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Innovative Approach to Crash Detection in Passenger Cars Enabled by Passive RFID Tags

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Abstract

Reducing fatalities in traffic is one of the main goals of the automotive industry. Today, active safety systems are gaining more importance – but passive safety system still builds the basis, when it comes to an accident. The today's detection of a crash is based on acceleration and pressure sensors and has some deficits related to the measurement principles. Detection of the severity and direction of the crash are not optimal. This paper presents a new approach to crash detection based on passive RFID tags in two different ways, which are discussed. Therefore critical requirements are specified and are compared to what passive RFID technology is able to do. Therefore, different performance tests are conducted and the results are interpreted regarding the requirements. The idea of this approach is supported by first measurements for communication robustness, too. Additionally, an algorithm concept is presented. In the end essential benefits are shown.

Keywords: High speed RFID; Crash detection; Crash sensors; Crash algorithm

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1. Introduction

In its White Paper, the European Union set the target of halving the number of road fatalities within the next decade [1]. This challenge is part of Vision Zero which aims to reduce the number of traffic fatalities to zero – a challenge the various development sectors of the automotive industry plan to meet. Active safety systems play an ever-increasing role when it comes to measures to reduce the risk of injuries. However, conventional passive safety with its protection systems such as seat belts and airbags remains important as full avoidance of accidents will not be achieved in the foreseeable future.

When evaluating the protection systems in use today, their being irrevocable components which can only maintain optimum protection for a few milliseconds is a key aspect. The deployment timing within the temporal sequence of an accident therefore is of fundamental importance for the protective effect that can be achieved.

The airbag control unit is the core component of today's airbag systems. During an accident, this processor unit uses highly complex algorithms to evaluate, among other things, the severity and direction of the ongoing crash. Based on this evaluation, the suitable deployment times of the restraint devices installed in the vehicle, e.g. airbags and belt pretensioners, can be calculated. Depending on the accident type, deployment decisions must be reached within approx. 10 ms to 50 ms after the initial contact with the crash opponent. One of the key parameters influencing the decision is the vehicle deceleration which is determined using acceleration sensors (Figure 1) [2]. An inherent problem of this measuring principle is that vehicle deceleration is not a direct measure for a crash. Decelerations caused by misuse events such as collisions with wild animals, driving through large potholes or contact with a curb can also result in major, immediate vehicle deceleration.

A correct decision must therefore be reached to the extent possible so as to avoid unfounded and unnecessary deployment of the restraint devices inside the vehicle. In the extremely short periods of time after the start of a crash in particular, the decelerations caused by a misuse event only differ marginally from those caused by crashing into another vehicle at higher speeds (e.g. ODB at 64 km/h, refer to Figure 2). This is due to the physical structure of the crash opponents: A hard and solid object, such as a post on a parking lot or a concrete barrier, results in immediate deceleration of the crashing vehicle.

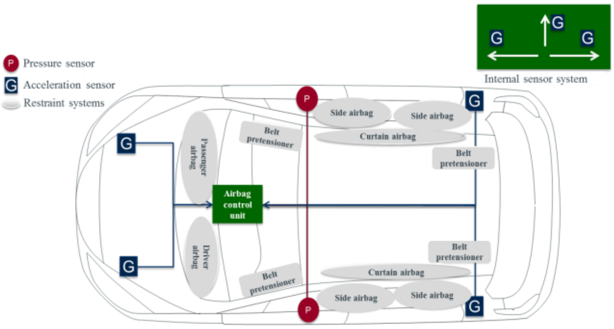


Fig. 1. Conventional airbag system

In contrast, collision with another passenger car only results in minor deceleration at the start of the crash (Figure 2). This is due to the soft, energy-absorbing crumple zone of the crash opponent. It is only after approx. 60 ms that the hard vehicle structure of the crash opponent takes effect.

Furthermore, the capability of acceleration sensors to provide data on the precise direction of the crash opponent is very limited.

