# INNOVATIVE TEST METHODS AND FACILITIES FOR PREDICTIVE PEDESTRIAN PROTECTION

**Stephan Zecha**
Continental Safety Engineering International GmbH
Germany
**Dr. Gunnar Jürgens**
Continental Safety Engineering International GmbH
Germany
**Peter Quittenbaum**
Continental Safety Engineering International GmbH
Germany

Paper Number 13-0377

## ABSTRACT
The development of new forward looking sensor generations has created new possibilities in enhancing vehicle safety. The capabilities of forward looking sensors have been systematically extended from the recognition of well defined objects such as road signs to the identification and classification of other vehicles. New generations of forward looking sensors are now also able to detect pedestrians in different road traffic conditions.
Using these new sensors the car can be equipped with predictive protections systems. In predictive protection systems the sensor provides information on objects such as pedestrians to the vehicle, so that the vehicle can react by warning the driver, reducing speed or even braking or steering. Predictive pedestrian protection systems can thereby help to further improve the level of vehicle safety on the roads, especially with regards to vulnerable road users.
During the development of the related sensors and vehicle functions such as advanced autonomous emergency brake systems (AEB) it is key to have appropriate testing tools which help to validate the sensors and the safety functions of the vehicle. Different working groups especially in Europe have focused on the definition of system testing of AEB systems. Test scenarios have been derived from accident statistics and general design rules for the testing methods, test rigs and test methods have been established.
Continental has developed a testing environment which allows a qualified testing of different predictive pedestrian protection systems.
Based on a description of relevant test scenarios this paper refers to the tool chain required for testing of these protection systems. This testing environment consists of the following main elements:
1. Position reference system based on sophisticated transponder technology
2. Pedestrian Target Device (PTD) for a precise conduction of pedestrian tests with high repetition rate
3. Drive robot systems for precise vehicle path control

The paper discusses the usability of the described tool chain with regards to relevant test scenarios. A special focus is put on a new transponder based technology for the localization of vehicles and test objects. This technology has been developed by Continental as a result of the German research initiative Ko-TAG and applies a trilateration technique between transponders in the infrastructure and transponders attached to the moving objects to measure the precise position. Being less bulky than conventional localization systems, the transponder based localization can provide a localization quality which is similar to sophisticated DGPS systems. Moreover, due to its independence from satellite signals it can be applied on any test track and any test scenario, independent from the local signal quality of nearby satellites.

## OVERVIEW PREDICTIVE PEDESTRIAN PROTECTION SYSTEMS

Pedestrian protections systems have been introduced in different stages within the last decade accompanied by succeeding tightening of the related rules and consumer group demands. These pedestrian protection systems can be distinguished in “passive” and “active” protection systems.

*Passive pedestrian protection systems:*
A basic passive pedestrian protection is nowadays provided through purposeful “softening” of the potential impact areas at the car front structure. This provides a basic protection for the pedestrian.

*Active pedestrian protection systems:*
These measures can be improved by the activation and subsequent inflation of damping elements for the softening of the pedestrian impact after the detecting of the collision. A straightforward and very robust sensor concept for the detection of the impact is the pressure tube of Continental, which will be integrated in the front bumper and allows a precise discrimination between use- and misuse-cases [1].

The above passive and active pedestrian protection systems have already led to a continuous reduction of the number of fatalities among pedestrians in Germany [2]. The underlying measures however cannot reduce the effect of the secondary impact when the pedestrian is colliding with the ground after the impact at the car. At least 25% of the serious and fatal injuries of pedestrian accidents are caused by this secondary impact [3]. In order to reduce the consequences of the secondary impact it is necessary to reduce the impact velocity of the car significantly before the impact of the pedestrian occurs. This ultimatively requires *predictive pedestrian protection (PPP) systems* which enable a speed reduction of the vehicle in advance to a collision by either initiating a specific driver warning leading to a driver intervention or by activation of an autonomous brake maneuver.

These systems however require a highly reliable detection and classification of the pedestrian in order to activate such a drastic maneuver. Different sensors can be applied for the solid pedestrian detection:
A pure mono camera system using a straightforward classification will be sufficient to initiate a driver warning. A sophisticated radar system could also be applied stand-alone. Besides of the precise distance measurement capability, the usage of sub-doppler information would allow the classification of a moving pedestrian.
The most reliable sensor systems for pedestrian protection, however are those which supply two complementary information: The distance to the object and the image information about the object. An appropriate and integrated sensor supplying such information is the stereo-camera as it is illustrated in the figure beneath.

