DEVELOPMENT AND PERFORMANCE OF CONTACT SENSORS FOR ACTIVE PEDESTRIAN PROTECTION SYSTEMS

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ABSTRACT

Over the past few years, the demands on future vehicle generations concerning pedestrian protection improvement have been discussed especially in various European and Japanese automobile committees, consumer protection organizations and by legislation. These discussions led to, amongst other activities, government regulations for Europe and Japan, which prescribe various testing which verifies pedestrian protection. In order to fulfill the prescribed head impact tests, a certain stiffness characteristic of the bonnet is necessary, which can be achieved besides passive means with an active bonnet lifting device. They consist of a sensor system, which detects the pedestrian impact, and an actuator system, which lifts the bonnet.

In this article, the main focus will be on the development of a sensor system including the discussion of requirements arising from legislative specifications and OEM market trends. Furthermore, typical test and simulation procedures are presented which provide the input for algorithm development. A central point regarding algorithm performance is the capability of pedestrian detection, especially under consideration of different temperatures, mounting and production tolerances and an inhomogeneous front end stiffness distribution. The differentiation of pedestrian collisions from misuse objects (e.g., stone- and bird-impact, parking dent) is also an important aspect, because a high misuse activation rate has a negative influence on customer satisfaction. This item will be also discussed.

INTRODUCTION

In order to fulfill the legal requirements from the European directive 2003/102/EC on pedestrian protection which will come into effect 2005 (phase I) and 2010 (phase II), passive as well as active protection measures can be used. Design solutions must be found for the bumper, the front end and in particular the bonnet in order to provide the capability for kinetic energy absorption without exceeding load limits for the pedestrian. This in turn requires an appropriate (low) vehicle structure stiffness in conjunction with a necessary deformation space. A protection concept which has been frequently examined concentrates on the lifting of the bonnet before the head impacts the vehicle in order to provide the necessary energy absorption capability in this area. Apart from the actuators, which are lifting the bonnet, this active protection system also requires sensor technology to recognize and classify the collision object.

A holistic approach is a fundamental requirement of developing an active pedestrian protection system. Among other things this means that suitable actuators need to be developed dependant on the sensor technology's performance. The possibility of the actuators' reversibility must be more or less comfortably characterized according to the detection safety of activation and misuse loading cases. Sensor systems which supply little information about a collision object can necessitate a high level reversible actuator, in order to avoid a garage stop after misuse activation and to ensure customer satisfaction. On the other hand, a sensor with high differentiation capabilities could be combined with a pyrotechnical actuator, because misuse activation probability is low. This relationship is visualized in Fig. 1.

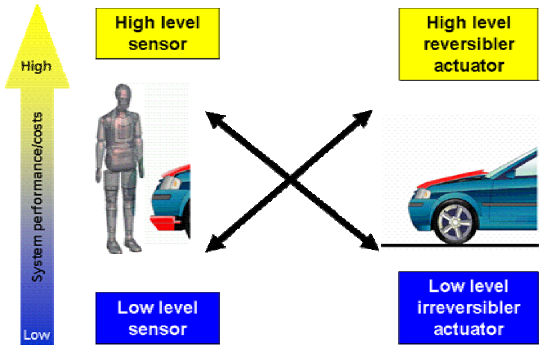

Figure 1. Relationship between sensor and actuator capabilities.

A further decisive point is the time required by the sensor system to generate a decision to activate (time to fire, TTF). The shorter the TTF, the lower the requirements of the actuators regarding the positioning time.

Against this background it seems desirable to use predictive (pre crash) sensors for pedestrian detection. Since this however does not seem realistic before 2010 due to the technological challenges which have to be mastered, in short term the sensing of contact via force or deformation in the bumper area will be a considerable solution.

CONTACT SENSORS SYSTEMS REQUIREMENTS

Contact sensor system requirements can be split up into the ability to recognize collision objects and therefore also the differentiation or classification of those, and requirements regarding sensor integration into the vehicle.

Differentiation / Classification

The most important requirement is the ability to classify the object of collision which comes about depending on the necessity of differentiating between the deployment or activation loading case (fire) and a misuse loading case (no-fire).

Legal Requirements or Specifications

An activation loading case based on current regulations must be recognized and the protection system must be activated. In future, Europe must obey the EC directive 2003/102/EC for pedestrian protection [1] in connection with document 2004/90/EC (technical prescriptions for the implementation of article 3 of directive 2003/102/EC) [2]. Therefore, the lower leg impact should be considered as a basic activation loading case.

