Top Level Newsletter: Connected Vehicle

(Published by IEEE Orange County Section)

March 2024
Volume 49.0

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Systems Research Development and Innovation

Vol 49: Contains articles featuring:

1. **On the Safe Road Toward Autonomous Driving**
2. **High-Performance Automotive Radar: Signal Processing Algorithms and Modulation Schemes**
3. **Sensor Fusion Expanding in Step with Vehicle Sophistication**

General Notes

This series of newsletters is intended to provide the IEEE member with a top level briefing of the many different subjects relevant to the research, development and innovation of the connected vehicle.

The objective is to provide a platform for fast learning and quick overview so that the reader may be guided to the next levels of detail and gain insight into correlations between the entries to enable growth of the technology. Intended audiences are those that desire a quick introduction to the subject and who may wish to take it further and deepen their knowledge. This includes those in industry, academia or government and the public at large. Descriptions will include a range of flavors from technical detail to broad industry and administrative issues. A (soft) limit of 300 to 600 words is usually set for each entry, but not rigorously exercised.

As descriptions are not exhaustive, hyperlinks are occasionally provided to give the reader a first means of delving into the next level of detail. The reader is encouraged to develop a first level understanding of the topic in view. The emphasis is on brief, clear and contained text. There will be no diagrams in order to keep the publication concise and podcast - friendly. Related topics in the case of Connected Vehicle technology, such as 5G cellular and the Internet of Things will be included. The terms Connected Vehicle and Automated Driving will be used inter-changeably. Articles from other published sources than IEEE that add to the information value will occasionally be included.

This newsletter forms part of the regional Advanced Technology Initiative (ATI) of which connected vehicles form a constituent part. Technical articles solely from IEEE journals/magazines are referred to by their Digital Object Identifier (DOI) or corresponding https link. The link for each article is provided. Those readers who wish to delve further to the complete paper and have access to IEEE Explore (www.ieeexplore.ieee.org) may download complete articles of interest. Those who subscribe to the relevant IEEE society and receive the journal may already have physical or electronic copies. In case of difficulty please contact the editor at kaydas@mac.com. The objective is to provide top level guidance on the subject of interest. As this is a collection of summaries of already published articles and serves to further widen audiences for the benefit of each publication, no copyright issues are foreseen.

Readers are encouraged to develop their own onward sources of information, discover and draw inferences, join the dots, and further develop the technology. Entries in the newsletter are normally either editorials or summaries or abstracts of articles. Where a deepening of knowledge is desired, reading the full article is recommended.

Article 1. On the Safe Road Toward Autonomous Driving: Phase Noise Monitoring in Radar Sensors for Functional Safety Compliance (by Michael Gerstmair et al)

Published in: IEEE Signal Processing Magazine, September 2019, Vol 36, no 5, Page(s):60 to 70).

Abstract:
The first approaches to improve vehicle safety were so-called passive safety systems, which did not directly interfere with the driving process but protected the occupants during a crash. In contrast, the first assistance system was the antilock braking system (ABS) successfully introduced in the early 1970s. This active system was developed to avoid an accident by automatically intervening in the braking behavior of the car. At about the same time, the first automotive radar prototype was presented. Since the invention of this very unwieldy radar system, organizations all around the world spent significant efforts in pushing the development of automotive radar systems forward. Today, radar sensors together with ultrasound sensors, lidar, and cameras form the backbone of advanced driver assistant systems (ADASs) as well as autonomous driving (AD), which is in the prototype stage. In particular, because of their robustness against adverse lighting and weather conditions, radar sensors are considered a key technology for modern vehicle safety and comfort systems. Along with the trend toward higher automation, more cars will be equipped with radar sensors in the near future. Because ADASs directly influence the vehicle dynamics, new regulating functional safety (FuSa) requirements, such as the ISO 26262 standard, were introduced. These requirements are mandatory to protect the road users.

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Modern automotive radar systems make use of the frequency-modulated continuous wave (FMCW) principle. Despite many advantages to pulse-based radars, one of the most limiting factors of an FMCW radar is the phase noise (PN) contained in the transmit (Tx) signal, which significantly affects the sensitivity and range. To fulfill the ISO 26262 standard, it is thus of high importance to monitor the PN of a radar system throughout its whole lifecycle. In this article, we present the most common PN measurement and estimation techniques for CW signals. Further, we address the problem of estimating the PN of an FMCW signal, which is of particular relevance for automotive FMCW radars and the aforementioned monitoring to fulfill the FuSa requirements. Finally, we present state-of-the-art methods for PN estimation and monitoring in automotive FMCW radar systems. (551 words)

DOI: https://doi.org/10.1109/MSP.2019.2902914

Article 2. High-Performance Automotive Radar: A Review of Signal Processing Algorithms and Modulation Schemes, (by Gor Hakobyan et al)