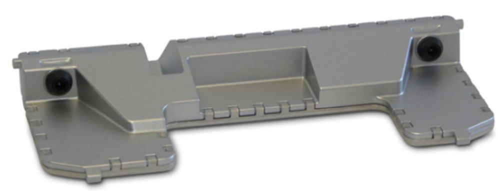

*Figure1.* Stereo Camera from Continental

This sensor technology seems to be the most promising for PPP systems. Thus significant development and qualification efforts had been spend within Continental to set-up this stereo-camera sensor. All system tests concerning the stereo-camera pilot project have been conducted with the tests rigs in the Continental Safety Park in Alzenau. These test methods and facilities will be explained in the following chapters.

## TESTING DEMANDS

This document does not include the significant efforts which have to be performed for real-world testing but focuses on the development and qualification tests which have to be conducted at test tracks.

### Test scenarios

In Europe two independent working groups (WG) , vFSS and AEB, have worked on the definition of test scenarios for predcitive pedestrian protection systems. Both WGs have set-up quite similar test scenarios for the testing of the Predictive Pedestrian Protection function. The initial test catalogue included crossing manouvers of the pedestrian with and without obstruction. The test vehicle could move either straight towards the crossing pedestrian or would conduct a turning manouver. These scenarios derived from accident statistics are illustrated in the figure beneath.

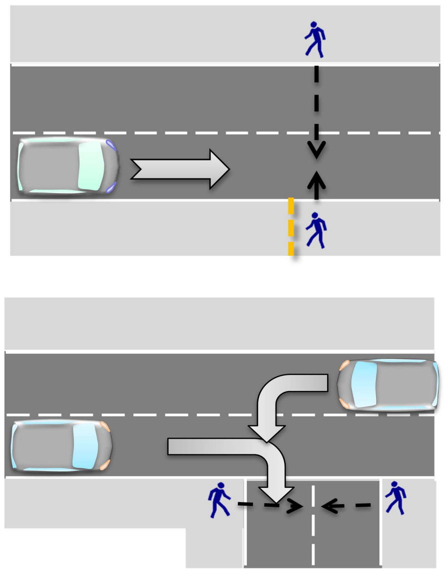

*Figure2*. Envisaged test scenarios for PPP testing

Currently only the scenarios with the straight moving vehicles are expected to be the requested scenarios. However the other scenarios with turning vehicle or with turning pedestrian remain interesting in order to proof the robustness of the system and might be conducted nevertheless.

**Test dummies and boundary conditions for test conduction**

Currently an adult dummy representing an 50% male person and a child dummy representing a 6-year-old child are selected as test devices.

Both dummy types have to fulfill minimum criteria with respect to the applied sensor. Thus the Radar cross section, the near-infrared characteristics and the general characteristics of the clothing have to be representative for a broad range of pedestrians. The values for these characteristics ar still under discussion.
The typical dummy types which are applied by Continental Safety Engineering are illustrated in the following figure

*Figure3*. Lightweight test dummies at Continental

The following test velocities are under discussion depending on the test scenario:

Vehicle speed range: 10 … 60 km/h
Dummy speed range: 5 … 10 (12) km/h

Currently the test tolerances are not specified for the accuracy of the test conduction. According to the latest test protocols of EuroNCAP with respect to Safety Assist Systems the following tolerances might be realistic:

- Collision speed + 1.0 km/h
- Lateral deviation from test path 0 ± 0.05 m
- Yaw velocity 0 ± 1.0 °/s
- Yaw acceleration 0± 4.0 °/s2
- Steering wheel velocity 0 ± 15.0 °/s

These tolerances might require the application of drive robots at least for release test campaigns.

## TEST METHODOLOGY OF CONTINENTAL SAFETY ENGINEERING

### Testing principles

System tests for Predictive Pedestrian Protection systems can be conducted with different test set-ups regarding the test specifications as explained in the chapter above.

The main trade-offs are firstly connected to the motion concept of the dummy: Cable way and hanging dummy or moving platform and standing dummy. The second trade-off concerns the point whether a collision with the dummy can take place.