Field Stability

An activation loading case in the field and in the approval tests should be detected. Due to part II, chapter I, section 1.1.2 of document 2004/90/EC which states that

"All devices designed to protect vulnerable road users shall be correctly activated before and/or be active during the appropriate test. It shall be the responsibility of the applicant for approval to show that the devices will act as intended in a pedestrian impact"

it seems appropriate to design lower limit impactors, which are able to provide impact characteristics of the smallest relevant pedestrian for verification of active systems. In case these impactors are not available or the sensor algorithm is not proven to activate automatically at higher impact energy in case it does in the lower limit case, full scale crash tests with the dummy of a 6 year old child, the 5 %ile-woman, the 50 %ile- and 95 %ile-man can be conducted. However, the correlation between human and dummy regarding mechanical characteristics in a pedestrian accident is an open issue which needs to be examined further in future.

Frontal Crash Detection

An erroneous activation must be avoided if the safety of the vehicle's occupants becomes endangered. This could be the case for example during a car to car crash or the impacting of an obstacle. A raised bonnet which has not been secured further could possibly penetrate the passenger compartment.

Misuse Stability

Erroneous activation during a vehicle collision for example with stones, snow drift or a traffic beacon (traffic sign) should be avoided in order to ensure customer satisfaction. This point becomes significant particularly with non-reversible actuator systems, when an erroneous activation would require a visit to the garage afterwards. Misuse objects with a high probability of being involved in accidents are listed in Table 1.

Table 1.

Important misuse objects

Snowdrift, snow hill
Tree, branch on street (after storm)
Big deer (red deer, wild boars,...)
Traffic sign, traffic light
Fence, barrier grid,...
Traffic beacon, pylons, post
Ball
Stone

Physical collision parameters such as collision speed, mass and shape of collision object and front end deformation characteristics (point of contact, intrusion, intrusion speed) can be considered as differentiation criteria. In addition to the choice of differentiation criteria, the relevant thresholds must be determined, in order to distinguish the activation loading cases from the misuse cases. Usually parameters of the collision object (e.g. mass) cannot be determined directly, but rather indirectly via energy, deformation or dynamic characteristics on the front end. Vehicle speed can be processed as additional information from an ABS system via the CAN-Bus.

Activation thresholds for the collision speed can be derived based on statistical investigations for the distribution of injury severity and the frequency of pedestrian and cyclist accidents. Regarding injury severity, it can be seen that at a collision speed of 20 kph to 30 kph, the majority of pedestrians and cyclists (around 80%) remain uninjured or only minimally injured (MAIS 1), whilst approximately 20 % casualties suffer injuries of severity MAIS 2 to 4 [5]. The risk of having lethal injuries in this speed range is however almost zero. An upper threshold for the activation speed range came about due to the fact that already almost 95% pedestrian and cyclist collisions occur under 60 kph. The majority of all pedestrian and cyclist accidents are therefore covered by protection systems, which work in this velocity range [4]. However, precise examination – also with consideration of legal requirements – needs to be carried out in order to establish appropriate upper and lower velocity thresholds for the protection system activation.

Vehicle Integration

Integration into a vehicle places further requirements onto a contact sensor system:

Adaptability to Varying Levels of Stiffness on the Front End

Usually the bumper area of a vehicle is not built homogeneously throughout the width, but rather, shows certain features e.g. openings in the foam for the tow hook and parking sensors or changes in the outer paneling geometry. These variations in constructive design lead to differing stiffness distribution of the bumper over the whole vehicle width. This can lead to different sensor signals being measured at different impact positions with the same collision object. A contact sensor system should be in a position to take these variations into account.

Adaptation to Varying Operating Temperatures

Temperature changes to the front end lead to a change of the mechanical characteristics. This leads for the same collision object to different sensor signals at high or low temperature compared to the signal obtained at room temperature (see section 3.2). These effects must also be taken into account by the sensor system and must not lead to an erroneous activation.

Service Life

The sensor system must work throughout the lifecycle of the vehicle. Requirements arise regarding ageing, environmental conditions, vibration, petty damage etc., according to each automobile manufacturer's specifications.

