Top Level Newsletter: Connected Vehicle

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Vol 22 comprises:

(1) Joint Radar and Communication Strategies for Autonomous Vehicles

(2) Advances in Single-Photon Lidar for Autonomous Vehicles

(3) MIMO Radar for Advanced Driver-Assistance Systems

(4) Toward Smart Vehicle-to-Everything-Connected Powertrains

(5) Deep Learning-Based Wireless Resource Allocation for Vehicular Networks

(6) Toward Reliable and Scalable Internet of Vehicles

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.

A note on the Connected Vehicle Newsletter development: Volume 18 was a top-level synopsis of the 74 most recent entries from the twelve previous volumes (vol 17 to vol 6) since March 2020. Volume 19 returned to the usual format. Volume 20 departed from the norm and included a complete article.

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.

1. Joint Radar and Communication Strategies for Autonomous Vehicles, by Dingyou Ma et al.
Published: IEEE Signal Processing Magazine (Volume: 37, Issue: 4, July 2020, pp 85-97)

Abstract: Self-driving cars constantly assess their environment to choose routes, comply with traffic regulations, and avoid hazards. To that aim, such vehicles are equipped with wireless communications transceivers as well as multiple sensors, including automotive radars. The fact that autonomous vehicles implement both radar and communications motivates designing these functionalities in a joint manner. Such dual function radar-communications (DFRC) designs are the focus of a large body of recent work. These approaches can lead to substantial gains in size, cost, power consumption, robustness, and performance, especially when both radar and communications operate in the same range, which is the case in vehicular applications.

Sensing and communication in autonomous vehicles: To reliably sense the environment, autonomous vehicles are equipped with multiple sensing technologies, including computer vision acquisition, i.e., cameras, lidar, laser-based sensors, GPS, and radar transceivers. Each of these technologies has its advantages and disadvantages. To allow accurate sensing in a broad range of complex environments, self-driving cars should simultaneously utilize all of these aforementioned sensors. Radar, for instance, provides the ability to accurately detect distant objects and is typically more robust to weather conditions and poor visibility compared to other competing sensing technologies.

Radar systems, which detect the presence of distant objects by measuring the reflections of electromagnetic probing waves, have been in use for over a century. Radar has been most commonly used in military applications, aircraft surveillance, and navigation systems.

In addition to their ability to sense their environment, autonomous vehicles are also required to carry out various forms of communications:

- (V2V) vehicle-to-vehicle transmissions allow self-driving cars to share attributes with neighbors;

- (V2I) vehicle-to-infrastructure messages facilitate intelligent road management by conveying information between cars and roadside units;

- (V2P) vehicle-to-pedestrian communications can be used to warn or alarm nearby pedestrians;

- (V2N) vehicle-to-network and vehicle-to-cloud (V2C) links: service providers and cloud applications exchange possibly large amounts of data with self-driving cars.

The resulting broad range of different tasks, which substantially vary in their latency, throughput, and reliability requirements, can be implemented by using individual communications technologies for each application or by using a unified vehicle-to-everything (V2X) strategy, possibly building upon the cellular infrastructure.

Automated cars, thus, implement two technologies that rely on the transmission and processing of electromagnetic signals: radar and wireless communications. A possible approach in designing self-driving cars is to use individual systems for radar and communications, each operating separately. An alternative strategy is to jointly design these functionalities as a DFRC system. Such schemes are the focus of extensive recent research attention. In particular, it was shown that jointly implementing radar and communications contributes to reducing the number of antennas, system size, weight, and power consumption as well as alleviating concerns for electromagnetic compatibility and spectrum congestion. Utilizing such joint designs in vehicular systems can mitigate the mutual interference among neighboring cars, facilitate coordination, and improve pedestrian detection.

Some DFRC methods use existing V2X communications waveforms as radar probing signals, thus allowing high communication throughput with relatively limited sensing capabilities. Alternative schemes embed digital messages in the radar signals, thus supporting low data rates, which may be more suitable to serve as an additional channel to the standard communications functionalities of autonomous vehicles.

Automotive radars operate under different requirements and constraints compared to conventional radars, such as those utilized in military applications and air traffic control. First, conventional radar systems are required to detect a relatively small number of targets in ranges on the order of tens or hundreds of kilometers, while automotive radars must detect a multitude of objects in short ranges on the order of a few tens of meters. Furthermore, automotive radars are incorporated into mass-produced vehicles and, hence, have more strict constraints on cost, size, power consumption, and spectral efficiency compared to conventional radar. Finally, automotive radars are densely deployed in urban environments; thus, they must be robust to interference while inducing minimal interference with neighboring radar systems.