Cable-way

Platform [4]

*Figure4*. Main pedestrian test facility concepts

Continental has selected a cableway concept allowing a dummy collision due to following reasons

1 Reproducability:
The cableway allows a precise movement of the dummy along the trails without any deviation. Different kind of curved trails allow nevertheless a variation of the dummy movement as it is illustrated in the figure beneath:

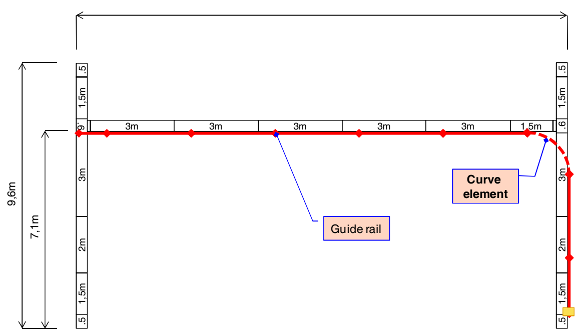


*Figure5*. Top View Test Rig

2 Repetition rate
The simplicity of the cableway concept allows a quick repetition of the test scenarios. The dummy can be moved quickly back into the starting position and the test can be repeated immediately.

3 Robustness:
The cableway concept with the decoupling of drive unit and dummy makes the system much more robust against malfunctions, allows lightweight dummies and thus allows test conduction up to dummy collisions.

4 Flexibility and extensions
The animation of the dummy limbs can be much easier achieved with a "hanging" dummy than with a standing dummy. This motion of the extremities might become a significant test condition especially for radar based PPP systems.

**Test conduction**

Predictive Pedestrian Protection tests in the Continental Safety Park are conducted following the master-slave principle. This principle has been described in [5] and works in the following way: The motion of the test vehicle initiates and controls the motion of the pedestrian dummy. In the most simple form the dummy motion will be initiated through a trigger signal when the test vehicle passes a light barrier. In order to achieve the right contact point between vehicle and dummy the motion of the dummy is started after a delay time which is calculated by using the measured velocity at the light barrier. The speed of the test vehicle is either kept constant by using an already in the car integrated speed limiter or by using a throttle control, if accessible or by using a pedal-drive robot.

If the vehicle speed shall be left variable, an online velocity measurement has to be applied to adjust the dummy motion then accordingly. This is currently not implemented at Conti Safety test facilities.

If the test shall be conducted with a high lateral accuracy the test vehicle will be equipped with a steering robot unit to keep the vehicle on track with a lateral deviation of maximum 2 cm. Also dedicated evasive maneuvers for false positive avoidance tests can be properly conducted with this steering robot.

*Figure6*. High-g steering robot system in the Continental Safety Park

## TEST RIG

The Pedestrian Testing Device (PTD) in the Continental Safety Park is a cable way system as it is illustrated in the figure beneath.

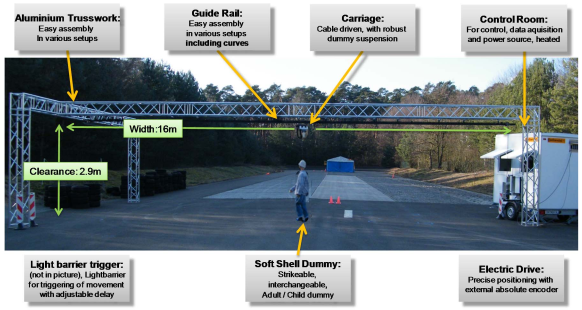


*Figure7.* Pedestrian Testing Device (PTD) at Continental Safety Park

The main structure consists of a gantry made of truss elements. The rail system of the cableway is attached underneath the truss elements. The rail system can consist of curved and straight elements, such that the dummy motion can be either completely straight or can include turning maneouvers. The regular set-up in the Continental Safety Park includes one curve which allows the simulation of a veering pedestrian.
The rail system guides a trolley unit which can be moved by a cable control system. The pedestrian dummy is attached to this trolley in the following way: At the trolley a hinge unit is attached which allows the upwards movement of the dummy when a collision with the test vehicle will take place. The dummy itself is attached to the hinge by using a robust CFRP rod. The height of the dummy over ground can be adjusted by shifting the rod within the hinge unit.
Usually the proofing ground has usually a certain curvature for “water outlet”, This curvature can be adapted by adaptation of the distance between rail and truss elements. Thus the dummy feet will remain close to the ground throughout the entire path length of the dummy motion.

*Figure8.* Attachment of the Pedestrian Dummy at the trolley

The dummy motion is controlled by using a revolving rope which is powered by a variable transmission unit which itself is driven by an electromotor. The transmission ratio can be adapted to achieve different speed ranges of the dummy. The electromotor is controlled by a standard PC unit. With this computation unit different motion profiles can be pre-progammed varying the distance, speed and accelerations. The motion profile is initiated by the car motion as explained above. This set up allows the following performance data of the dummy motion:

| **Performance data** | **Value** |
|---|---|
| Max. acceleration | 5 m/s² |
| Max. deceleration | 10 m/s² |
| Max dummy velocity | 15 km/h |

Table 1 Performance data dummy motion

Most of the cable-way based dummy test facilities struggle with unfortunate osciallations of the dummy caused by acceleration or eventually occurring gusts. These oscillations are suppressed in the PTD facility in 2 ways: The stiff structural attachment of the dummy to the cableway using the CFRP-rod and the rigid hinge element reduce the low-frequency oscillations. An active control mode of the motion control software additionally suppresses further unfortunate oscillations.

