ENVIRONMENTAL PERCEIPTION FOR FUTURE INTEGRATED SAFETY SYSTEMS

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ABSTRACT

World wide social developments towards Mega-Cities, define future tasks for automotive safety systems. Advanced driver Assistance systems in combination with new preventive safety systems offer great potential for mitigating accidents, reducing accident severity and increasing occupant protection. Traffic in Mega-Cities is characterised by a much higher degree in complexity and dramatically reduced observation time. Thus, automotive safety systems have to face much faster decision requirements compared to present day cruse control systems. Hence, the capability to assess and perceive the actual driving situation in complex traffic situations is the key enabler for future vehicle comfort- and safety systems. The symbiotic exploitation of the electromagnetic spectrum by means of Radar- and optical sensors like Scanner and Vision sensors allows the comprehensive and precise detection even at adverse conditions. The article describes possible approaches.

1. INTRODUCTION

With the introduction of the first brake assist function and it´s logical next step the emergency braking system (e.g. PRE-SAFE Brake® in the Mercedes-S-Class) it became obvious that environmental perception is the key technology to pave the ground for a new era of safety functions. A combination of near- and far range radars was fused to provide the required environmental information.
The next step towards integrated safety was introduced with enhancement of our Pre-Safe Brake function with Pre-Crash capability in the new E-Calls in 2009. Based on the environmental perception of two short range radars, the Pre-Safe occupant protection means are triggered in case of a critical object approach [1]. Up to now, assistance functions on the market concentrate on the use of one single sensor technology like ultra-sonic-, radar-fixed beam lidar-sensors and mono-vision. Sensor fusion enhances the information of one single sensor technology, as e.g. long range radar and near range radars for collision mitigation, to a level which enables the function tasks. This is sufficient for functions which operate in clear driving situations e.g. highways and/or have to perform moderate actions like distance control.
Future comfort- and especially safety functions will more and more address urban regions with dense traffic and therefore have to perform more complex tasks in more complex traffic environments. Thus, the near and mid range distance of the vehicles environment will become more important along with a wider lateral observation horizon in order to cover e.g. crossing scenarios or classical pre-crash situations ind driving direction as well as side-crash situations. This imposes challenging requirements for the environmental sensing, since it translates into dramatically shrinking time scales in terms of observation horizons and reaction times compared to classical ACC and collision mitigation functions of today.
Hence, a much faster up-date rate combined with more detailed and precise information about the traffic environment in terms of localisation and object type is mandatory to allow for a reliable situation assessment. This can be achieved over a two way strategy. First, enhance the sensing performance of each environmental sensor technology in terms of higher spatial resolution towards wide field of view image like properties.

One approach could be the introduction of imaging capabilities to Radars. Add classification knowledge as one perception aid to the sensor information. Second, synergetic exploitation of the electromagnetic spectrum by fusion of different physical sensor technologies, like Radar, Camera or Lidar.
More sophisticated optical sensors like scanning Lidar and Stereo-Vision sensors have made a great stride ahead to meet vehicle relevant maturity and packaging constraints, which will make employment in vehicle systems very likely in the near future.

2. SENSORS

Radar sensors have long been the leading edge in vehicular remote sensing. They determine highly precise distance information and provide instantaneously the corresponding target/object - velocity at nearly all environmental conditions. State of the art radars operate in multi mode covering long and short range distances in one sensor. One field for optimization of todays Radars is the limited field of view along with limited angular resolution, which limits the precision of the target/object localization.
Recent developments in short range radar technology overcome these limitations and are very promising candidates also for side crash scenarios as introduced in section 3. Up to now radars suffer from limited classification capability. On research level, imaging radar approaches are investigated, which definitely will close these present performance gaps to make radar an utmost device [2]. The potential is described in section 4.
Advances in scanning Lidar technology make it an interesting candidate for remote sensing, which offers excellent spatial information along with an extremely wide field of view starting from ±45° up to ±120° and cover ranges from 0 up to 200 m. Recent filter development on the supplier side has enabled velocity information to be provided nearly simultaneously to the spatial information. Since Lidar is an optical sensor, it suffers like vision systems from a limited all weather capability. However, the high end Lidar versions e.g. from Hella KGaA Hueck & Co, have considerably improved even in this area. The high information density allows much better object localisation including dimension and orientation information of the objects. As long as no classification information is required, they could operate as the ideal tandem arrangement to a radar. A very prominent example is described in section 5 for crossing scenarios where a very fast wide field of view and very precise object localisation is required to allow for pre-crash detection.

Vision systems add those information, which cannot easiliy or even never be provided by Radar or Lidar systems. Such as classification information lane-prediction, traffic sign recognition or classification of pedestrians, cylist, vehicle-type etc. . Thus, depending on the safety or comfort function to be realized, vision is the necessary supplement to both Lidar and Radar. Some approaches are described in section 6.

