A Multifunctional Automotive Short Range Radar System

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Abstract
The paper presents a 24GHz radar system which has been developed since 1997 by s.m.s smart microwave sensors GmbH in close co-operation with Volkswagen AG. A number of test cars have been equipped with this multi-functional system. It was designed to detect objects in the vicinity of a vehicle, either only at the front and/or at the back or even with full 360° coverage. It uses distributed small and intelligent radar units and performs detection, tracking, object classification and data fusion algorithms using latest DSP technology. Not only parking aid, but also blind spot surveillance, ACC support and pre-crash sensing applications can be realized.

Introduction

In the recent past 77GHz radar systems have been introduced in the passenger car market. The first application for those radars was the ACC (Adaptive Cruise Control) function. It was implemented as a new comfort feature in the cruise control systems which before did not control the distance to the vehicle ahead [2].

Technology in this frequency range is still quite expensive, and if it was possible to apply 24GHz radars for the application, the ACC systems would be much cheaper. But for those “long” range (1...200m) applications the 24GHz ISM-Band technology is not suitable, because of the large antenna apertures which would be required.

The 77GHz systems, however, have one significant disadvantage, too: all systems on the market or under development usually cover only a small angular section (typically 10...15°) in front of the car. Hence, even simple stop&go scenarios can not be handled with those systems, because after a “stop” situation, the radar is not able to scan the full width of the lane for obstacles (in particular at short range) to enable the “go”. The reason for this is the layout of the antenna, which is designed to have a high gain and to provide a good signal-to-noise ratio even with reflections from distant targets.

Even if the antenna was redesigned and made broader, there will never be a realistic chance to cover more than 60-120° with only one central sensor in front of the car. For the intended applications at “short” range (0...20-40m)

- ► Parking Aid
- ► Blind Spot surveillance
- ► ACC Support
- ► Pre-Crash Obstacle Detection

a system design which used distributed sensors appears to be much better suited. A 360° coverage becomes possible. Moreover, with the inexpensive 24GHz RF frontends, combined with low-price automotive DSPs the cost is not very high.

The Radar Network

Thus a network comprising up to 20 distributed radars (“Sensor-Processors”, see Figure 1) and a central ECU was designed and built up. The number of radars can be determined by the car manufacturer and can be adapted to the mechanical conditions of the equipped vehicle type. The software in the central processor is prepared to handle any number of sensors between 1 and 20.

Each individual radar measures range and speed of all detected objects. It does not determine the angular position of the object. The target data are transmitted via CAN. The calculation of the exact position is done by the central processor in a sophisticated triangulation and tracking algorithm. The central processor does also perform the communication with the vehicle, controls the HMI, in particular the "Parking Aid Bar Displays", and synchronizes all sensors. The cycle time can be made as low as 10ms, or even faster, depending on the desired range interval.

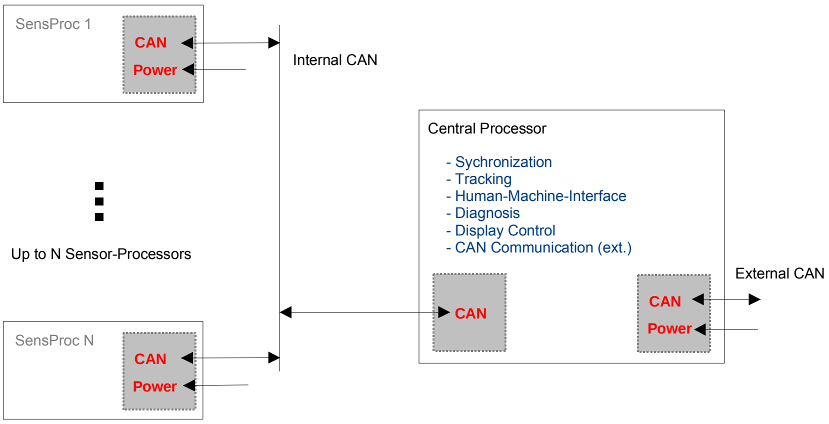


Figure 1: The network of radars consisting of Sensor-Processors and the central ECU

The radar system uses multi-mode-operation. This means that it can be switched from (the very demanding) pre-crash mode to (the more simple) parking aid or any other mode. It is also possible to run combined modes, like for instance ACC support and blind spot detection at the same time. In the very versatile system the operational mode and all parameters can easily be remote-tuned via a digital bus (CAN was selected here). Downloading new software via the same digital bus is also an interesting feature.