Insensitivity Compared with Installation and Manufacturing Tolerance

The operativeness of the sensor system may not be impaired due to the variation of component characteristics, e.g. variations of the hardness of the bumper foam and the sensor's position tolerance.

Electro-Magnetic Compatibility

The sensor system's reliability performance must not be impaired by electro-magnetic radiation.

Design Neutrality

The sensor system should be able to be integrated into the vehicle without influencing the exterior. Modifications to components which are not visible and placed on the inside are however allowed but they should be kept to a minimum.

FIBER OPTIC CONTACT SENSOR (FOS)

Before choosing an appropriate sensor system for active pedestrian protection, the requirements listed in the previous section need to be considered. The fiber optic contact sensor shows a system which correspond with the requirements in a particular way. The signal is not influenced by electro-magnetic waves and minor position deviations. Changes in temperature and a different distribution of stiffness of the front end can be taken into account.

Setup

The sensor itself is made up of a number of synthetic optical fibers, which are surrounded by light absorbing material, see Fig. 2.

Figure 2. Set up of fiber optical sensor.

Operating Principle

The sensor's operating principle is based on the effect of micro bending. Each optical fiber is covered by a reflective coating, in order to minimize the losses during light transfer. By a specific treatment process, the coating is partially removed from the fiber. This results in an amplification or reduction of the light intensity compared to a reference state, depending on the bending direction, see Fig. 3.

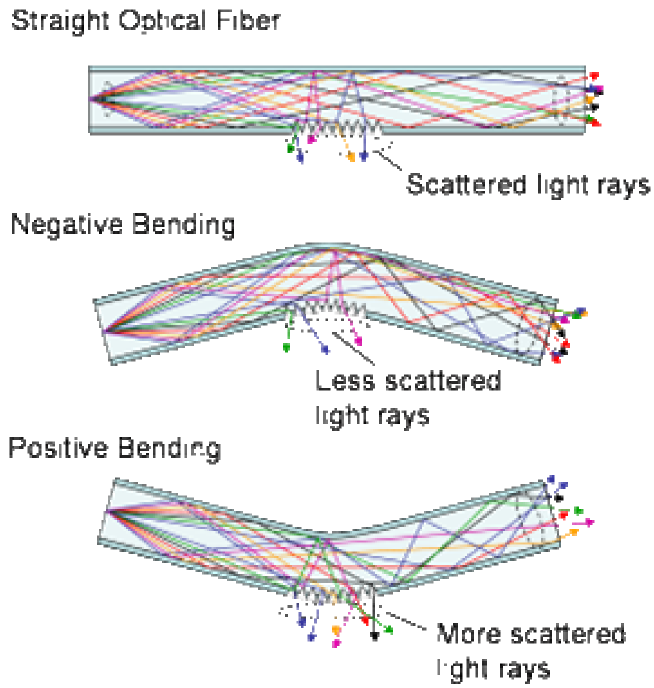

Figure 3. Micro bending principle.

A constant loss of light exists with straight fibers which extends on upward flexion and decreases on downward flexion. The rate of loss is directly related to the direction of the fiber flexion and the height of the rate of loss is proportional to the strength of the curvature. The light intensity is converted in an optoelectronic interface into a voltage signal which is directly in proportion to the curvature in the sensitive area of the fiber.

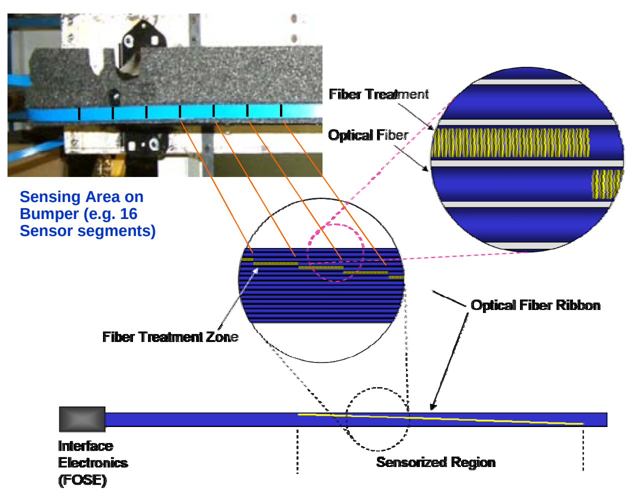

Figure 4. Sensor tape with single segments integrated in bumper foam.