3. FUSION CONCEPT FOR SIDE CRASH SENSING

Viewing the last years, active and passive car safety systems have improved considerably. A lot of active driver assistance systems that support the driver are available on the market. These systems help to reduce the risk of accidents, but in some cases an accident is unavoidable. In these situations passive safety systems, like pre-crash systems [3;4], protect the passengers by activating restraint systems, e.g. reversible belt pretensioners [5].

Radar, LIDAR or camera sensors provide the basis for these applications. By now, most of these safety systems have a benefit in detecting front- and rear accidents. Figure 1 shows that front- and rear-accidents make up only 45% of all accidents causes. To protect the passengers in the 55% not covered by front- and rear sensors, another sensing scheme, possibly up to 360°, is necessary.

Figure 1. Accident impact angle statistics [8].

The importance for 360°-sensing shows up among others in EURO- and US-NCAP crash tests (see figure 2), which are based on crash statistics and cover the most usual accidents, including side crashes (car to side and pole impact). Although the severity of these accidents is reduced by passive safety structures, the passengers will benefit from electronic safety systems, which mitigate the consequences of the crash even more. Using a 360°-sensing method, not only the behaviour in crash tests, but the overall performance for real life safety [6] can be improved.

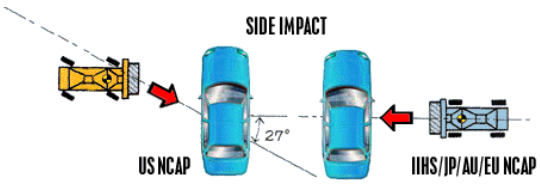

Figure 2. Example of European (EURO-NCAP) and United States (US-NCAP) side impact crash tests [9].

Sensor setup

To cover all accident causes, as shown in figure 1, a sensing method has to be incorporated to observe the car's entire environment. This can only be achieved by either a lot of sensors, or as pursued in this approach, a few sensors with a wide field of view. In addition to that, the sensors must work reliably in all weather conditions like rain, fog or snow. Weather conditions are still a problem for optical sensors like camera and LIDAR, whereas radar sensors can cope with bad weather conditions quite good. Until today, the field of view of automotive radar sensors is typically up to 80°, which is better than that of common cameras, but not sufficient for sensing more than just a small part of the car's surrounding. As radar technology advances and sensors get cheaper and better, radar sensors with a field of view of 150° and a range up to 60 m are becoming achievable. Suitable sensors, fulfilling the requirements for automotive side- or 360°-sensing are the multi-beam radar sensors provided by Valeo, which will be used here. To perceive the environment of the car, 4 of these multi-beam radar sensors are used. They are mounted on the corners of the car and placed invisibly behind the bumper. The surveillance region of the sensors is show in figure 3. With this sensor setup the environmental sensing of both car sides is possible by using only 4 sensors that cover mostly the entire car environment. Although not addressed here, other applications, e.g. front- and rear pre-crash, lane change support, and blind spot monitoring, are also addressable with this setup.

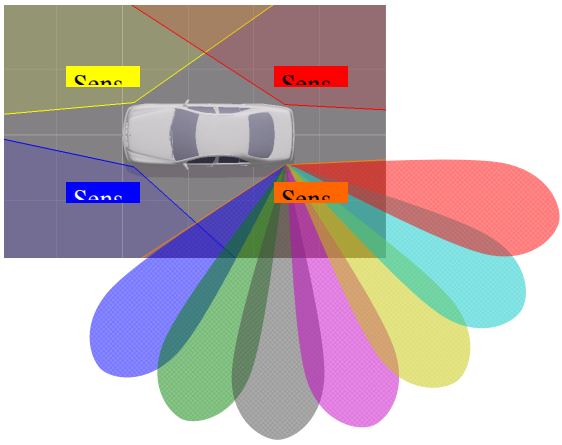

Figure FSZ3. Experimental setup of a test car using four multi-beam radar sensors.

Subsequently a suitable pre-processing technique, the multi-sensor fusion and the performance of this sensor setup will be shown.

Pre-Processing

The target detection list of each sensor is traversing a pre-processing algorithm before being incorporated in the main multi-sensor fusion.

Each sensor has seven beams where up to three beams have overlapping detection areas. Thus, such a multi-beam radar sensor may detect targets with larger radar cross sections in more than one beam. One way to cope with this, while still using a one-to-one data association algorithm, is to integrate the data sequentially (beam by beam) in the multi-sensor fusion. Another approach, which is taken here, is to pre-process the data to reduce the number of computations necessary in the fusion process. The pre-processing algorithm is shown in Figure 4.

