Chapter 1

Introduction

1.1 Short History of Radar

The word RADAR is an acronym that stands for RAdio Detection And Ranging. The history of radar started at the beginning of the 20th century with an invention of the engineer Christian Hülsmeyer. Driven by the tragedy of a ship collision on the river Weser, the German engineer invented and built the first Radar in 1904 [Huelsmeyer 1904]. He called his invention the Telemobiloskop and the intended use was to detect approaching ships under foggy weather conditions, in other words an all weather collision avoidance system for ships. Although his presentations of the Telemobiloskop were internationally recognized, the engineer did not find financial support for his invention and finally dropped his work on radar.

Nevertheless, this was the beginning of what today is an independent field of electrical engineering. The first practical applications of radar were military. Radar techniques were developed to detect approaching ships and aircraft as early as possible. Today many of those techniques can be found within civil navigation for air and sea traffic control.

Also, the natural environment has increasingly become a favored object to be observed with radar systems. Weather radars are used in meteorology to detect areas with rain fall. Geology and geography examine the earth surface by using airborne synthetic aperture radars (SAR) or satellite SAR systems.

All these applications of radar have one thing in common: The radar device is the prominent center of a system which delivers data and services to a huge number of users. This way, despite the great cost of the radar itself, the construction and operation of these systems can be a profitable business. The arrival of modern microwave technology has expanded the range of possible applications by making small and low cost radar sensors viable.

Today small radar sensors can be developed for basic detection and ranging tasks such as the measurement of the liquid level in a tank. More advanced systems that can resolve multiple targets and estimate the targets angular position are under development, some such systems are already available. Radar systems which enable the robust interpretation of a target scenario like a road traffic scene are currently under research. A radar with this performance allows many comfort and safety applications for road vehicles.

After a century of radar research, fields like automotive radar follow the inspiration of Christian Hülsmeyer and keep alive the idea to use radar for a safer journey and to protect human lives.

A detailed overview of the history of Radar can be found in [Willis 1991].

1.2 Automotive Applications

Automotive applications provide an interesting field of research in advanced radar systems today. Small automotive radar sensors are already available for adaptive cruise control (ACC) systems. However, new safety applications have higher demands on the sensor specifications. These new applications and appropriate sensors are still under research. Examples for safety applications are blind spot surveillance, pre-crash recognition, and collision avoidance.

1.2.1 Adaptive Cruise Control (ACC)

A standard cruise control system keeps the vehicle at a constant, preselected speed. An ACC system has an increased functionality. It keeps the vehicle speed constant until another car with a lower speed appears in the path of the controlled car. The ACC will then adapt the driving speed to the speed of the car ahead. When the car that is followed changes lane or accelerates, the ACC increases the speed until the preselected speed is reached.

The ACC system is a comfort system, although some systems also alert the driver when there is a potential danger of colliding with a preceding car. At present ACC radars solely detect moving objects as this is a situation readily managed by todays technology. The systems work well when the vehicle is on a highway and both the vehicle and the surrounding traffic is moving. An additional “stop and go” functionality increases the range of use to situations where the traffic ahead comes to a full stop.

It is crucial for an ACC system to correctly determine whether a preceding car is in the driving lane of the host vehicle or not. Practical systems equipped with a far distance sensor show that this is basically possible for moving objects. Moving objects can be separated well from other objects, especially from the many stationary objects in a typical traffic scene. Their target angle can be measured very precisely when integrating over multiple measurements. The actual difficulty lies within the prediction of the host vehicle's drive path.

The development of a "stop and go" functionality is aiming at the use of the ACC in dense traffic scenarios on motorways, in traffic jams, and in city traffic situations. In these situations, distances to other road users are smaller. To have sufficient time to react to a changing of lanes and in cut-in situations, a wide angular coverage of the near distance area around the front of the car is desired. The "stop and go" functionality also raises the question how to handle stationary objects that enter the observation area. Since it is not clear yet how the angular position estimation and the determination of the drive path can be made sufficiently accurate, the fallback solution is to react to stationary objects only if they were previously recognized as moving objects that have since decelerated to a full stop.

1.2.2 Blind Spot Surveillance

When turning or changing lane, other road users approaching on the neighboring lane can be overlooked. A blind spot surveillance system alarms the driver during a turn or lane change if another road user is getting dangerously close.