All these challenges can be met today using known sensor concepts. However, this results in the installation of an ever-expanding number of sensors at additional positions inside the vehicle. In addition to the problems resulting from the limited installation space available, all these sensors must be wired and do not provide a general solution for the physical problems described.

This paper is to present a fundamentally new approach. The target is to provide direct temporal and spatial data on intrusions in the vehicle structure in order to generate a measurement which is proportionate to the crash sequence.

The sensors used shall ideally be wireless to facilitate their integration in the vehicle. The number of measuring points can thus be increased significantly.

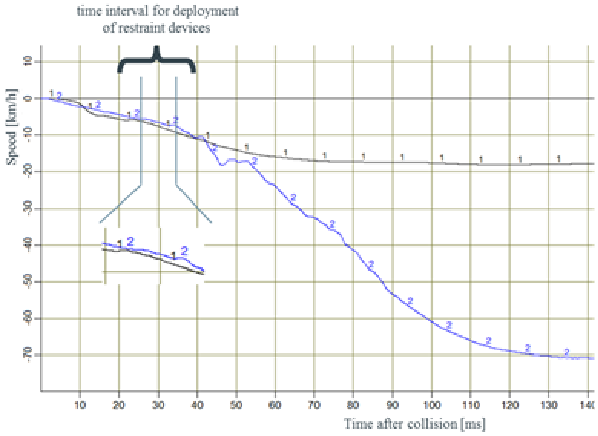


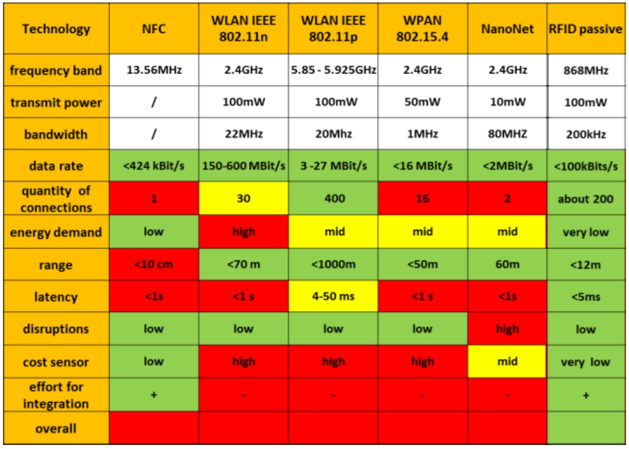
Fig. 2. Signal plots of RCAR test at 16 km/h versus ODB test at 64 km/h

2. Requirements on wireless crash sensors

As part of a comprehensive technology search (Figure 3), various wireless technologies were examined with regard to their general suitability for use as crash sensors. The criteria in question can be subdivided into two categories.

The first consideration are the application-related criteria such as integrability into the vehicle. The second consideration are technological framework conditions such as range, number of possible simultaneous data connections, data rate and energy demand. Unlike many other requirements on wireless communication, the temporal aspects are of key importance here. This is due to a vehicle crash sequence taking no more than a few milliseconds. Minimizing the latency between transmitter unit and receiver unit therefore is one of the crucial factors.

Taking all criteria into account, passive RFID (radio frequency identification) tags meet most of the key requirements to a large extent. In terms of energy demand, latency and integrability in particular, they display the greatest potential of all technologies examined.



Technology	NFC	WLAN IEEE 802.11n	WLAN IEEE 802.11p	WPAN 802.15.4	NanoNet	RFID passive
frequency band	13.56MHz	2.4GHz	5.85 - 5.925GHz	2.4GHz	2.4GHz	868MHz
transmit power	/	100mW	100mW	50mW	10mW	100mW
bandwidth	/	22MHz	20Mhz	1MHz	80MHZ	200kHz
data rate	<424 kBit/s	150-600 MBit/s	3 -27 MBit/s	<16 MBit/s	<2MBit/s	<100kBits/s
quantity of connections	1	30	400	16	2	about 200
energy demand	low	high	mid	mid	mid	very low
range	<10 cm	<70 m	<1000m	<50m	60m	<12m
latency	<1s	<1 s	4-50 ms	<1 s	<1s	<5ms
disruptions	low	low	low	low	high	low
cost sensor	low	high	high	high	mid	very low
effort for integration	+	-	-	-	-	+
overall	🟥	🟥	🟥	🟥	🟥	🟩