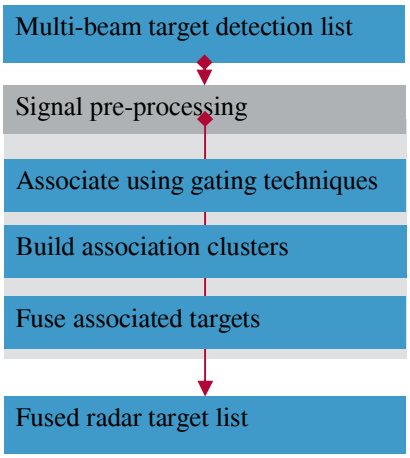

Figure 4. Multi-beam radar sensor signal pre-processing.

The first step in fusing the multi-beam target detection list is finding target-to-target associations with a nearest neighbour algorithm. The next step involves the building of association clusters [see JPDA clustering]. An association cluster contains all detections that have associations in common, e.g. Target 1+2, Target 2+3 → Cluster Target 1+2+3. With this information at hand the target list is then fused, hereby reducing the measurement errors of targets sharing multiple detections. Using this technique, the overall target count is reduced as well. An example of the outcome of the algorithm is shown in figure 5. Targets are pictured by rectangles, the measurement accuracy is shown by the 3□-ellipses, and detections of different beams can be distinguished by colours. The resulting target with smaller covariance is shown using a dotted line.

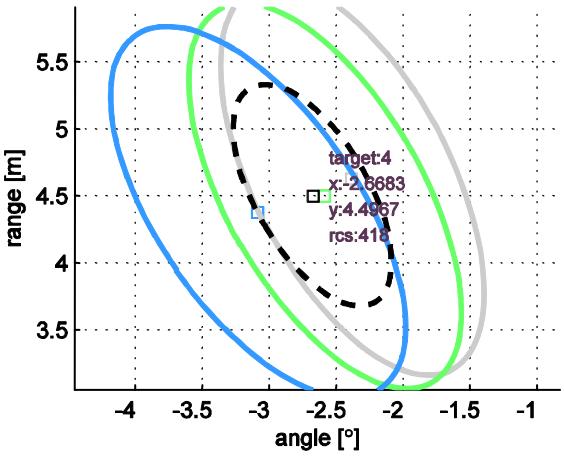

Figure 5. Example of a target which is detected by three beams. Beams are plotted using colours as seen in figure 3; the fused target is plotted using a dotted line.

The pre-processed data is then integrated into the multi-sensor fusion described in the next section.

Multi-sensor fusion

The multi-sensor fusion is realized using a multi-sensor multi-target tracking with the common technique of Kalman filtering. Figure 6 shows the sequence of the fusion process.

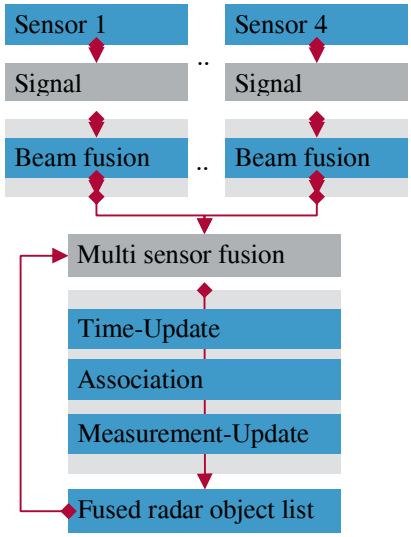

Figure 6. Multi-sensor fusion method for 360°-sensing.

The pre-processed target list data is integrated sequentially as follows. The track states of the system are predicted to the current measurement interval. Using the calibration data of the sensors, the new sensor measurements can be mapped to the car's coordinate system and vice versa. This way a measurement-to-track association is made and the measurement update of the Kalman filter is calculated. In this approach an extended Kalman filter is used for the estimation process, the measurement vector consists of the entries range, bearing and Doppler velocity. The Doppler information, the direct measuring of target speed which is a benefit of radar sensors, is used to initialize the state of the tracks [7]. This technique avoids wrong associations that result from the great velocity uncertainty if only position measurements where used. Filter settling times are also reduced, hereby improving the overall performance of the estimation process.

Triggering restraint systems

The demo vehicle, used to verify the algorithm's performance, has active seat belt pretensioners, but other actuators could be used as well. The actuators will be triggered just before an imminent crash is detected to reduce the severity of the accident. The position and velocity information of the estimated tracks is used to calculate a time to collision (TTC), and the point of impact (POI). In this approach a propagation of the covariance in time and space is performed, resulting in time (→TTC) and space (→POI) probabilities. The fused radar object list serves as input to this detection module, which is subsequently used to trigger restraint systems (see figure 7).

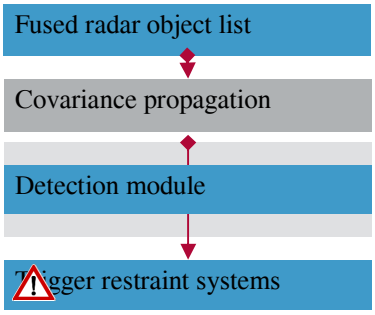

Figure 7. Decision algorithm for triggering restraint systems based on a fused radar object list.