The PTD facility shall allow tests with various sensors of PPP systems. Besides of camera based systems also Radar based systems shall be testable. Thus the PTD had been optimized with respect to Radar reflections. The Radar cross section has been minimized by using stealth technology to cover the test rig. The test rig with the stealth sheets enables now a clear visibility of the dummy in the radar raw data. The test rig is invisible to the applied Radar sensors.

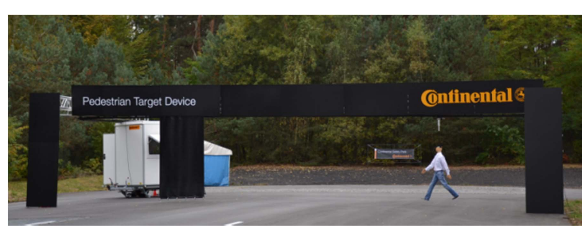


*Figure9.* PTD with stealth sheets

**TAG-BASED REFERENCE SYSTEMS**

Development and testing of modern driver assistance systems makes it essential to get highly accurate positioning data of all objects involved in the test. To meet this demand with adequate effort, Continental has developed a landmark-based positioning system.

The basic task is quite common an there have been lots of different approaches which can be seen in [6]. The most common approach is the use of satellite guided positioning systems (GNSS) since these systems are used for different daily navigation tasks (vehicle, marine and aircraft). But accuracy of these systems is heavily dependent on the availability of a sufficient number of satellites and for adequate positioning offset correction data is needed. So if either not enough satellites are available or no correction data is received precise positioning is not possible.

Here the Continental system is located. It is intended to provide a navigation solution in areas with weak GNSS availability which is comparable in quality for a reasonable price.

The basic measuring principle of the system is the distance measuring of radio waves using the round trip of flight principle (RTOF). Despite of the pure time of flight (TOF) measurement principle this technique has the advantage that the distance measurements can be clearly assigned to the radio tag. Further the used correlation principle gives the ability to determine the measurement quality. The system operates at a frequency of 2.4 GHz and reaches under optimal conditions a standard deviation of 4.7cm. Measurement hard- and software have been developed within the research project Ko-TAG, detailed information can be found in [7] and [8].

The position system setup is as follows: Eight radio tags are placed around the testing ground on precisely measured landmarks. Each tag is equipped with two antennas in different heights. This has the advantage that two distance values for each landmark are measured and ground interference effects can be corrected due to plausibility checks of both distances. Counter-part to the radio tags on the roadside is an onboard unit (OBU) which calculates the position directly on the measurement object. Differently to [9], where the angle of arrival (AOA) is used, the Continental positioning system is based on pure distance data. This brings the advantage that the antenna can be kept much smaller since no antenna array for the DoA is needed. Also the field of view of the system is wider (360° compared to 120°) since an omnidirectional antenna can be used.

To calculate the actual position out of the single distances each value is tested for plausibility and forwarded to a trilateration algorithm which calculates a raw position value. This value is then used as input for a Kalman-based position filtering based on a constant velocity model. [10]

Before the predicted position in the filter is corrected by the measurement value it has to match a certain gating criteria. The gating value is the Mahalanobis distance between the predicted value and the raw position value. Since there is no directly measured speed the speed is taken into account which would have been needed to reach the measured position based on the prior filtered position.

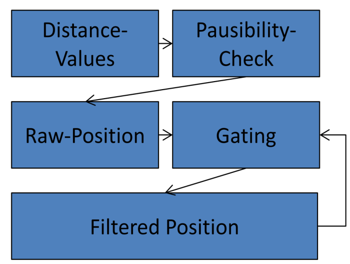


*Figure10.* Functional diagram of the position filter process

In addition to position filtering the Kalman-filter is used to derive dynamic values as velocity and heading of the measured object.

To test the quality of the system it was set up on the area of the Continental Safety Park in Alzenau, Germany and the positioning data was compared to the output of a corrected GNSS system. Since the standard deviation of this system is 2cm this deviation was not taken into account for the quality benchmark.