Applied Sensors

The applied radar RF frontends were manufactured by AMP M/A-COM. The different RF signal waveforms, the timing as well as the analog and digital signal conditioning are done by the perfectly adapted DSP board which is placed inside the sealed sensor housing. This board and all software (both for Sensor-Processor and central ECU) was made in Braunschweig, Germany, in the labs of s.m.s GmbH. The individual sensors are fully self-calibrating and precisely determine range and speed of multiple targets under all conditions.

The continuous development will lead to a commercial product in the near future. With the expertise in waveform design and adapted signal processing, which was collected during the course of the development of this multifunctional system, the application of other types of frontends is also possible.

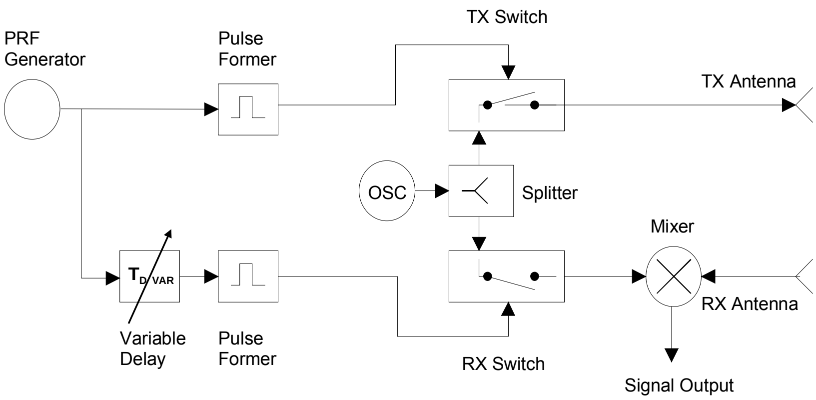


Figure 2: Structure of the Applied Sensor

In the Figure 2 the structure of the actual RF frontend is illustrated. In the displayed scheme, it operates in pulsed mode using ultrashort pulses, thus assuring a high range resolution. Below some technical data are given:

Parameter	Value
Carrier Frequency	24.125GHz
Range Interval	0.1...20m or up to 40m
Range Resolution	0.2m
Range Accuracy	Typ. 0.01m
Antenna Type	Patch Antenna
Field of View	70° (Azimut) 16° (Elevation)
Size (including processor)	140 x 90 x 35mm (WxHxD)
Cycle Time	typ. < 10ms

The software for the target detection, which runs in the Sensor-Processor, is completely separated from the software in the central processor. Thus the multifunctional central triangulation, tracking and classification software could also include the data of other types of sensors in its situation analysis, or could read the results from the 77GHz ACC sensor and include it in the data fusion.

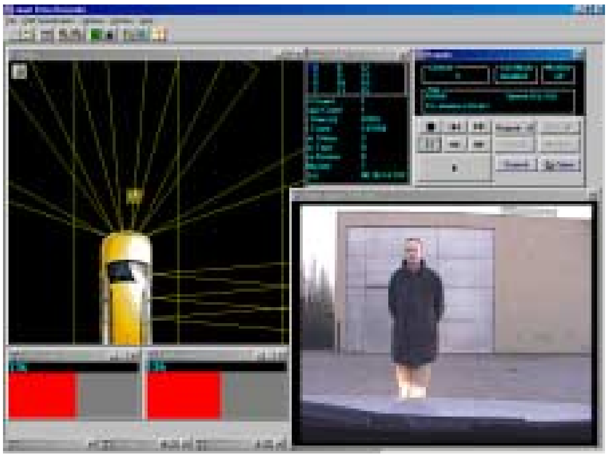
With the very short pulses, the radars operate quite well in parking aid mode. Even under 20cm distance, a target is reported present although its range cannot be precisely determined. Above this value, an accuracy of 1cm can be achieved in most cases. The high range accuracy and resolution is essential for the applied triangulation principle, otherwise false interpretations might occur.