Testing the algorithm with non-destructive tests is quite demanding, as own ship vehicle and target motion is highly dynamic. For testing the 360°-sensing capability of the presented system, a test facility on proving ground will be put into operation soon. By using this setup, predictable and repeatable test data will be gained and overall system performance in these challenging situations can be evaluated.
Side crash sensing is being deduced by the ever increasing safety functions in cars. New generation of radar sensors provide wider field of views, which are necessary for 360°-sensing, as well as further driver assistance systems. The packaging for automotive use is easy, because the sensors can be mounted invisibly behind the bumpers. The pre-processing of multi-beam radars reduces the demands on computation time and improves sensor accuracy. The multi-sensor fusion approach shown here is suitable for side-sensing, but is independent of the application.

Figure 8. Demo vehicle (Mercedes S-Class) with grill guard

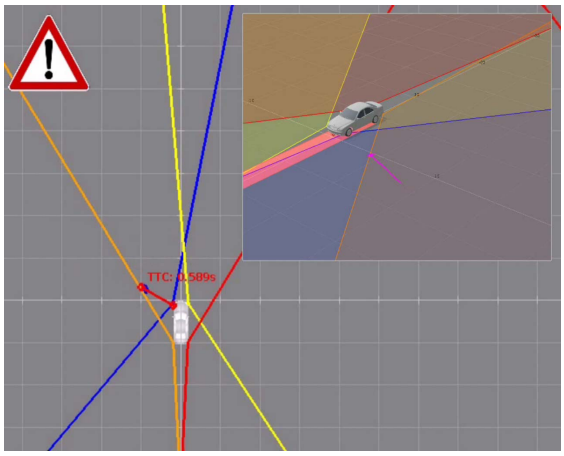

Figure 9. Example of an impact detection. The object is approaching the demo vehicle at an angle of approximately 60°.

It can be generalized to support front- and rear-precrash functionality and thus provides the basis for an automotive 360°-surveillance for a new generation of car safety functions.

4. Imaging Radar potential

Due to a variety of important advantages radar sensors have become common in driver assistance systems for about a decade. E. g., the robust performance even under poor weather conditions like fog or rain. Beyond these aspects, in contrast to lidar and camera sensors radar sensors can measure radial velocity towards the ego vehicle directly by the evaluation of the Doppler shift of the reflected electromagnetic wave. Another competitive edge of radar sensors is the measurement accuracy of the distance to other objects in a traffic scene. It can be

determined more accurately by radar than by stereo cameras, especially at mid to large distances and vehicle relevant stereo bases. These aspects are summarized in table 1.

Table 1.
Comparison of automotive sensor systems

	video	radar	radar (scanning)	lidar (scanning)
distance resolution	-	+	+	+
azimuth resolution	+	-	O	+
velocity measurement	-	+	+	-
weather robustness	-	+	+	-

Although radar sensors are commonly used in series vehicles for Adaptive Cruise Control (ACC), there is still demand for optimization. The determination of distance and velocity of other non-stationary vehicles is precise enough for the basic functionality of ACC.
However, former radar sensing technology had its limitations concerning ACC applications. A crucial point for the distinction of relevant stationary objects in the lane (e. g. at the end of a traffic jam) from irrelevant objects like traffic signs is the robust recognition of the oncoming lane course. Moreover, stationary objects have to be perceived separately from the road boundaries. This could not be achieved robustly by former radar sensors due to their comparatively low field of view and low resolution of the azimuth angle. Consequently present ACC systems only react on moving targets or stationary targets that have been seen in motion before.
On the other hand, there are radar-based driver assistance systems reacting on stationary targets as well. In the case of a possible collision with a stationary obstacle these systems warn the driver and e. g. activate the belt pretensioner. As soon as the collision becomes inevitable, the vehicle brakes autonomously and so mitigates the oncoming collision.
The inclusion of stationary obstacles in ACC functionality and the precise determination of the point after which a collision with a stationary obstacle gets inevitable are two examples for the importance of improvement of radar measurement accuracy. Autonomous breaking reactions as a severe intervention into the guidance of a vehicle may only be initialized when the driver does not have the chance to avoid the collision by steering any more

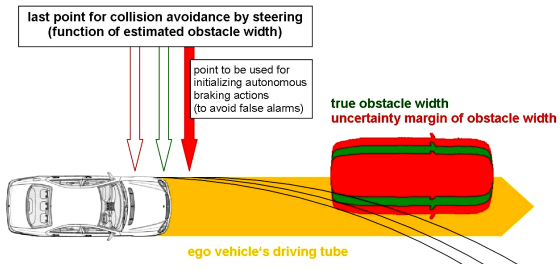

Figure 10. Relation between estimated obstacle width and the point to be used for initializing autonomous braking actions.