Fig. 3. Various wireless technologies in comparison (NFC [3], WLANn [4], WLANp [5], WPAN [6], NanoNet [7], RFID [8])

3. RFID technology basics

In terms of establishing radio communication for data transfer, RFID systems are comparable to other wireless technologies. RFID systems generally consist of two components: the transponder (RFID tag), which mainly provides information, and the evaluation unit [9]. Depending on the application, there may be more than one transponder. These tags are available on the market in various designs for a multitude of applications [10]. However, they consist at minimum of a microchip for data processing and one or several antenna(s) for communication. RFID systems can be subdivided into active and passive systems. Active systems have a power supply to the transponder and the evaluation unit and are therefore not suitable for the planned application.

The advantage of passive RFID tags is that they do not require a separate source of energy but collect the energy required for operation from the radio waves of the evaluation unit [11]. Evaluation units for a large number of specific applications can also be found on the market. They consist at minimum of a processor unit for data processing and an antenna system. The antenna system is used to receive the tag data and to transfer energy for the data transmission. The system is shown in Figure 4.

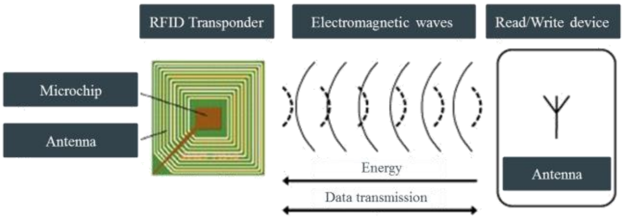


Fig. 4. Schematic representation of passive RFID tag data transmission [12]

Operation is on various unprotected frequencies (e.g. 868 MHz UHF band) which RFID systems must share with other users. For the systems found on the market, the attainable range is approx. 10 m [13].

In terms of an environment related to the automotive sector, RFID technology is used in logistics. By attaching tags to goods of all kinds, their route through production facilities can be tracked at any time. The basic requirements resulting from industrial use of this wireless technology have therefore already been met.

However, use in the application stated in this paper implies a variety of additional requirements. These must be examined and must eventually be implemented in the development of an RFID crash sensor tag which is suitable for the mass market. When subdividing these requirements into categories, challenges arise from the use in a passenger car environment. These include possible influence or interference resulting from the high metal content of the vehicle, requirements regarding service life, temperature and humidity and requirements regarding specific designs required for the installation on vehicle structures.

In addition, there are specific requirements resulting from the use as crash sensors. Examples of such requirements are the very high requirements on transmission speed and the number of tags to be monitored at the same time in a very confined space.

High requirements are placed in particular on the latency within the detection process of the evaluation unit. The data from an amount of tags must be processed within a single-digit millisecond range to enable a timely detection of any crash situation. Thereby, the number of tags accounts for a specific amout of time to process them. So it is not possible to change the number of tags without keeping the necessary process time in mind.

4. Sensor system concepts

The operating principle of the airbag algorithms used today has been described in Chapter 1. They derive the accident type from vehicle deceleration values measured by acceleration sensors. Airbag algorithms which use information from RFID tags are based on a completely different detection concept. Here, the accident type in question is to be determined directly from the destruction of the vehicle structure / components on the vehicle (Figure 5).