The whole contact sensor is made up of individual sensor segments, see Fig. 4. With simple calibration methods the assigned bend angle for each sensor segment can be determined from the voltage signals. The foam deformation can be calculated via a geometric correlation from the bend angles occurring during operation.

System Concept and Operating Method

The conceptual set up of the protection system and the operating method are to be described as follows. Fig. 5 shows the principle set up of the system.

Should the vehicle collide with an object, the deformation of the front end leads to bending of the sensor segments, which in turn, as described in the previous section, results in a change in light intensity. The measurement of light intensity change takes place on the reception side of the FOS-loop. These signals are called up constantly on a millisecond cycle. Voltage signals are generated from the light signals via an optoelectronic interface from which the relevant angle can be calculated, by means of calibration data. The processing of the angle data in the algorithm then provides the bumper deformation. The deformation of the front end and the sensor strip is dependant on the collision speed, the mass and the mechanical set up of the collision object. The characteristics of the collision object can be determined from the sensor signal by an appropriate algorithm.

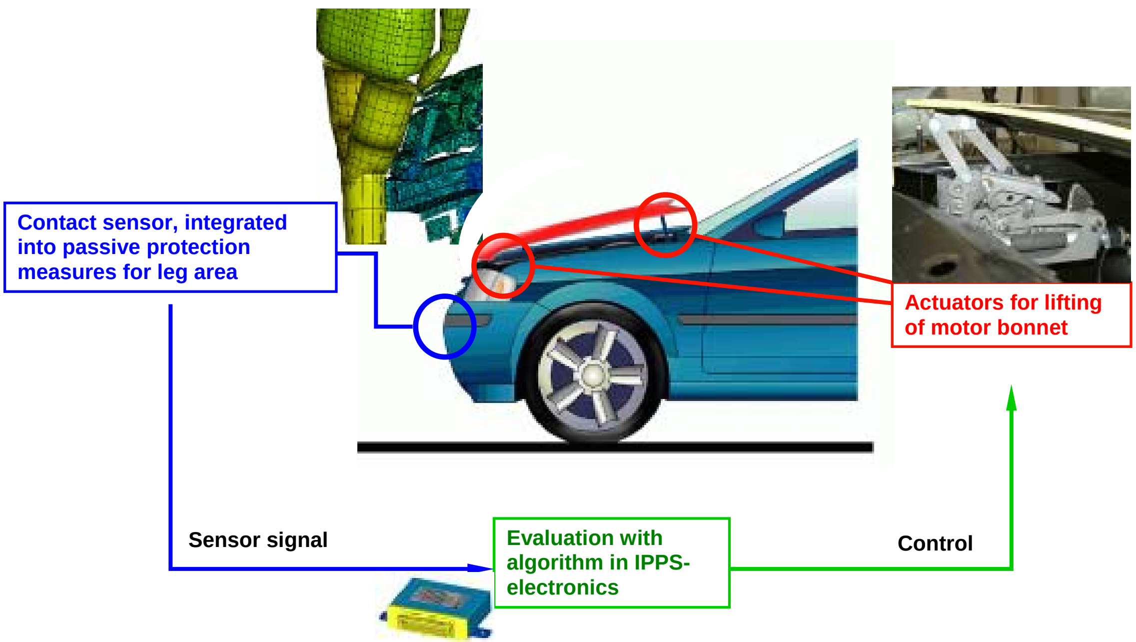

Figure 5. System set up.

Data is passed on to the evaluation electronics as the whole bumper is scanned in a millisecond cycle, so that immediate data processing is possible in real time. A fire or no-fire decision can therefore be made within the required time. A typical requirement is that the trigger time – the time of the first contact of the collision object until the fire or no-fire decision – is less than 10ms for higher collision speeds. Higher trigger times can also be accepted in cases of lower speeds due to pedestrian kinematics. But the set up times of the actuators system must always be considered when determining the trigger times. Due to the condition, both times are linked to one another so that their sum cannot be larger than the time of the first contact of the pedestrian with the vehicle to the head impact on the bonnet.

If the algorithm reaches a trigger decision, the actuators are controlled by the system's electronics and the energy required for triggering or releasing is delivered.