Published in: IEEE Signal Processing Magazine (Volume: 36, Issue: 5, September 2019) Page(s): 32 – 44

Abstract:
The ongoing automation of driving functions in cars results in the evolution of advanced driver assistance systems (ADAS) into ones capable of highly automated driving, which will in turn progress into fully autonomous, self-driving cars. To work properly, these functions first must be able to perceive the car's surroundings by such means as radar, lidar, camera, and ultrasound sensors. As the complexity of such systems increases along with the level of automation, the demands on environment sensors, including radar, grow as well. For radar performance to meet the requirements of self-driving cars, straightforward scaling of the radar parameters is not sufficient. To refine radar capabilities to meet more stringent requirements, fundamentally different approaches may be required, including the use of more sophisticated signal processing algorithms as well as alternative radar waveforms and modulation schemes. In addition, since radar is an active sensor (i.e., it operates by transmitting signals and evaluating their reflections) interference becomes a crucial issue as the number of automotive radar sensors increases.

This article gives an overview of the challenges that arise for automotive radar from its development as a sensor for ADAS to a core component of self-driving cars. It summarizes the relevant research and discusses the following topics related to high performance automotive radar systems: 1) shortcomings of the classical signal processing algorithms due to underlying fundamental assumptions and a signal processing framework that overcomes these limitations, 2) use of digital modulations for automotive radar, and 3) interference-mitigation methods that enable multiple radar sensors to coexist in conditions of increasing market penetration. The overview presented in this article shows that new paradigms arise as automotive radar transitions into a more powerful vehicular sensor, which provides a fertile research ground for further investigation.

Introduction
When the idea of radar was first explored back in the late-19th and early-20th centuries, it was primarily seen as a technology for military applications. Other applications gradually emerged, however, and in the last four decades, radar has been studied for use in the automotive sector for such applications as predictive crash

sensing, obstacle detection, and braking. The term *radar* is short for *radio detection and ranging*, an indication that radar is used to detect objects (obstacles and other road users) near the vehicle and to estimate their range as well as velocity and angle relative to the radar. For many years, production cars have made use of these capabilities to facilitate various driver-assistance functions, such as emergency brake assist and adaptive cruise control. More complex functions, such as fully autonomous driving, also rely heavily on radar as an environmental sensor, as it is capable of direct range and velocity measurements, can sense long distances ahead, is robust to bad weather and poor light conditions, and can be hidden behind a bumper.
A detailed overview of the status of automotive radar during its first several years is presented in [1]. The evolution of automotive radar is discussed in the references. Other review articles provide overviews of the signal processing architecture and of the millimeter-wave technology for automotive radar. A more recent review article discusses the state-of-the-art signal processing algorithms for automotive radar and gives a bird's-eye view of estimation techniques, radar waveforms, and higher-level processing steps, such as tracking and classification.

This article gives an overview of the signal processing and modulation aspects of high-end automotive radar systems and discusses recent advances in these fields. We address the use of digital modulations, such as orthogonal frequency-division multiplexing (OFDM) and phase modulated continuous wave (PMCW) waveforms, for automotive radar and multiple-input, multiple-output (MIMO) radar in particular; discuss their potential benefits and challenges due to increased complexity; and survey recent research in this area. We also point out that classical automotive radar signal processing does not fully accommodate performance improvement through simple upscaling of the radar parameters (e.g., bandwidth, measurement time, antenna aperture) due to underlying fundamental assumptions. We provide a signal processing framework based on a more advanced signal model that surpasses these limits at a feasible computational cost. Next we explore the reliable operation of future automotive radar systems for which interference mitigation is vital and complete the discussion with a survey of interference-mitigation methods. These include some promising paradigms, such as interference-aware cognitive radar and centralized coordination for interference avoidance. (709 words)

DOI: https://doi.org/10.1109/MSP.2019.2911722

Article 3. Sensor Fusion Expanding in Step With Vehicle Sophistication, (by Lamar Ricks, CTO, Transportation Sensors)

Published in: SAE Automotive Engineering (March 2024, Pages: 26-29)

An accelerating need to enable automated-driving and efficiency-enhancing features is driving sensor-fusion innovations.

When drivers of passenger vehicles change lanes, brake at stop lights, or accelerate on the highway, they're probably not thinking about sensors. Sensors monitor, regulate and alert on changes in fluid and component conditions, such as tire pressure, fuel and oil levels and engine temperatures. They also report on the position of motor components, wheel speed and antilock braking systems as well as monitor internal and external air temperature, helping to maximize passenger comfort.

The typical non-electric vehicle now is fitted with between 60 and 100 sensors, with 15 to 30 dedicated to managing the engine. Commercial trucks have up to 400 sensors, with up to 70 allocated to engine management.