Other dual function topics: spatial beamforming, spread spectrum waveforms, OFDM (orthogonal frequency division multiplexing) waveforms…

(666 words)

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2. Advances in Single-Photon Lidar for Autonomous Vehicles: Working Principles, Challenges, and Recent Advances by, Joshua Rapp et al

Published: IEEE Signal Processing Magazine (Volume: 37, Issue: 4, July 2020, pp 62-71)

Abstract: The safety and success of autonomous vehicles (AVs) depend on their ability to accurately map and respond to their surroundings in real time. One of the most promising recent technologies for depth mapping is single-photon lidar (SPL), which measures the time of flight of individual photons. The long-range capabilities (kilometers), excellent depth resolution (centimeters), and use of low-power (eye-safe) laser sources renders this modality a strong candidate for use in AVs. While presenting unique opportunities, the remarkable sensitivity of single-photon detectors introduces several signal processing challenges. The discrete nature of photon counting and the particular design of the detection devices means the acquired signals cannot be treated as arising in a linear system with additive Gaussian noise. Moreover, the number of useful photon detections may be small despite a large data volume, thus requiring careful modeling and algorithmic design for real-time performance. This article discusses the main working principles of SPL and summarizes recent advances in signal processing techniques for this modality, highlighting promising applications in AVs as well as a number of challenges for vehicular lidar that cannot be solved by better hardware alone.

Introduction: Before AVs can reshape the transportation landscape, numerous challenges have to be addressed. Engineers must first demonstrate the ability of AVs to perform basic driving functions safely and reliably. While driving, AVs must translate high-level goals—such as route planning, safe driving, efficient energy consumption, and adherence to rules of the road—into low-level decisions about the mechanics required to follow a planned trajectory. To achieve these goals, the complex control systems determining driving decisions must rely on information from sensing systems that are as good as, or preferably better than, human perception.

Autonomous system designs usually propose some form of sensor fusion, combining the strengths of various sensing modalities to overcome their individual limitations. In addition to classical GPS receivers, future commercial AVs are likely to include video cameras for identifying road signs and objects, short-range ultrasound sensors as currently used for parking assistance, and weather-robust radar for low-resolution position and velocity estimation. However, the centerpiece of most AV sensing systems is the lidar unit. Just as radar detects echoes from radio-frequency electromagnetic waves, lidar detects reflections from optical-frequency laser illumination to generate a long-range, high-resolution point cloud corresponding to the positions and reflectivity values of millions of points in the surrounding environment. Since optical wavelengths can be easily focused into narrow beams, lidar can distinguish much smaller objects than radar, which is crucial for navigating alongside pedestrians, cyclists, and other potential hazards. Although laser ranging has been under development since the 1960s, mostly for military use, terrain mapping, and atmospheric monitoring, commercial lidar development has greatly accelerated since 2005, when all vehicles that completed the DARPA autonomous driving Grand Challenge employed lidar for depth mapping.

Sensing systems for AVs are evaluated on several criteria considered necessary for reliable real-time performance, including the maximum operating range, transverse and longitudinal resolution, field of view, refresh rate, transmit power (especially with respect to eye safety), robustness to ambient light and weather conditions, processing requirements, and cost. Many of these factors are determined, in part, by hardware and manufacturing constraints, such as the quality and capability of lasers, detectors, and scanning mechanisms, which have improved through continuous investment and refinement. For instance, the cost of a lidar unit was long considered a barrier to widespread deployment in AVs since the Velodyne systems originally used in the Grand Challenge cost upward of US$75,000, but after more than a decade of development, lidar manufacturers such as Luminar have announced units priced at less than US$1,000. (604 words)

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3. MIMO Radar for Advanced Driver-Assistance Systems and Autonomous Driving: Advantages and Challenges, Shunqiao Sun et al

Published: IEEE Signal Processing Magazine (Volume: 37, Issue: 4, July 2020, pp 98-115)

Abstract: Important requirements for automotive radar are high resolution, low hardware cost, and small size. Multiple-input, multiple-output (MIMO) radar technology has been receiving considerable attention from automotive radar manufacturers because it can achieve a high angular resolution with relatively small numbers of antennas. For that ability, it has been exploited in the current-generation automotive radar for advanced driver assistance systems (ADAS) as well as in next-generation high resolution imaging radar for autonomous driving. This article reviews MIMO radar basics, highlighting the features that make this technology a good fit for automotive radar and reviewing important theoretical results for increasing the angular resolution. The article also describes challenges arising during the application of existing MIMO radar theory to automotive radar that provide interesting problems for signal processing researchers.