Figure 10 shows the relation between the lateral offset a vehicle has to build up for collision-avoidance with an obstacle and the last point at which the driver has the chance to avoid a collision by steering.
Not only the requirement of accurate measurements of single objects for collision mitigation systems leads to the need for enhanced sensor performance. The transfer of driver assistance systems' functionality from simple highway scenarios to highly complex urban scenarios in the typical Megacity of the 21st century requires the robust perception of highly complex traffic situations.
Robust means availability of service even under adverse weather conditions as well as highly precise localization of objects. For this reason, perception performance of radar sensors have to be further optimized. Radar may also benefit from vision systems and their better azimuth resolution. Object classification information, if required, can also be provided by camera systems. However, vision usually suffers from poor robustness under bad weather or backlighting conditions. Research activities investigate the fusion benefit (see section 5). Therefore, new radar approaches are the key. Whereas former radar systems only registered single points of reflections from the environment, imaging radar systems now provide a detailed image of the environment. Providing angular resolutions of about 1° they are already installed in series-production vehicles. Figure 11 shows an image from a mass-produced imaging radar sensor as the representation of a traffic scene. The new degree of detail leads to new chances and challenges in processing radar data. Research activities are trying to evaluate the performance of image processing algorithms used for the processing of radar images. In this connection, radar-specific characteristics have to be accounted for. E. g. the noisy raw data

from imaging radar

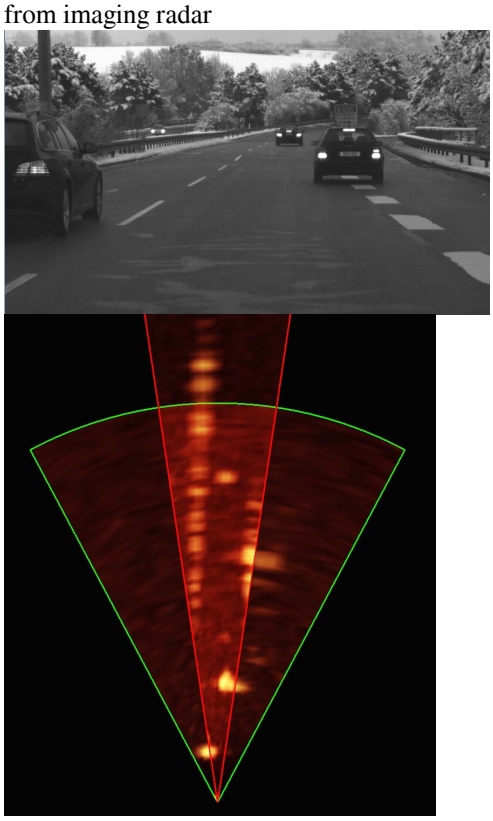

Figure 11. Image from an imaging radar sensor (red bordered area: long range radar, green bordered area: short range radar). The three vehicles and the lane boundaries (above) are clearly to be seen in the radar image (bottom). Integrating raw data over time or evaluating the Doppler shift of moving objects are only two possibilities to increase perception robustness.

sensors can be integrated over time, leading to an improved signal to noise ratio as sown in fig. 12. The radar image on the left (middle) shows the raw radar image of the scene (top) with a significant amount of noise. The radar image on the right (middle) is integrated over time. Here, the image from preceding measurements is weighted with 0.9 and the current measurement with 0.1, leading to significant noise reduction. As a consequence, this step can increase the robustness of following radar image processing steps. After a following Prewitt edge detection size and position of the two vehicles in front of the ego vehicle can be seen more clearly in the integrated image compared to the raw data image (bottom). The picture also shows radar sensors' capability to perceive vehicles hidden by others. Whereas the car in front of the nearest car can hardly be seen in the video picture (top),

Figure 12. Images from an imaging radar sensor without (left) and with (right) integrating raw data over time before (middle) and after (bottom) the application of a Prewitt edge detection algorithm.

it can clearly be seen in the radar image (middle/Bottom).

Another radar-typical benefit besides direct velocity measurement is the height determination of targets. The height of targets may be determined from the evaluation of the radar cross section (RCS) value over time (see fig. 13) [11]. There are also approaches trying to distinguish artificial from natural objects by evaluating polarisation differences of radar reflections [11].

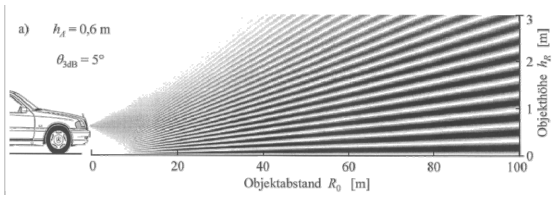

Figure 13. Waves emitted by continuous wave radar sensors lead to a typical, height-dependent interference pattern. The height-dependency may be used to distinguish relevant obstacles with low height from higher located irrelevant objects like traffic signs [11].