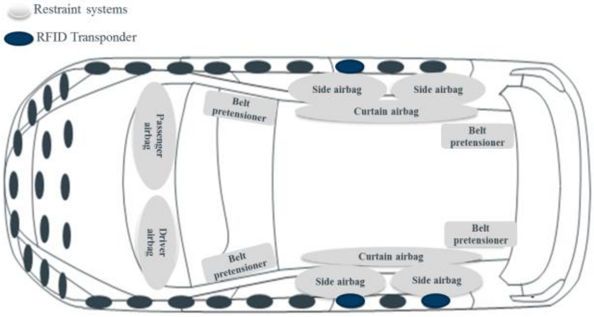


Fig. 5. Distribution of RFID tags inside the vehicle

4.1 Trajectory Tracking

For this approach, RFID tags are installed on or close to the outer skin of the vehicle. The tags can be identified unambiguously by their ID and their known position in the coordinate system of the vehicle and are assigned to previously defined installation positions in the vehicle. In an accident scenario (e.g. two vehicles crashing), the vehicle structure generally suffers major deformation at the point of impact. By contrast, other structures which are not directly influenced by the impact remain without deformation. This physical behavior is used for the algorithm concept. The evaluation control unit cyclically monitors all tags and determines their position in the coordinate system of the vehi-

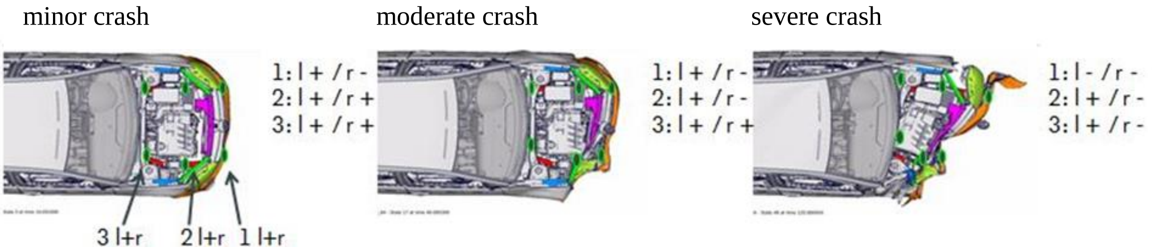


Fig. 6. Failure measurement

cle using triangulation / transit time methods. In the event of a collision with an intrusion (e.g. of the right-hand fender), the tags attached to it move in the direction of the impact and follow the deformation of the vehicle. By determining the ID of the tags which change their spatial position and their respective absolute intrusion travel, the acceleration of the impacted components as well as their location can be determined directly.

As the typical crash behavior of the respective vehicle has been determined in application tests and simulations in advance, this data can be used to establish the precise crash type and position during a real accident.

This method offers a number of advantages: The number of RFID tags required per vehicle is small, the measurement method is directly proportional to the vehicle destruction and the scope of integration required in the vehicle is negligible as the same or similar positions can be used in most vehicle types. On the other hand, there are significant disadvantages: The necessary transit time method is extremely complex and cannot be implemented in a real vehicle environment taking into account the existing boundary conditions: A typical EuroNCAP crash test, such as the 64 km/h ODB test, results in the vehicle structure becoming displaced by approx. 0.09 m within the first 5 ms. The signals between tag and evaluation unit are ideally propagated at the speed of light. For a typical distance between tag and evaluation unit, this would result in the need to measure a propagation delay of approx. 0.6 ns. Taking the expected component and propagation tolerances and interferences in the vehicle environment into account, such a highly precise measurement is technically not feasible or requires a disproportionally high expenditure. Despite the significant advantages of this approach, particularly with regard to the precise knowledge regarding the trajectories of the vehicle structures involved in the crash, this approach is not practical.

4.2. Failure measurement

For this second approach RFID tags are distributed over the entire vehicle body.

The tags are attached on or to the vehicle contours as well as in inboard vehicle areas behind these structures where they are mounted on various components.

Here, the tags can also be identified unambiguously via their ID and their known position in the coordinate system of the vehicle, and they are assigned to the previously defined installation positions in the vehicle. In an accident scenario, such as in the event of two vehicles crashing, the vehicle structure suffers major deformation at the point of impact. Other structures, which are not subject to the impact, remain intact. For this approach, the point in time is measured at which the RFID tags are destroyed that are attached to the structures which are subject to the impact.