Experimental Results

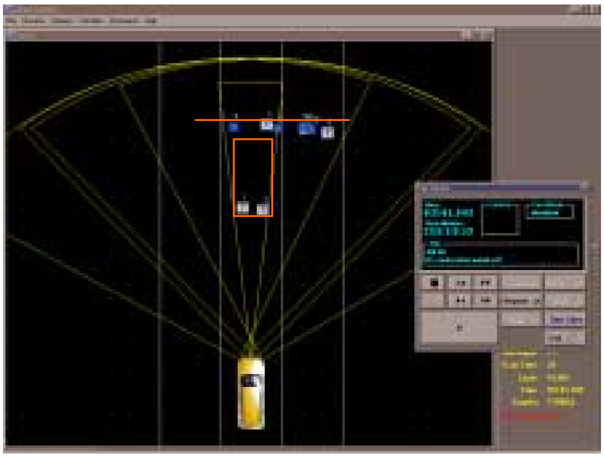
For the applications parking aid, blind spot detection and ACC support (for the stop&go function) some results are shown below.

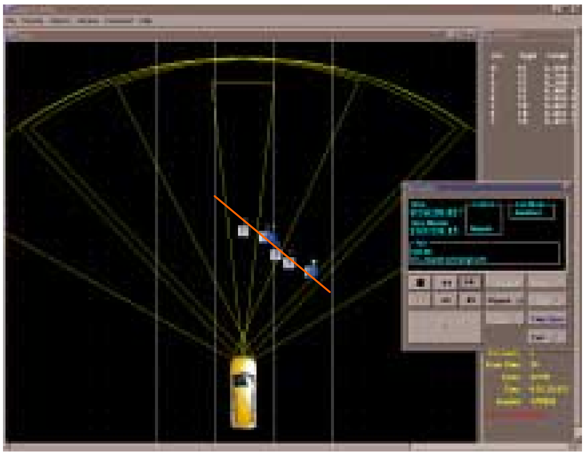
In the first three figures, a typical stop&go or parking aid scenario shall be represented. As can be seen video image, a person is present at different positions in front of a car. The bird's eye view displays the position of the individual radars, their aspect angle with respect to the vehicle's axes and finally the target returns. Note that the field of view of each radar is shown narrower than the true azimuth angle for a better overview. The red bars at the lower left side of the screenshot represent the "Parking Aid Bars", known from some upper class cars. Those bars show the same behavior as the backlight LCD bars in the car. At full length, an object as close as 20cm is present, zero means 3.5m.

While in the first two figures only targets of the individual sensors are displayed, the third figure shows the final result of the triangulation and tracking – a very reliable position information of the detected person. 9 sensors were used to cover a 180° field.

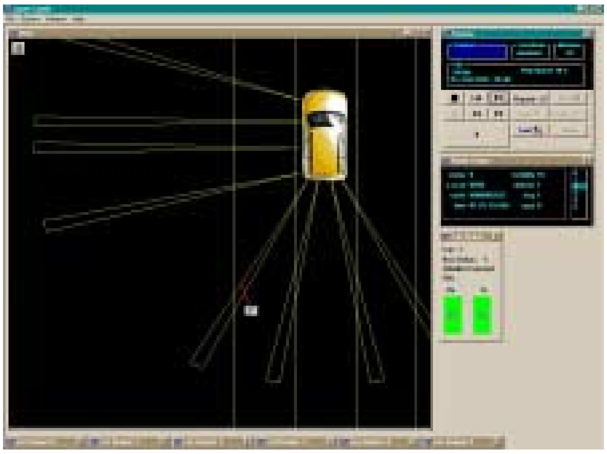


The following figures show two different situations: in the left picture a parking car is illuminated from the back. It is standing in front of a wall. And in the right figure, the test car was brought into a position where the wall was illuminated at an inclined angle (see the illustrated positions of the wall and the car, represented by the lines). In these pictures, the true azimuth of all four radars is sketched with a range of 20m. The ACC sensor's field of view is also displayed up to that range.