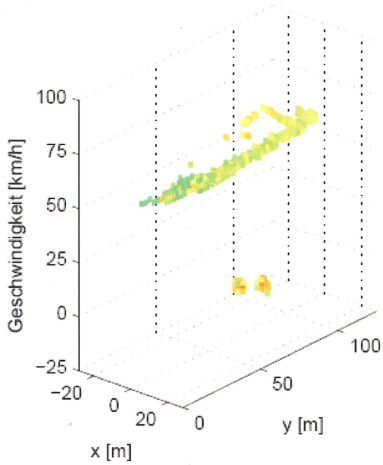

Figure 14. Three-dimensional statement of measurement data in lateral and longitudinal position and speed (here on the vertical axis) [10]. Including height information would provide a forth dimension for segmentation.

In a nutshell, treating data from imaging radar comes with its own challenges and chances. The most important challenge is the still comparatively bad angular resolution of 1°, usually. On the other hand, the directly measured radial velocity of targets (see fig. 14) and the determination of target height provide new dimensions for segmentation and object separation. Object classification strategies may be supported by evaluating polarisation differences of the reflections.
The increased necessity for computational power by new signal processing algorithms will be compensated by Moore's law – falling prices for computational power will help to achieve the aim of improved perceiving performance for future driver assistance systems.

5. Fusion of Laserscanner and Short Range Radars for Pre-Crash detection

Scanning laser devices emit laser pulses bound to fixed angle steps. Reflected by objects in the environment they generate distance measurement points using time-of-flight calculation. Because angle steps range from few degrees to a fractional amount of a degree, respectively, a multitude of reflections originates from a real world object, what leads to complex environmental scans showing the contours of real objects. Figure 15 shows an example. Large parts of the truck are simply not visible to the radar sensors (bigger circles), whereas the laser scanner perceives its dimensions (small dots). The ability to perceive object geometries together with a high measuring accuracy in position and a large field of view makes the laser scanner a profoundly appropriate device in a perception system utilized in complex environments like intersections and inner city areas.

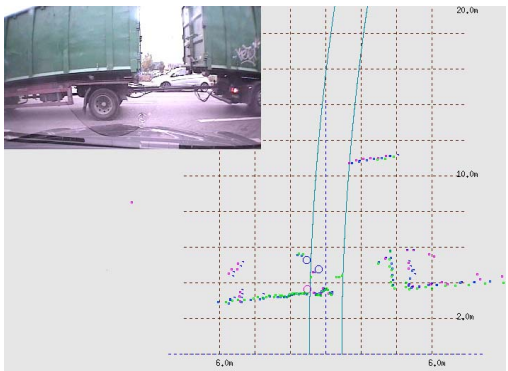

Figure 15. Environmental scan example. Single laser echos are shown as dots, the bigger circles represent radar targets.

Nevertheless, laser scanners as well as other optical sensors are sensitive to pollutions and bad weather conditions like heavy rain, snow or fog. A combination with radar sensors can provide support in order to make the complete system more robust. Another advantage of radar sensors is the capability to measure velocities directly whereas for laser scanner data the velocity information has to be derived from changes in position. With a skilful sensor data fusion the advantages of both sensor types can be combined to achieve a precise estimation of position and dynamics parameters of surrounding objects enhanced with dimension information with preferably short delay.
Depending on the used sensors and the requirements on the application, data fusion can be realized on different levels. Thereby, it is distinguished between signal level, target level (=midlevel) and object level fusion. In case of laser scanner in combination with radar sensors the different sensor principles exclude a fusion on raw data level due to missing correlations between single laser reflections and radar echos. Fusing on target level systematically

combines the advantages of each sensor that is, on the one hand, the precise position estimation provided by the laser scanner, and, on the other hand , the velocity estimation provided by the radar sensors.

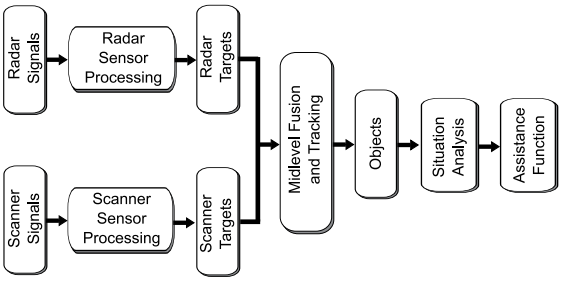

Figure 16. Target level fusion architecture

Figure 16 gives an overview of the system architecture. Data capturing is followed by a preprocessing step for each sensor separately. For the radar sensors preprocessing is the target formation from different echos. The preprocessing of raw laser scan data includes the segmentation of the point clouds followed by the feature extraction from the several segments.

Segmentation is performed using a grid-based approach. The design of the (radial) segmentation grid is based on the measurement principle of the scanner. Cell size increases with the distance to the scanner and the absolute value of the angle [12] [13]. In a first step, all scan points are projected onto the grid. In a second step adjacent occupied grid cells are melted together to form a segment.