SYSTEM DEVELOPMENT

During system development, three types of tests can be conducted in order to generate a database for algorithm development: Drop tower tests to gain experience about the basic performance of a sensor system in a specific frontend followed by impactor tests to check system performance e.g. in case of a lower leg impact. By the aid of full scale crash tests, results regarding the system performance can be obtained, which are as close to the real accident scenarios as possible with the currently available testing technology, see also [3].

Each test scenario can also be investigated in numerical simulation, which is especially advantageous in case when extensive parameter studies have to be considered.

Fig. 6 visualizes the development process.

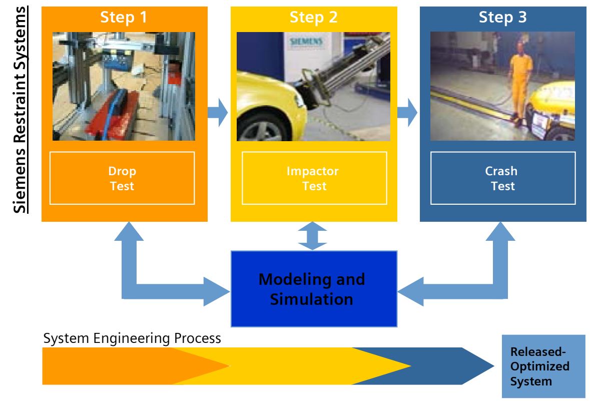

Figure 6. Development process.

Full Scale Crash Tests

In order to analyze the sensor behavior in real accidents, crash tests can be performed. In Fig. 7 two typical scenarios are shown: The left side shows a pedestrian collision (upper part of Figure) with the associated sensor signal (lower part). On the right side a misuse object (traffic beacon) is presented, again with the associated signal.

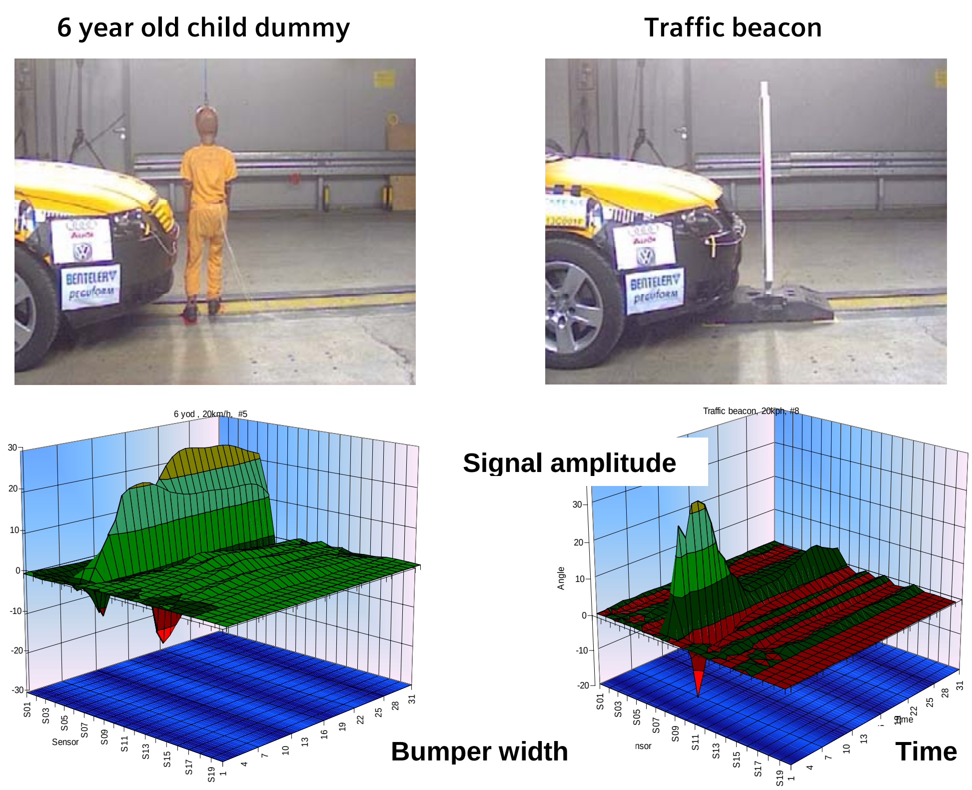

Figure 7. Crash test configurations and associated sensor signals.