In a typical vehicle crash, e.g. with an off-set frontal collision on the right-hand side at high impact speed, the tag on the right-hand fender is the first tag to be hit. This is followed by an impact on the tag at the right-hand headlamp which in turn is followed by an impact on the tag on the right-hand crossmember, etc. The position of the failed tags provides information on the direction of impact. The number of tags failing one after the other and their temporal sequence provides direct information on the crash type and severity (Figure 5). Digits 1 to 3 mark the sequence of the tags in rows; “l” and “r” indicate the installation position (left and right-hand side).

From a technical point of view, this process is significantly easier to implement. The costs for antenna system and evaluation unit can probably be kept within limits acceptable for high-volume application. The drawback is that the number of tags required per vehicle increases significantly and, in particular, that the tags and their installation position must be determined separately for each vehicle. This is due to the temporal sequence of the crash destruction inside the vehicle from the point of impact to the vehicle inside being highly dependent on the vehicle body, the steels used and the arrangement of the components, e.g. in the engine compartment.

5. Examining robustness of communication performance

Communication is essential for the practical application of the technical solutions presented as well as for their robust use. Chapter 2 revealed that passive RFID technology which uses the UHF band is the most suitable for the requirements in question. However, use of this technology in crash sensor systems is beyond its planned application. As a result, the requirements of this use case have not been considered in the development of this technology. Meeting these requirements is therefore coincidental or inadequate. The challenge consists in finding an approach which represents a compromise between requirements in hand and performance at reasonable expense. To this end, the shortcomings of the technology must be considered, and optimization must be striven for.

With regard to both approaches shown in Chapter 4, robust, reliable and absolutely interruption-free communication between reader and tag is crucial for correct operation. However, performance testing cannot be done separately but must be performed in a vehicle environment. At the start of the tests, it is already evident that communication behavior in a laboratory setup differs profoundly from that in the vehicle. However, a laboratory setup provides important initial findings on communication behavior and forms the basis for robustness analyses. It must then be followed by further communication testing in the vehicle. The findings on communication performance derived from table setups and initial installation tests are described and evaluated in the following. Various influencing factors found in a vehicle environment are demonstrated in an exemplary manner. The objective is to provide a qualitative statement as to whether and to what extent the individual factors actually influence communication before these effects can no longer be isolated for analysis in the vehicle environment.

Different angles between antenna and tags are first examined during the laboratory measurements. In addition, tests with different materials in the air interface are performed, and the influence of water is examined. This also applies to the influence of application materials: according to literature, metal and other conductive materials in particular have an adverse effect on communication performance. In varying constellations, all these factors are also prevalent in the front end of a vehicle. Combinations of the identified factors are therefore tested during measurements.

Figure 7 shows the basic setup of the measurement chain.

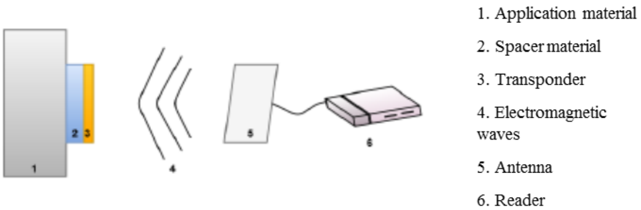


Fig. 7. Communication equipment

For a first approximation, the temporal aspect of the communication is independent of the identified factors. On the selected passive RFID tags, a communication range above 1 m is available on the UHF band only. This by default results in the prevalent EPC Class 1 Generation 2 standard if a standard that is already on the market is to be used [14]. Given the objective to find an economically attractive solution, this is the preferred approach. This standard provides implemented basic mechanisms which have a direct influence on communication performance – or more specifically on the temporal sequence and therefore on the minimum transponder response times to a reader request. Transmission of high data volumes or of memory information is not required. Using the EPC, the transmitting tag can be identified unambiguously. This is considered sufficient for the use case in hand. The requirements detailed in this paper clearly show that the main focus is on robust and fast communication. Temporal investigations therefore represent another approach to basic measurements.