The shift toward ADAS and automated driving is stimulating unprecedented demand for sensors. Future generations of EVs, particularly those equipped with autonomous or semi-autonomous functionality, may have two to three times the number of sensors as their comparable predecessors. What's more, the emergence of software-defined vehicles (SDVs) is set to further impact market demand, as they enable a new service delivery model. Instead of hardware determining the features a vehicle can offer, manufacturers will build basic, mid-level, and luxury vehicles with pre-integrated sensor-enabled functionality that can be turned on and off with software, encouraging standardization across the industry.

But that's not all. The expansion of autonomous capabilities extends to a variety of vehicle types, regardless of the power-source technology. Among these, hybrid vehicles, combining both ICE and electric propulsion and fitted with automated-driving features are likely to have the most significant sensor content. To support these industry advancements, original equipment manufacturers (OEMs) are pivoting from domain-based to zonal electrical architectures, which are homogeneous and bus-based.

Maximizing efficiency with sensor fusion

The more sensors a vehicle has, the smarter it can be. However, sensors take up space and become increasingly expensive as they offer greater functionality or higher performance. As a result, the solution for basic and mid-level vehicles is not always to deploy more sensors or the best ones – but to ensure they address the job at hand most effectively. Luxury consumers, on the other hand, may be willing to pay more for a vehicle with advanced sensor solutions that deliver a higher level of safety, comfort and convenience.

The methodology of integrating multiple sensors into one package or combining the output data of multiple sensors is referred to as sensor fusion. The goal of sensor fusion is to eliminate redundant packaging to minimize system cost or to combine the outputs of various sensors to achieve insights or decision-making abilities that would not ordinarily be possible with isolated sensor data.

While homogenous technologies can be easily integrated, sensors may use different substrates, making it an engineering challenge to combine them. For example, sensors on silicon substrates are not easily integrated with those on silicon-carbide or gallium arsenide substrates. To address this, component manufacturers are exploring new ways to develop multifunctional sensors that deliver added value, optimize the use of space and reduce costs. As an example, the market now offers an integrated module that merges temperature and humidity sensors, enabling a vehicle HVAC system to automatically activate windshield defogging and wiper systems.

Sensor fusion also refers to using sensors, high-speed data connectivity, artificial intelligence and machine learning to provide situational awareness and act on changing environmental and operational conditions. For SAE Level 2 to Level 5 automated driving functionality, sensors help enable varying levels of automation. Lidar, cameras, radar and vision technology facilitate vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2X) communications, increasing process efficiency and reducing the need for sensors to 30 or fewer. Fully autonomous vehicles use sensor fusion to collect and integrate data, recognize patterns and automate a controlled response, such as determining the position and speed of a vehicle and swerving or braking suddenly to avoid a pedestrian crossing in front of the vehicle.

Exploring alternative sensing technologies

In addition to leveraging sensor fusion, OEMs and system suppliers are exploring the use of alternative sensing technologies to further reduce costs. Technologies using Eddy Current and xMR (magnetics) are emerging as potential alternatives for resolvers, a passive transformer technology traditionally employed for measuring rotary position.

The adoption of these alternatives will primarily be evaluated based on their cost-effectiveness relative to performance. Depending on the end application and performance requirements, these solutions may be adequate and, as a result, cannibalize existing business. For example, in systems where a secondary eMotor serves as a backup, the performance requirements may be lower than for the primary motor. In such cases, opting for a sensor technology that presents a more cost-effective solution, even with a slightly lesser performance, could represent the better strategic and economical choice.

High-resolution wheel-speed sensors have four times the resolution of legacy wheel-speed sensors. Improved resolution increases vehicle-position accuracy in areas where GPS is unavailable and supports enhanced ADAS features such as lane keeping, lane departure and vehicle positioning. The improved accuracy facilitates quicker updates on vehicle movement, aiding in maneuvers such as automated parking in tight spaces. When it comes to eBraking, systems historically have been hydraulic-based, offering wet-wet braking capabilities. However, by transitioning from pressure to force sensors, OEMs can enable full-dry electronic braking systems, which provide increased responsiveness.

Digital sensors to dominate :

Vehicle architectures also are evolving to reduce power consumption and extend the range of EVs and autonomous vehicles. For example, analog sensors that were connected to electronic control unit microprocessors or circuitry and simply turned functionality on and off have gone by the wayside. With bus-based architectures, digital outputs capitalize on massive bandwidth to enable more functionality and ultra-fast response times. In addition, they are easier to plug in and plug out to reduce power consumption. As a result, digital sensors will predominate with new SDV architectures.

The development pace in the passenger vehicle market is advancing at lightning speed: from ICE to EV and from driver-assistance to high levels of automated driving. As the pace of innovation accelerates, the focus will continue to shift both to sensor fusion and alternative sensor technologies as they play an invaluable role in bringing new and advanced functionalities to market. (1027 words)

DOI: Not required.