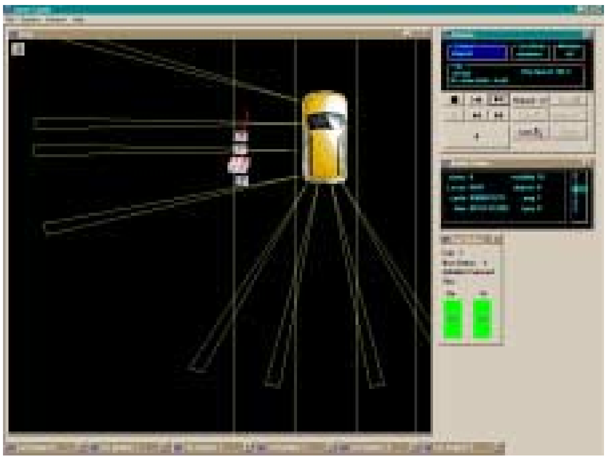


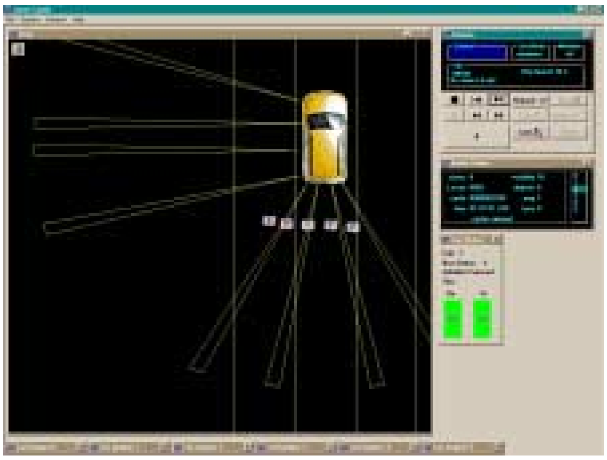
In the next figures a different setup was selected, eight radars were placed on two sides of a test car to cover a 180° section beside and behind the car. At first a walking person is displayed, its (small) relative speed vector is given by the line pointing in the direction of the movement. Secondly, an MPV was slowly moved beside the test car, its position and the direction of the movement again can be deduced from the figure.



In the last image, the same MPV is standing behind the test car at a fixed position sideways across the road. Although the complete shape of the vehicle can not be given from the radar returns, the position and the angle of the side panel of it can clearly be deduced from the picture.

These figures are a good demonstration of the high resolution of the radar system.





Beside the tests on automobiles, the feasibility of other applications has been tested. One system was working quite successfully on a subway train for an automated train coupling system, here the range between the two cars needs to be measured very precisely. Beside the distance measurement for the coupling procedure, the sensor system also reported obstacles on the subway train's track.

Outlook

A number of radar systems have successfully been built up to test different applications with this multi-functional system. It was shown that it is feasible to reliably detect targets for parking aid or in ACC support mode. Reasonable results were obtained in the blind spot surveillance, based on a system using too few sensors having only a small sensitivity. With only four radars, excellent detection results could be recorded during the tests of the subway system (mainly because of the huge radar cross sections of the objects to be detected). The feasibility of all desired applications, except for the pre-crash detection was proven.

The very demanding pre-crash mode is still under optimization and will shortly be realized using a new generation of sensor frontends. In the months to come further research will be done here.

As indicated above, the introduction of a commercial product based on the multifunctional software and hardware described in this paper, will be done as one next step. Once those short range radars will be produced in larger quantities, reasonable prices can be achieved allowing for many new application in the automotive and industrial environment.

References

[1] Klotz, M., Rohling, H.: „A High Resolution Radar System Network for parking Aid Applications“ 5th International Conference On Radar Systems 1999, Brest/France, May 1999

[2] Mende, R., Rohling, H., A High Performance AICC Radar Sensor – Concept and Results with an Experimental Vehicle, International Radar Conference, Edinburgh 1997

[3] Mende, R., Radarsysteme zur automatischen Abstandsregelung in Automobilen, Ph.D. Thesis, Technical University of Braunschweig, 1999

The parallel video and radar data recordings, displays and screenshots were made using the commercial software ***Drive Recorder***, further information on this is available under www.smartmicro.de.