The signal diagrams in Fig. 7 show a different shape for the dummy and the misuse object, which can be used to derive criteria for differentiation and classification of collision objects. According to the mass and stiffness distribution of a collision object, a specific object kinematics and deformation of the bumper occurs, which is reflected in the sensor signals.

For the dummy, one can observe a continuously increasing signal amplitude up to approximately 10 ms, then a short constant amplitude followed by a second increase and finally a slow degrease phase. The first increase is associated with the effect of the first dummy leg coming into contact with the bumper, followed by the impact of the second one, which results in the second signal increase.

A completely different signal is generated by the traffic beacon. Here, one can observe a short contact duration due to the elasticity of the beacon and the relative low "effective" mass acting onto the frontend.

If one considers the frontend and collision object as a dynamic system, the first natural frequency – which depends on the bumper stiffness and the colliding mass – is different. This is also reflected in the sensor signals in form of the contact duration.

Impactor Tests

Impactor tests are typically used to gain information about the system behavior in case of lower leg impacts (Fig. 8).

Figure 8. Impactor test configuration.

Furthermore, they are used to investigate the influence of different operating temperatures. Results of these tests are shown in Fig. 9, which indicate a clear temperature dependence of the frontend deformation and the signal amplitude. However, this effect can be compensated in the algorithm.

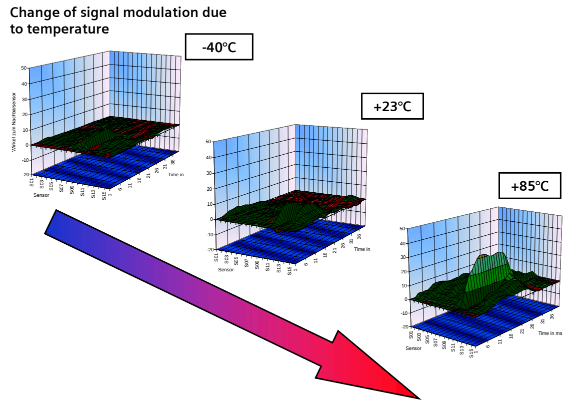

Figure 9. Temperature dependence of frontend deformation.

System Simulation

With the aid of numerical simulation, important questions can be clarified in the engineering process. Simulation has a particular advantage compared to testing in the determination of head impact times, due to the availability of validated human models, which represent accident kinematics better than test dummies. Another important advantage is the possibility to carry out extensive parameter studies at low cost, e.g. regarding different dummy postures, point of impact, collision speed, etc.

In order to support pedestrian protection system development by numerical simulation, a process chain was established, which connects different simulation programs, see Fig. 10. FE-codes like PAMCRASH or LS-DYNA are used for mechanical simulations, MATLAB/Simulink for support of algorithm and electronic development and own developed codes for sensor simulation.

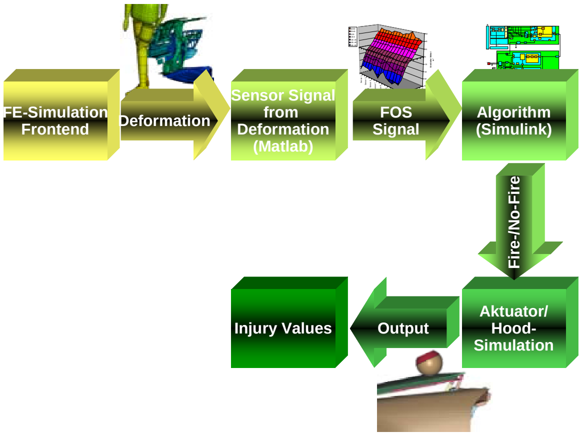

Figure 10. Simulation process chain.

A standard task of simulation is the configuration of the energy absorption foam insert for passive lower leg protection. For active pedestrian protection systems special attention has to be paid to sensor integration, which necessitates in some cases model updates in order to represent the sensor in an appropriate way. A typical Finite Element Model is shown in Fig. 11.