As is the case for all communication technologies, a method must be found to prevent a collision of exchanged data in the air interface if more than one tag is used. Various approaches are conceivable, all of which have different effects on communication speed. Multiplexing is capable of handling several connections simultaneously, for example by using several frequencies for transmission. EPC Class 1 Generation 2 uses a time-based anti-collision process to ensure that only one transponder transmits data at a time and that the transponders are handled in sequence. In addition, readers and transponders cannot transmit at the same time; data exchange uses the half-duplex mode. A drawback of this principle is that it results in idle times in which no data is transmitted. As the number of transponders increases, the amount of time in which no data is transmitted, increases disproportionally. However, there are optimization methods such as the Q algorithm which reduce the unused time slots and increase the total transmission rate.

Fig. 8. Dogbone RFID Tag

To quantify this effect, testing starts with a variation of the number of tags measured taking into account the response time. An Impinj Speedway R420 [15] reader optimized for high performance is used for the purpose. The transponders used are DogBone transponders produced by Smartrac (Figure 8).

The measurements are performed in a neutral environment in a room of approx. 40 sqm which is completely empty except for the transponder holder, antenna and reader. Any metal objects have been removed from the room. During the measurement, there are no other objects emitting electromagnetic radiation (e.g. mobile phones, WiFi) in the measuring room. The transponders are bonded to a polyacrylic panel with a thickness of approx. 5 mm which does not influence the propagation of electromagnetic waves [16], [17]. The center of the antenna and the center of the transponder holder are located approx. 1.10 m above the floor. To the best of knowledge, any deviations in the measurement results can therefore be traced back to a modification of measurement parameters and are influenced as little as possible by the environment. The measurements are performed three times, each measurement lasting 60 s. To evaluate speed, the refresh interval of the individual tag is decisive. It must be short enough to ensure that communication would be possible several times within the decision time span for the deployment of the restraint devices. The measurand therefore is the time between two completed communications of a transponder [18].

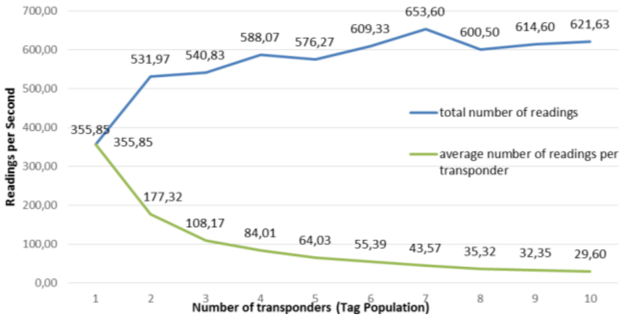


Fig. 9. Temporal performance of the RFID Tags

Figure 9 shows the number of readings of one transponder and the number of readings of all transponders in the test during one second and at a set distance of 1.5 m and maximum available transmission power of 30 db. As can be seen, saturation occurs at approx. 600 readings/second. This is partly due to the idle times described above, in which no data is transmitted. In addition, the manufacturer specifies a limit of approx. 700 readings per second[15]. It is therefore possible that the performance limit is also due to the use of a commercially available reader.

In addition to the refresh interval of the individual tags, the cycle time required to refresh all transponders is important. Testing reveals that acceptable cycle times can be achieved up to a total of five tags (Figure 10).

Further measurements which have been described at the start of this chapter are performed on this basis. During the measurements several different tags were tested. Tags are available as linear polarized and as circular polarized tags.

