Radar Requirements and Architecture Trades for Automotive Applications

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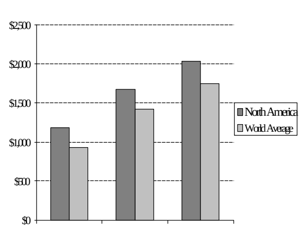
Abstract

There continues to be significant interest in the field of autonomous intelligent cruise control (ACC) and collision warning (CW)/ collision reduction (CR) radar systems for in-vehicle applications. With some products already deployed on truck and bus platforms, and the imminent application of such systems in some highend automobiles, this paper provides an overview of the system requirements and architecture trades. The main body of emphasis in on various designs of forward looking millimeterwave radars, and how their capabilities meet the requirements for wide field-of-view sensors. Additionally, there are updates on costs targets and application rate projections.

Introduction

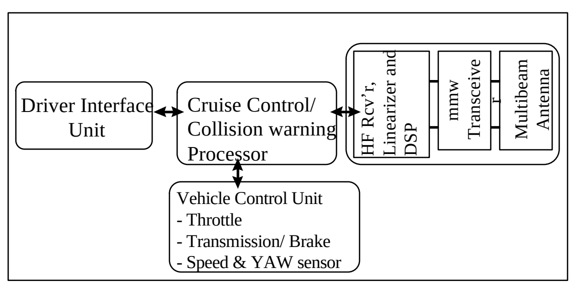
Continued advancements in semi-conductor technologies, and increasing transition of military design expertise, have made in-vehicle millimeterwave sensors nearly affordable . The list of companies publishing progress on radar sensors and advanced safety systems represents a who's-who of defense contractors and automotive OEMs. See the reference list [1, 10] at the end of this paper for a partial list of recent publications - many of which are incorporated in this article. Figure 1 continues to confirm projections of a robust automotive electronics market.

Figure 1. Forecast for Growth in Electronics Content per Car



With an average of 50+ million vehicles produced yearly, this amounts to nearly $71 Billion in electronics and at 0.05% application rates for radar based products - upwards of 25K sensors @ less than $1000 per unit in 2000-2001. Naturally this very modest number will grow as the cost per sensor is reduced and system performance meets customer acceptance. Figure 2 illustrates representative block diagrams for ACC and CW systems. Typically, each system consist of several functional subsystems and, include the front end sensor, the vehicle speed (longitudinal motion) processor unit, and vehicle/driver interface unit. This article will discuss the sensor element only, which typically gets vehicle speed and yaw information, and returns target(s) trajectories, range and relative velocities.

Figure 2 - Representative ACC and CW System Block Diagram



Convenience and safety Applications

In North America, where there are well established and extensive interstate highways, cruise control applications are expected to be the first system configurations of forward looking sensors. Europe and Japan likely may have collision warning configurations as the priority application, however the first system in both countries are (lidar-Japan and mmw radar-Germany) are intended as Type 1 cruise control systems. The automobile industry will generally initially offer systems designed for driver convenience, However, much tuning still needs to be done, such that

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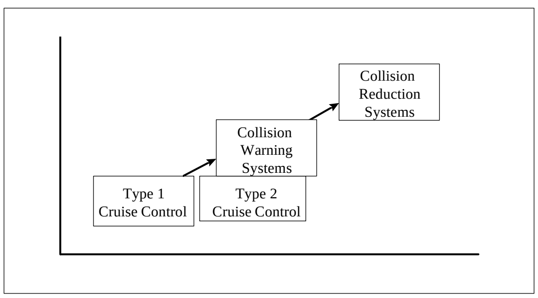
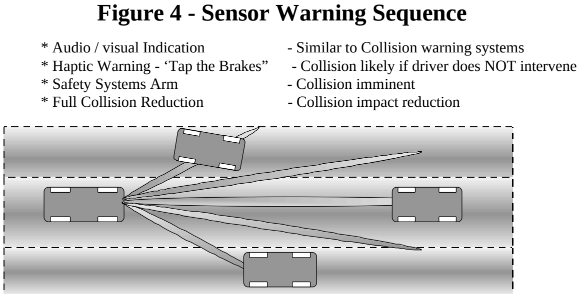
however, the safety implications cannot be ignored. Thus, a system designed to ease the automobile longitudinal motion control in highway use, needs to also anticipate changes in driving patterns due to driver reliance on such convenience. The general premise is that a convenience system always requires the driver to be an active supervisor , whereas a safety system designations implies automatic and autonomous actions by the processor in control. One such study indicated that ACC systems, if they lead to degraded driver reaction times, possibly, result in more severe accidents. In light of such scenarios, it is likely that these systems will evolve from autonomous cruise control, to collision warning, to collision reduction products. The popular term, collision avoidance, is generally a misnomer, but collision reduction systems may include active safety features for restraint deployment . Figure 3 illustrates such possible evolution of radar sensor based systems.

Figure - 3. Possible Evolution of Radar Based Products



Here, it is expected the system on the subject vehicle will use multi-beam or equivalent capability to track numerous vehicle trajectories, while maintaining some set headway between it and the nearest in-path vehicle. These trajectories are typically assigned a probability of intercept value, and a head-room based algorithm takes progressive levels of action as a consequence. ACC systems use in path vehicle information for maintaining desired head room, and CW/CR system use intercept probabilities for warning and active safety interaction. This is illustrated in Figure 4.