1.2.3 Pre-Crash Recognition

Safety systems for road vehicles like airbags and seat-belt tensioners have proven to be effective life-savers. These systems require some time to reach their maximum effectiveness. Especially for side-impact airbags that protect passengers from impacts in the area of the vehicle doors, the deployment time is still a very crucial point. Pre-crash recognition systems are under research to detect impacts earlier than conventional mechanical systems do, in order to gain a few milliseconds of time for the deployment of airbags and belt tensioners. Also, the type and severeness of the crash can be reported to adaptively adjust the restraint systems.

1.2.4 Collision Avoidance

The next level of complexity for radar aided safety applications is represented by collision avoidance systems. For these systems, a likely collision has to be detected early enough to have time for automatically initiated countermeasures. These can be applying the brakes or performing evasive maneuvers. The goal is either to completely avoid the crash or to at least reduce the energy of the impact.

While blind spot surveillance and pre-crash recognition applications are aiming at very specific situations, a collision avoidance system needs a detailed interpretation of the traffic scene including a prediction of the vehicles drive path. A collision avoidance application can be regarded as the extention of an ACC stop and go system that also reacts to stationary targets. To perform evasive maneuvers, the observation area has to be greater and oncoming traffic has to be detected. Additionally, this application requires a high target detection rate and a very low false alarm rate under all circumstances. This requirement is a real challenge in the system design.

Chapter 2

A Radar Network with Four 77 GHz Sensors

The basis of this work was given by the European research project "multifunctional automotive radar network" (RadarNet). One of the goals of this research project was to provide a common sensor network for a wide range of applications. Since all applications use the same data generated by all the available sensors, a great reduction in system complexity and cost can be achieved.

As shown in Figure 2.1, four distributed sensors are mounted along the front side behind the bumper of the vehicle. The individual sensor does not provide any measurement of the target angle. Instead, a network processor combines the range measurements of each individual sensor and does a target position estimation by means of lateration techniques. This strategy reduces complexity in the production of the individual sensors. The concept of trilateration is shown in Figure 2.2. Additionally, a long distance sensor is provided for ACC functionality.

Each sensor transmits a continuous wave (CW) signal in the 77 GHz domain. The CW signal is modulated by a linear frequency modulation (LFM) technique. This waveform allows the simultaneous measurement of target range and radial velocity. Also the relatively low complexity of the high frequency front-end for a CW sensor reduces the overall system cost.

Within this work, the signal processing software for the LFMCW processing in the individual sensor (single sensor processing) and the radar network processing are both investigated. For the first time 77 GHz LFMCW sensors were designed as near distance sensors to be used in a radar network. At first, classical LFMCW processing techniques were implemented