A feature extraction step reduces the amount of data and generates object hypotheses that comprise information about position, orientation and dimension. The calculation of possible occlusions and the extraction of further segment describing features like convexity, compactness, aspect ratio, etc. are tackled in this processing stage as well.

Laser and radar targets are combined within a measurement vector fusion. For object tracking and object formation well-known Kalman-Filter techniques are used [14]. If measurements of both sensor types are within the gate of a predicted object a fused measurement updates the existing track. The property of the laser scanner to detect expanded objects necessitates investigation in special cases in the fusion step. If radar targets are located within a segment box, but far away from the reference point, the measurement vectors of both sensors are not fused in order to avoid high jitter in object tracking. Nevertheless, the information about the object being detected by the radar sensor at all, is not discarded, but can be used for object validation, afterwards.

Within the framework of APALACI (Advanced Pre-crash and LongitudinAl Collision mitigation), a subproject of the European Integrated Project PReVENT, an application that recognizes frontal collisions with stationary objects was developed based on the described architecture [12]. During the project a host vehicle was equipped with sensors, actuators and processing hardware to run the application in real-time (see Figure 17). The laser scanner has been mounted below the number plate covered by a black plastic faceplate that is transparent for the emission wavelength, thus it integrates into the car's design. In case an unavoidable collision is detected to happen within the next 200 ms the system triggers reversible belt pretensioner which bring the passenger into an upright position.

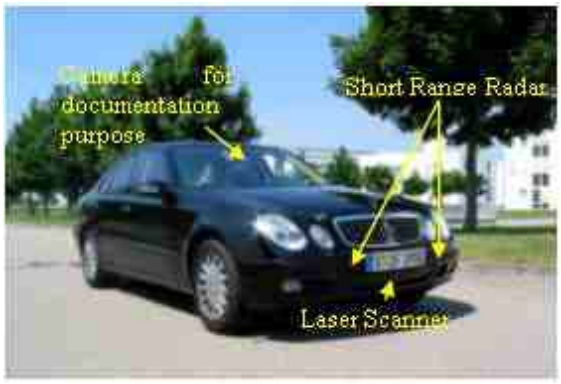

Figure 17. Experimental vehicle

The application has been validated in complex crash and non-crash scenarios conducted at a test site with foam cubes and cylinders as obstacles. The scenarios comprise factual and near missed collisions with stationary objects at different velocities, in curves, with deceleration, sudden lane changes and lane changes of a leading vehicle obstructing the sight to the obstacle. In total, the results were a false alarm rate of 1.1% (1 out of 95 test runs) and a missed alarm rate of 6.9% (7 out of 102 test runs). For a complete description of the test catalogue and a discussion of the results we refer to [13]. Furthermore, the application was tested in normal traffic on highways, rural roads and in urban areas. All in all, a distance of 1600 km was covered facing adverse weather conditions like rain, fog as well as different driving situations like rush hour, traffic jam and stop-and-go. No false alarms occurred during these tests.

Ongoing research investigates in refining and further improving the sensor data processing and fusion methods in order to provide advanced driver assistance functionality especially with regard to more complex and dynamic environments. Today's assistance and safety functions have to work in a very restrictive way in order not to risk severe false

alarms due to driver acceptability and product liability reasons [15]. Therefore, the development of algorithms for environmental perception aims at detecting impending threats both quickly and reliably. Providing further information about surrounding objects in excess of position and velocity like dimensions and possible occlusions helps to classify objects and facilitates situation analysis.

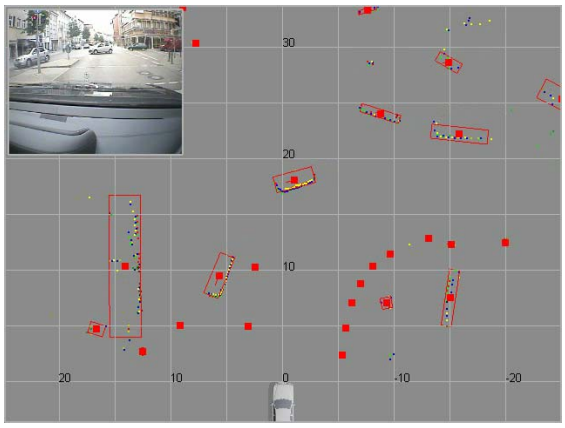

Figure 18. Sample data captured at an intersection and processing output. Red boxes represent confirmed tracked objects (stationary and moving)

Figure 18 shows results of object formation by means of a sample scene captured in city traffic. Object dimensions and orientations are calculated from laser segments and filtered over time. A small line at the object's middle point corresponds to the velocity vector, thus marking a moving object. The process of deriving good object state estimates from laser data can further be improved by a fusion with radar data. Laser objects form a region of interest where to look for radar targets. If radar targets are available, the (relative) velocity can be initialized directly with the Doppler information.

