Articulated pedestrian test target RCS signature in the 76 – 81 GHz band, MSw position [10]



Dummy Type: IDIADA ISw Position Frequency/Azimuth Average RCS (dBsm)						
Band (GHz)	76-77	77-78	78-79	79-80	80-81	76-81
Height=0.8m	-5.55	-5.92	-5.59	-5.51	-5.63	-5.64

Figure11. Articulated pedestrian test target RCS signature in the 76 – 81 GHz band, ISw position [10]

This result also confirmed the indications of sensor and algorithm suppliers regarding the necessity of reproducing the walking movement of the pedestrians for more realistic test implementation.

Discussion and limitations

This research was implemented as collaboration between Applus IDIADA and other OEMs. The activities described in this paper are complementary to other research activities in this field, such as the AsPeCSS project (EC funded) and the vFSS project (supported by major German OEMs).

The issues addressed in this research do not overlap the results provided by these other projects; this has a more specific focus in the development of the test target and the definition of a standard methodology for radar signature measurement.

CONCLUSIONS

This paper has discussed the most relevant aspects to be considered for the development of a test methodology and the suitable test tools for testing pedestrian detection systems. As a particular case, the paper has also presented some of the activities implemented for the development of an articulated pedestrian test target with moving extremities and the validation results.

The most relevant aspects to be considered are:

- **Geometry**, including shape and size. The size of an 50% adult male and a 6 years old child was proposed by several sources and used in the developed test target.
- **Walking posture**. As proposed by several sources, the test target should represent a walking posture. Postures between MSw and TSw are the most representative for camera sensors.
- **Walking movement**. As an addition to the walking posture, the complete walking cycle provides a more realistic behavior and would allow better sensor performance. The relative movement of the extremities can be reproduced by different mechanisms. The developed test target was able to correctly reproduce the walking cycle.
- **Crashability**. The pedestrian test target should withstand impacts up to 60 km/h with no damage for the vehicle under test and the test target. In case the target has an internal structure, some mechanical fuses or joints might be required in order to allow some deformation with no damage during the tests.
- **RADAR signature**. The RCS signature of the developed test target was compared to real humans. The metal structure of the test target does not disturb the signal and additional reflectivity might be requested. RCS signature of pedestrians is heavily influenced by the position of the extremities. Therefore, walking movement capabilities should be considered when designing a representative test target.

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