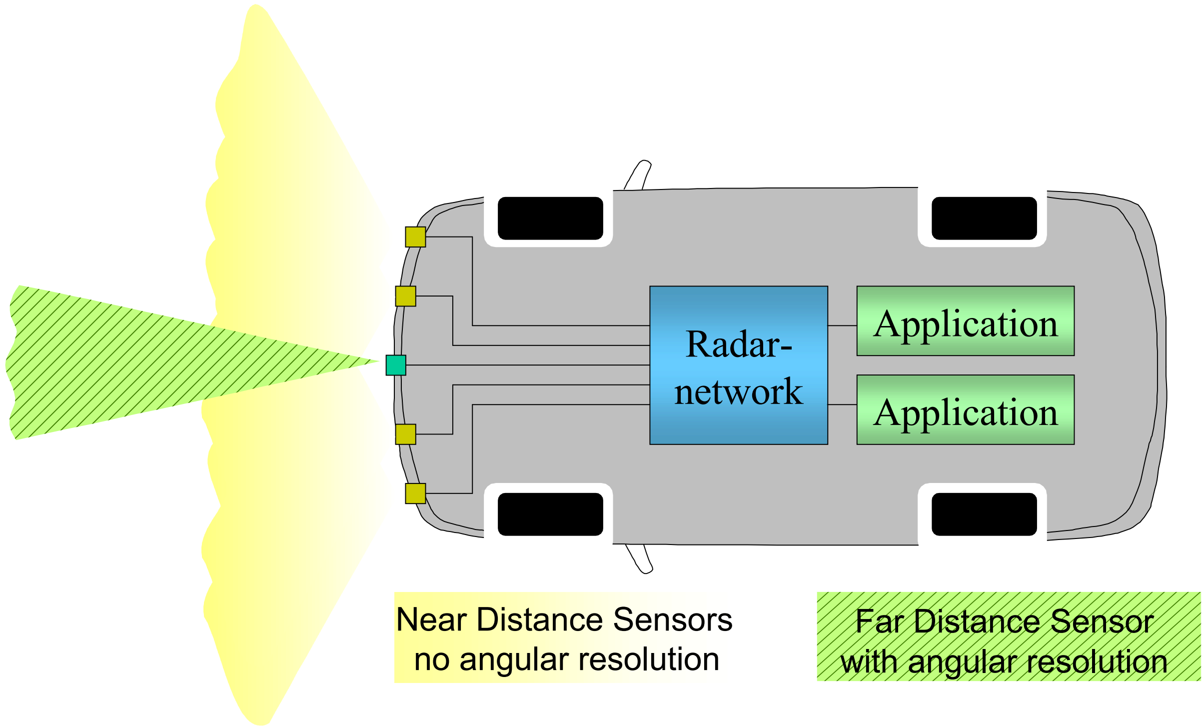

Figure 2.1: Radar network overview

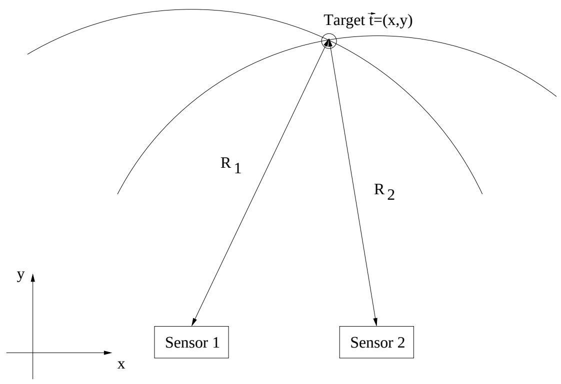

Figure 2.2: Concept of trilateration

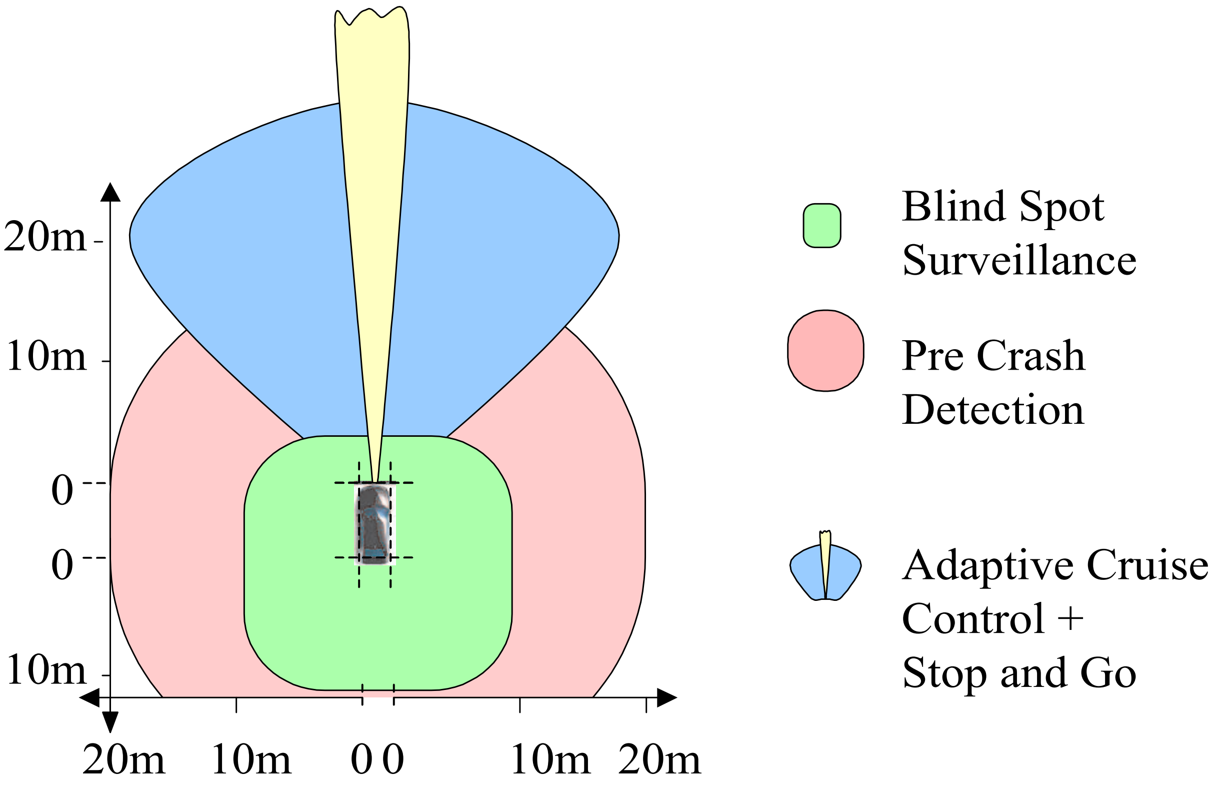

Figure 2.3: Observation areas for some applications

and it was recognized that these techniques had to be enhanced to achieve good results.

Also the classical radar network processing can be adapted to the characteristics of LFMCW sensors to improve performance.

2.1 System Requirements

The above-mentioned applications have different requirements on the radar system. Most obvious is the difference in the required observation area. As shown in Figure 2.3, the adaptive cruise control (ACC) application needs targets to be detected at a far distance but only within the drive path in front of the car. It therefore requires only a small azimuth coverage area. For the collision avoidance system, a wide area around the car needs to be observed to also detect traffic from the side. The blind spot surveillance has to observe the sides of the car. The pre-crash sensing application should be able to detect impacts in all areas of the car where deployment of passenger restraint systems is useful.

Collision avoidance and pre-crash sensing are safety applications that should quickly react on potentially colliding objects with high relative velocities. Therefore, these applications have a particularly high demand for fast object detection and a high update rate of the target reports to the application.

The ability of the radar system to resolve targets with different ranges and velocities is a requirement of nearly all applications that have to interpret road traffic scenes.

The following table shows possible specifications of the radar network requirements for different applications. These values are commonly agreed to be a useful basis on which to do research for the described automotive applications.

Parameter		ACC	Pre-crash	Collision avoidance
Target acquisition time	/ s	0.3	0.03	0.03
Update rate	/ Hz	50	100	100
Max. range	/ m	170	25	30
Range accuracy	/ m	0.1	0.1	0.1
Range resolution	/ m	>2	1	0.1
Angular accuracy	/ deg	<1°	1°	0.5°
Angular resolution	/ deg	-	5°	2°