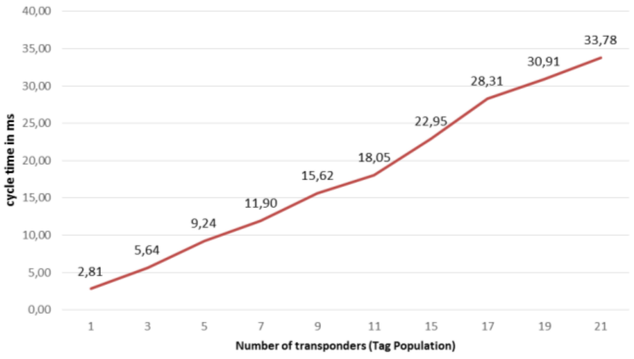


Fig. 10. Cycle times of RFID tags

They differ in performance, if an angle occurs between the antenna and the tags[19]. Figure 11 shows the performance of the Smartrac Dogbone, introduced in Figure 8. It summarizes the dependencies of performance, antenna distance and the number of tags in range. It can be observed, that a linear polarized tag does have a dependency of the horizontal angle between tag and antenna, as [20] also describes. This leads to the conclusion that positions of tags in the front end of the car have to be selected carefully, allowing only small angles, when using linear polarized tags.

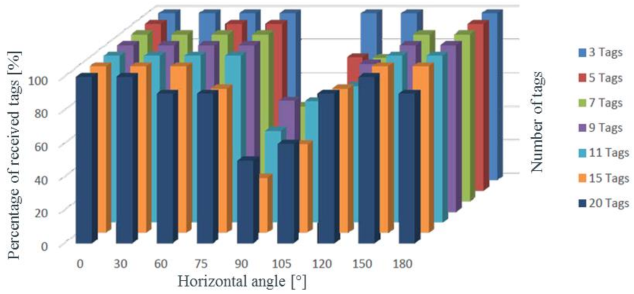


Fig. 11. Material dependencies

6. Algorithm

Data which are determined in crash tests (representing the accident scenario) under laboratory conditions form the basis for the generic development and vehicle-specific adaptation of airbag algorithms.

Many of these crash tests are stipulated by law. They not only serve to design airbag algorithms but to ensure and prove the protection potential of the vehicle. During the crash tests, the behavior of the vehicle structure and the crash-induced strain on the vehicle occupants are verified. These occupant values are determined using specially developed crash test dummies. To meet the requirements, various strain values at the head, the chest and other body parts must not be exceeded.

Both the type of the crashes to be performed as well as the maximum permissible strain values are defined worldwide by local legislators for their countries. This results in a variety of requirements which a passenger car must meet in order to be approved in the different markets.

In addition to the requirements stipulated by law, consumer test organizations have been founded world-wide in recent years. In the customers' interest, they test the protection potential of vehicles based on more stringent requirements and evaluate it with so-called star ratings. The most familiar organizations are EuroNCAP in Europe and the two test organizations USNCAP and IIHS in the U.S.[21].

The previous chapter shows that information regarding the point of impact on the vehicle, the vehicle destruction and its temporal sequence can be derived from the destruction of RFID tags during a crash. The spatial allocation of the transponders is in line with that of the sensors used today. Transponder identification is via their EPC. As the EPC has been matched to the tag position in the vehicle during production-side control unit calibration, the vehicle can assign each EPC received to the corresponding position in the vehicle.

To meet the various requirements described at the beginning of this chapter, this information must be evaluated such that it provides precise conclusions with regard to the accident event in question.

To do so, RFID tag installation in the respective vehicle must be such that the information provided is adequate to unambiguously differentiate between these different crash types on time. Using pattern recognition methods such as neural networks, the crash type in question can then be derived during real crash situations, and the deployment times required for the necessary restraint systems can be determined.

In the following, the process is illustrated using the load case differentiation between two typical requirements from the European requirements context as an example.

Both crash types are pure frontal crashes. One is the RCAR 16 km/h test. This is a requirement from the insurance sector which is used to determine the damage category for vehicle insurances. Given the low speed differential and therefore the low severity of the accident, no restraint device is required in this case to protect the vehicle occupants. By contrast, deployment of airbags or belt pretensioners is to be avoided 100% as this would unnecessarily increase the repair costs and therefore the amount to be covered by the insurance providers.