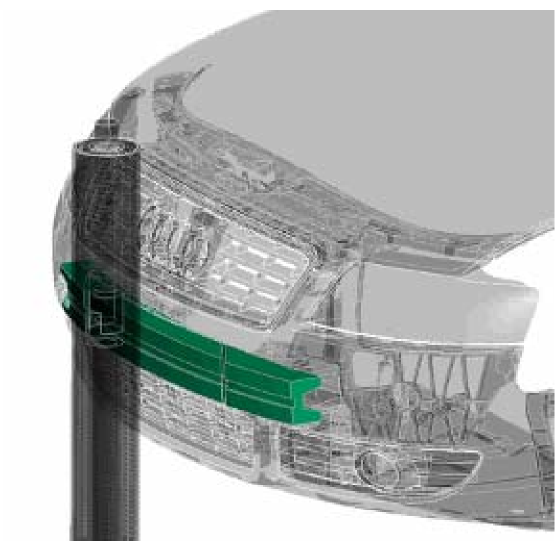

Figure 11. Simulation model.

Algorithm-Development

The significant element of the sensor system is the analysis of the data and it's evaluation and assessment in an algorithm which is as robust as possible. The objective is to establish optimized triggering criteria for the system. At the same time, aspects which have influence on the cost of the system as a whole are considered with respect to manufacturing and cost optimization. Close coordination between sensor development and algorithm development is necessary in order to, for example, minimize the number of individual sensor segments but simultaneously guarantee data or information density which is needed for a robust algorithm.

At the current development stage of the generic algorithms developed at Siemens Restraint Systems, the data is processed as follows: An offset correction is applied to the voltage raw data by means of various filter functions. The correlation between voltage signal and angle is ascertained from the calibration undertaken of the individual sensor segments so that the angle information per segment is available as an input variable size for the algorithm. If the angle value exceeds a starter threshold, the intrusion and further derived rates are calculated, amongst which, criteria which are proportional to the mass of the collision object. The decision about the activation or non-activation of the pedestrian protection system can only be made after the trigger thresholds for the individual criterion have been determined. Fig. 12 shows this process again schematically.

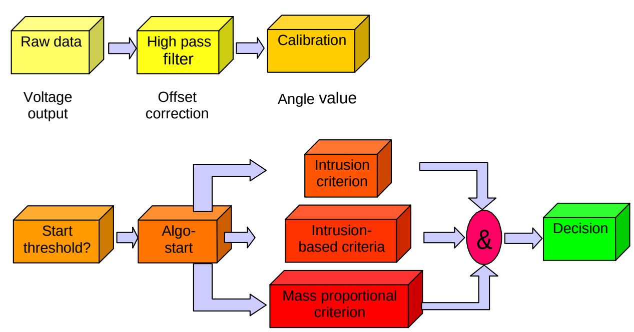

Figure 12. Algorithm set up.

The system performance is shown in Table 2. A broad range of misuse objects can be distinguished from activation load cases. Due to different collision velocities which are associated with a different deformation speed of the frontend, different activation times are obtained. However, a smaller collision velocity results also in a larger head impact time, which means that for a given actuator time (which is usually not velocity dependent) the "benefit" of low collision speeds can be given to the sensor system.

The currently discussed requirement of 10 ms TTF at 40 kph collision velocity is met by the FOS system.

Table 2.

Activation times for several load cases

Collision object	Velocitiy [kph]	Worst case TTF [ms]	Requirement
6yod	15	16	Fire
6yod	20	13	Fire
6yod	25	11	Fire
50%ile	20	13	Fire
	40	9	Fire
Small leg impactor	20	16	Fire
	40	8	Fire
Lower leg impactor	20	14	Fire
	40	7	Fire
Snow drift	20 - 50	No fire	No fire
Small animal	20 - 55	No fire	No fire
Ball	20 - 80	No fire	No fire
Hammer induced excitation		No fire	No fire
Road testing	0 - 80	No fire	No fire
Curb	60	No fire	No fire

CONCLUSION

The work carried out shows that a high amount of classification potential exists with the fiber optic sensor system and an algorithm correctly adapted to the vehicle. Misuse load cases can be differentiated between activation load cases. However, the more a misuse object approaches a pedestrian regarding its mass and stiffness distribution, the more difficult the differentiation will naturally be. When a borderline case object falls with its mechanical properties into the category of a pedestrian, a sensor system will no longer be able to differentiate between the misuse object and the pedestrian.

Since there is a high information content in the fiber optical sensor signal, there is far greater classification potential with this kind of system than with contact sensor systems, which are e.g. equipped with a simple switch and a constant threshold.

Further studies show that regarding the transferability of the fiber-optic sensor system and the algorithm on other vehicles, this is possible with relatively small changes since the algorithm parameters needed to be adapted are few.

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