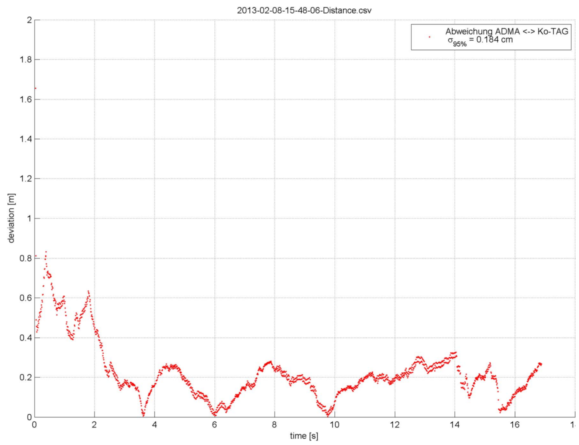


*Figure11.* Benchmark result

As a result it can be said that after the startup-process (within first 3s) the system offers track-accurate positioning in combination with an affordable effort. The smaller installation effort makes it possible to equip not only vehicle but also real pedestrians or in the case of the Continental Safety Park testing devices like the moving target device (MTD) or the pedestrian target device (PTD).

## CONCLUSIONS

A new generation of forward looking sensors enables sophisticated predictive pedestrian protection systems. The accurate identification and classification of pedestrians by the forward looking sensors is a prerequisite for any predictive pedestrian protection system.
The Continental Safety Park, situated in Alzenau, Germany, provides a wide range of state of the art test tools which are developed to test active vehicle safety functions such as predictive pedestrian protection systems. This paper describes a newly developed tool chain which is focusing on these protection systems. The tool chain consists of the following elements:
1. Position reference system based on sophisticated transponder technology
2. Pedestrian Target Device (PTD) for a precise conduction of pedestrian tests with high repetition rate
3. Drive robot systems for precise vehicle path control

The paper describes the underlying technology of the tool chain as well as its usability. Based on the discussion of state of the art test scenarios the Pedestrian Target Device reveals the following advantages:
- accurate representation of all state of the art test cases
- robustness for high repetition rates
- precise control for dummy movement
- flexibility with regards of usage of different dummy types
- flexibility for extensions such as different movement patterns of the dummy
- facilitation of dummy animation (feets and legs)
- collision of dummy possible without damage to dummy or ego vehicle
- Damping of dummy oscillation

Additionally the paper describes the usage of transponder based technology which supports a precise localization of the ego vehicle and the dummy during the tests. Due to the transponder technology this technology is independent of any GPS based localization. This is a significant advantage for many test tracks. Finally, the paper presents the application of a sophisticated drive robot system which helps to automate the movement of ego vehicle during repetitive tests. The combination of the describe tools has proven to be accurate, robust and cost effective for the extensive testing of different kind of Predictive Pedestrian Protection Systems. Thus with this tool chain the Continental Safety Park provides an ideal testing environment to support present and future development programs for the further enhancement of vehicle safety for pedestrians.

## REFERENCES

[1] B,. Haupt et al 2010. "Pedestrian Protection Systems PPS-pSAT – innovative sensing principle based on pressure satellites"
Airbag 2010, December 2010

[2] B. Lorenz 2012. "Basic and current status of international regulations"
Praxiskonferenz Fußgängerschutz 2012,
June 2012

[3] S. Zecha et al 2008. "Optimaler Fußgängerschutz durch situationsgerechte Einschätzung der Fußgängerbewegung"
24. VDI/VW-Gemeinschaftstagung
Integrierte Sicherheit und Fahrerassistenzsysteme
October 2008

[4] DSD, „UfO" - Ultraflat Overrunable Carrier for ADAS Testing, April 2012

[5] S. Hahn et al „Regelung von Testfahrzeugen und Testvorrichtungen zur Funktionsprüfung vorausschauender Fahrzeugsicherheits-
und Fußgängerschutzsysteme"
June 2012

[6] I. Skog and P. Handel. In-car positioning and navigation technologies—a survey. 10(1):4–21, 2009.

[7] C. Morhart, E. Biebl, D. Schwarz, and R. Rasshofer. Cooperative multi-user detection and localization for pedestrian protection.
In Proc. German Microwave Conf, pages 1–5, 2009.

[8] C. Morhart and E. Biebl. A cooperative code-based distance measuring system for a large number of simultaneous users.
Frequenz Journal of RF-Engineering and Telecommunications, 62:175–179, 2008.

[9] H. Kloeden, D. Schwarz, E. Biebl and R. Rasshofer. Vehicle Localization using Cooperative RF-based Landmarks.
In Proc. Intelligent Vehicle Symposium, 2011

[10] Y. Bar-Shalom and X.R. Li. Estimation and Tracking: Principles, Techniques, and Software.
Artech House, 1993