Figure 4 - Sensor Warning Sequence



early warnings are indeed helpful. Vehicle OEM Human Factors engineering teams will determine appropriate driver interfaces for such products.

Requirements

Abbreviated requirements for cruise control and collision warning systems are listed in Table 1. For CW/CR systems, especially where active safety features are implemented, the minimum range needs to be from the vehicle bumper. For ACC, this minimum target detection range can be relaxed to 1-2 m.

Table 1 - Systems Requirements

ACC and CW/CRsytem requirements

Target detection range	100 - 150 m +/-1m, or +/ - 5%
Relative velocity	+/ - 50 m/s, +/- .25 m/s
Reliability (failure rate)	<10 / millionhrs.
Driver interface	Activate - On/Off Warning
Longitudinal control	ThrottleTramsission & / or Brake
Curve Capability	Type I - straight roads Type II - 500m radius Type III - 120m radius
Following capability	From 1 sec.
Serviceability	none during 10 year life

These lead to a derived set of requirements for the radar sensor - listed in Table 2.

Table 2 - SensorRequirments

Radar sensor requirments

Frequency	77Ghz.
Chirp bandwidth	300 - 400Mhz.
Azimuth FOV	10 - 14deg.
Elevation FOV	3 - 5deg.
Number of beams	3 - 5
Target discrimination	Forward vehicle trajectories. Nearest in path obstacle
Update rate	10 - 20 HZ.

For system requirements, a key parameter is performance on curves and the ability to detect all tracking multiple target range, azimuth and relative

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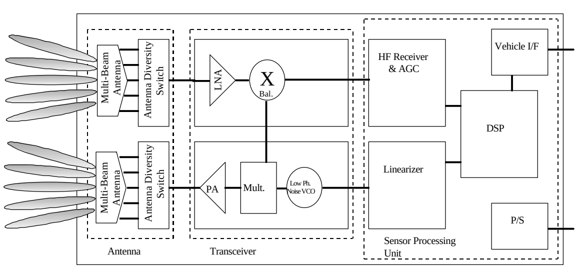
vehicles. Type 1 systems are defined for straight road systems, and Type 2 and 3 systems also perform on highway and exit ramp curves. Vehicle cross section vary from large, flat panel trucks to small motorcycles, and as there is no OEM agreement to augment the vehicle cross-section, it is standard to refer to 'all licensable vehicles and stationary in-path obstacles', as objects for detection. The requirements to detect stationary in-path obstacles is quite difficult. The azimuth field of view is intended to provide adequate performance on moderate curves, as would be typical for highways.

Capabilities

There are many published comparisons between competing technologies for forward looking long range sensors. The capability of determining relative speed simultaneous with distance - by looking at the Doppler shift is a major advantage for FMCW radar systems. Thus, this paper will concentrate on Doppler and FMCW type implementations in millimeterwave electronics. Figure 5, illustrates a typical sensor system block diagram, highlighting the 3 sub-systems - the multi-beam antenna, the transceiver and the processing unit

Figure 5 - Representative Sensor Block diagram



For complex distance warning and collision reduction tasks, the multi-target sensing capability of the sensor is essential. With it, movement trajectories of objects can be kept, and the potential danger can be determined at all times for each object. Numerous antenna configurations have been tried, including fixed field of view single beam configurations, mechanically scanned beam systems, and electronically selected multi-beam systems. Obviously the latter is most preferable due to it's ability to provide good angular resolution… thereby easing some of the digital signal processing (DSP) load. The continuing maturity of mmw MMICs are making this approach economically viable. The monopulse architecture is also viable and capable of velocity using BFSK FMCW and looking at diversity, phase shift etc.

Many suppliers looking to use discrete devices for the transceiver components. Eventually the mass production choice for low phase noise VCOs and low noise and high power mmw amplifiers is likely to be MMICs. This improves overall system noise figure, is readily integrated with mulit-beam antenna feeds, and can be packaged in small envelop MCMs. The issues of integrating the antenna switching network with suitable planar mmw modules, in a high thru-put manufacturing environment, however, are still pending.

In the area of sensor processing unit, the challenge continues to be to develop robust algorithms for essentially a 'moving platform radar' system. The continuing evolution in increased processing power [11] are making this easier.

Discussion

With such a sensor, it is now possible to independently determine range and relative velocity for multiple targets, and with suitable error correction modulation waveforms and algorithms, false signals can be minimized. However, robustness of such sensors and algorithms in real traffic situations needs to be evaluated in closed-loop situations - i.e. where the vehicle longitudinal motion controls are *actually* controlled. These then need to be tuned for user safety and ease of use. Additionally, there are numerous consensus building activities (for example: ISO TC204 to get agreement on attributes of both the systems and the sensors, such that regulatory agencies in the various countries can license deployment of such products. Finally, the cost of such sensors are still substantially above what would enable high applications rates in vehicles - limiting early deployment to options on select top-end vehicles. Maturing technology and experience in volume manufacturing will help drive the cost down, and with it, increase the application rates. But this must come hand-in-hand with meeting end-user expectations.

Conclusion

The early hype of imminent, low-cost, radar based forward looking sensors is being tempered with practical considerations of robust technology and experience in manufacturing methods. To be successful, suppliers and OEMs have to continue to partner, and jointly develop both sensors and systems which will find acceptance with the consumer - and this will require an increasingly sophisticated product capable of providing both convenience and safety features. Advances in mmw antennas and components, and DSPs, provide encouragement that this is being

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