6. Sensor Fusion of Radar or Lidar with Mono-Vision for Pre-Crash detection

6.1 Sensor Setup, Alignment and Preprocessing

Future driver assistance functions will perform fully autonomous interventions like automatic emergency braking or the triggering of occupant restraint systems even before the crash happens. In comparison to today's assistance functions, an increased degree of certainty is required for the environment perception subsystem in the object state estimation domain and - even more important - in the object existence and classification domain. One way to achieve this reliability is the fusion of multiple sensor data. In this context, a fusion system overview with ranging sensors and a monocular video camera is presented. For the ranging sensor part, radar and lidar are exchangeable. A requirement for each sensor fusion setup is a spatial and temporal sensor alignment. A hardware synchronisation of both sensors was chosen, as it is the optimal choice with respect to inter-sensor data association and computation time aspects. However, all future serial sensors intended for sensor fusion systems must provide any mechanism for temporal alignment, whether it is an external measurement trigger signal input or the generation of timestamps in relation to an external master clock in free running mode. The spatial alignment is computed with novel calibration procedures published in [16].

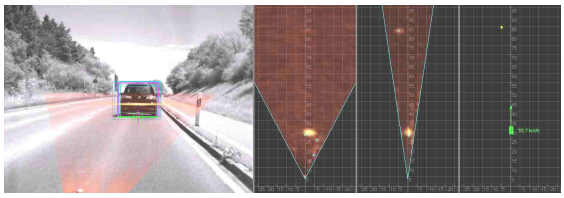

Figure 19 Sensorfusion with Radar and Video. The ranging data is associated with the image and measurements from both sensors are used for target tracking (right).

Using this alignment, the signal processing stage first projects the lidar or radar measurements into the image domain. The image regions containing an echo are further processed with a cascaded Boosting classifier based on Haar-like features [17]. This detection strategy combines the longitudinal position accuracy of the ranging sensors with the lateral position accuracy and the object classification performance of the video sensor. Beside these state refinements, a cross-validation of detections from both sensors increases the reliability of the environment model. In comparison to usual ranging sensor based systems, the presented sensor setup is not limited to moving objects.

Figure 20 Sensor mounting positions

6.2 Sensor Fusion Algorithm

The sensor independent fusion framework has a kernel-based design. The independent sensor modules deliver their measurements to the fusion system using their own measurement frequency. Each sensor module uses the same interface to the fusion module consisting of measurement vector **z**, corresponding uncertainties **P** and sensory existence measurements p_s. The fusion system uses the JIPDA method [18],[19],[20] for estimation of state and existence based on these measurements. Therefore, any optimization for the sensor setup is made in the sensor specific part of the models and the fusion kernel is completely sensor independent. The framework implementation comprises a complete existence probability based track management module, state and existence tracking. Furthermore, track splitting and merging can also be realized in the central track management module. Sensor modules need to provide measurements and have to implement a possibility to create and initialize new tracks according to the decisions of the fusion framework.

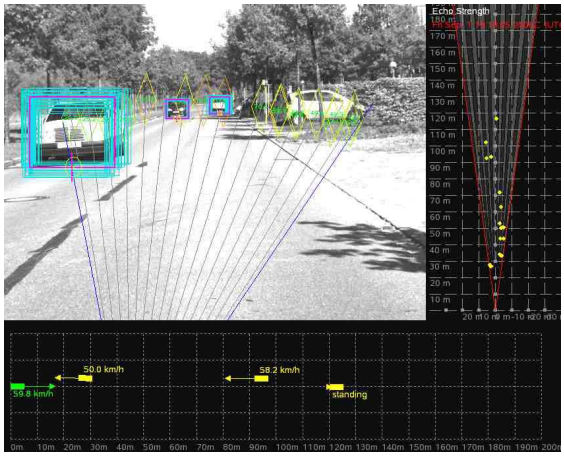

Figure 21 Lidar-Video sensor fusion: The Lidar echoes (top right) are projected into the image domain (top left). The image processing (cyan boxes) classifies objects as vehicles. Even non-moving vehicles can be tracked in distances up to 100 meters (bottom).

7. Conclusion

Introducing the PRE-SAFE Brake preventive protection system in the S-Class 2002, launched a system that for the first time employed the critical assessment of a vehicle´s driving dynamic state prior a propable impact for activating reversible safety counter measures. In 2009, the system has been enhanced in the new E-Class by the capability of the vehicle to monitor its near range environment to detect very likely collisions. This is the first step into real Pre-Crash situations and hence a great stride ahead towards urban area relevant safety functions. Further more effort is needed to fully exploit the potential of safety functions for dense traffic like f.e. Mega Cities. The paper has outlined that radar sensors will continue to be the key-technology and backbone of future safety functions. Especially Imaging Radar capabilities and intelligent fusion techniques will enhance the power of radar based safety systems. Assisted by optical sensor technologies, environmental sensing will be prepared to pave the ground for the safety needs in the future.

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