The second test examined is the ODB 64 km/h crash performed by the EuroNCAP test institute as described in Chapter 1. In this case, the accident severity is high. Correct deployment of the restraint devices is therefore essential.

To differentiate between both load cases, the RFID tags must provide sufficient relevant information. With regard to an algorithm based on tag destruction, this means that the tags must be attached to vehicle structures and components which are hit 100% in one case whereas in the other case the certainty of them not being hit is also 100%. These tag installation positions must be determined by simulating crash sequences for the specific vehicle, in this case a VW Golf.

In addition to the correct differentiation of the load cases, there is another decisive aspect: The deployment times required for the 64 km/h test are approx. 30 ms, i.e. correct differentiation before this point in time is imperative to enable timely deployment of the restraint devices. A number of simulations with different installation positions results in the constellation shown in the illustration below: one RFID tag each at the bumper (1,) cross member (2) headlamp (3), cylinder block (4), suspension strut mount (5) and bulkhead (6).

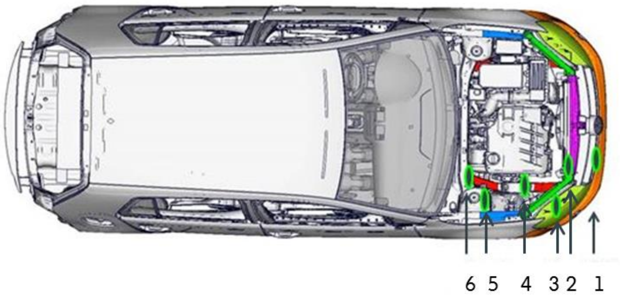


Fig. 12. Positions for RCAR 16km/h versus ODB 64 km/h

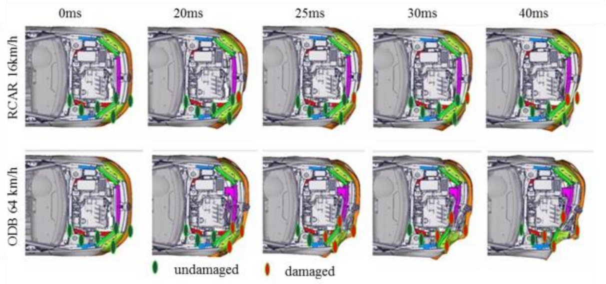


Fig. 13. Load case differentiation: RCAR 16km/h versus ODB64 km/h

When evaluating simulations of both crash types and analyzing the temporal sequence of the tag destruction, it is evident that only the tag at the bumper has been destroyed after 20 ms during the RCAR test. This is not followed by any further destruction until the tag at the cross member is hit after 40 ms. This behavior (minor damage pattern with slow progress) is typical of a low-speed crash. In contrast, the ODB test at 64 km/h shows clearly different results: After 20 ms, the first three tags have already been destroyed, 5 ms later the fourth tag (on the cylinder block) is also destroyed. This behavior, i.e. a major damage pattern with fast destruction is typical of a high-speed crash. In this example, a clear differentiation of the two load cases is possible after 20 ms to 25 ms, i.e. the restraint devices required can be deployed on time. The two remaining tags on the suspension strut mount and bulkhead are no longer required for differentiation. If only these two load cases were to be evaluated, they could be removed from the sensor set.

7. Conclusion

This paper describes a new approach to crash detection during accidents involving passenger cars. Sensor concepts on the market today generally consist of acceleration sensors. This measuring principle has various drawbacks that are to be eliminated by a new sensor concept.

As part of a technology search, various wireless radio technologies were examined with regard to their suitability for use in a crash sensor concept. Passive RFID tags meet most requirements to a very high extent.

Two different concepts to obtain information from these tags were examined and evaluated with regard to their suitability. A concept which involves measuring and evaluation of the temporal and spatial destruction of tags in the course of the vehicle crash was considered purposeful.

Using a specific example of two crash types, a concept for an algorithm based on this approach was detailed, and the fundamental suitability of the technology and algorithm was presented.

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