Max. rel. velocity	/ $\frac{m}{s}$	50	-5	100
Min. rel. velocity	/ $\frac{m}{s}$	-110	-250	-160
Velocity accuracy		$0.5\frac{m}{s}$	5%	2%
Velocity resolution	/ $\frac{m}{s}$	2	3	3

Table 2.1: Radar system specifications for researched applications

The target acquisition time is the maximum time the radar system has available to report a new target that has entered the observation area. For most applications, the actually critical parameter is the time available to react to a detected target. This time depends on the maximum expected object speed, the range of the observation area and the target acquisition time.

For safety applications the range- and angular resolution needs to be good enough to resolve all objects of interest. To react to moving targets, the ability to resolve targets by their velocity can replace the need for a high range or azimuth resolution.

2.2 Requirements for Networked Single Sensors

The radar network approach is to process the ranges measured by the individual sensors within a central radar network to obtain the target azimuth angle. Instead of measuring the angle by monopulse or sequential lobing techniques, the range measurements from spatially distributed sensors are trilaterated. In the previous section, Figure 2.2 shows the principal of the trilateration technique.

From this measurement principle it follows that the single sensor range accuracy needs to be very high to achieve good angular measurement results [Klotz 2002]. In numbers, the single sensor range accuracy needs to be in the range of 3 cm. It has been shown that this is technically accomplishable. Section 6.7 goes into the connection between sensor range accuracy and network position estimation accuracy in more detail.

LFMCW processing has proven to be practically useful for many applications. A major benefit of the used waveform is that it meets an important requirement of many applications. It is possible to measure target range and radial velocity simultaneously even in multitarget situations. Knowing this, it is of interest under which circumstances and for which applications the described radar network based on the 77 GHz LFMCW sensors is useful.