Introduction: Radar technology has been used in defense, civilian, and commercial applications since World War II. Surveillance radars have been in service for a number of decades. Ground-based air surveillance radars, such as air traffic control radar, are usually pulse radar systems with maximum detectable ranges of more than 100 km. Airborne surveillance radars carried by aircraft and unmanned aerial systems, such as the joint surveillance target attack radar system, can run in ground moving target indication and synthetic aperture radar imaging modes to detect moving and stationary targets on the ground at more than 250 km, respectively. To achieve a satisfactory return-signal power, the transmit power of such radar can be several kilowatts. Large phased-array antennas have been deployed to achieve electronic beam scanning. Since the late 1990s, radar sensors have found widespread applications in ADASs, such as adaptive cruise control (ACC) and automatic emergency braking (AEB). More recently, radar has emerged as one of the key technologies in autonomous driving systems, providing environmental perception in all weather conditions. Some of today's self-driving cars, such as Zoox, have more than 10 radars, providing 360º surround sensing. Differing from ground-based and airborne surveillance radars, automotive radars have a small size (multi-inch by multi-inch), short range (within multihundreds of meters), low power consumption (multiwatt), and low cost. They are integrated behind the vehicle bumper or windshield, operating in a highly dynamic environment with multipath.

(360 words)

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4. Toward Smart Vehicle-to-Everything-Connected Powertrains, by Marcus Eisenbarth et al.

Published: IEEE Vehicular Technology Magazine (Volume: 16, Issue: 1, March 2021, pp 75-82)

Editor's note: "Powertrain" refers to the set of components that generate the power required to move the vehicle and deliver it to the wheels. In internal combustion engine- driven automobiles the key components of a powertrain include an engine, transmission, driveshaft, axles, and differential. "A significant difference between conventional and electric vehicles (EVs) is the powertrain. The majority of EVs do not have multi-speed transmissions. Instead, a single-speed transmission regulates the electric motor."

Introduction: In the context of increasing electrification and the automation of future mobility, research and development of efficient powertrains requires enhanced test methods. One important aspect to consider is the complex interactions among a smart driving strategy, traffic flow, an individual vehicle's energy demand and emissions. Until now, the respective development domains of traffic flow control, powertrain control, component design, and intervehicle communication have usually been considered separately. This article presents a methodology that combines these areas and enables developers to obtain deep and highly realistic system insights, taking into account the mutual interactions among the domains. For this purpose, an X-in-the-loop validation platform is constructed that builds upon vehicular networking, road traffic, and a vehicle simulator, all coupled with two real drive-unit component test benches. We further show how this methodology can be used to investigate the effects of a novel predictive powertrain control algorithm that takes vehicle-to-everything (V2X) communication into account. Focusing on a typical urban reference route, we demonstrate that our algorithm enables performance to be maintained using electric motors with reduced specifications.

Motivation: In the coming years, motorized, individual mobility will change drastically, driven by technological and sociopolitical trends. Vehicles will be connected, automated, shared, and electrified. Along the way, new communication technologies will enable developers to integrate more information from the vehicle environment into control algorithms. In essence, this is important to continuously increase the level of automation for safer, more comfortable, and more efficient operation. The research and development of these algorithms requires the combination of various domains of expertise. Furthermore, multiple interdependencies among the drive units, the vehicle, and the car's environment have to be considered, as they influence each other. Ensuring the correctness and performance of the interconnected control algorithms is possible only with complex test scenarios.

Since the technology, legislation, and infrastructure for fully automated traffic are not currently ready, these types of scenarios are not yet available on real roads. Therefore, communication and traffic simulations are required for an efficient development process. Since other traffic participants change their behavior as a consequence of the predictive driving of the ego vehicle (e.g., other vehicles might overtake and cut in front of the ego vehicle as it slowly approaches a red traffic light), thus influencing their own actions, an approach that co-simulates the traffic flow and a vehicle is chosen. For investigations of the interdependencies between powertrain components and a vehicle, hardware tests are possible but require large investments in building a prototype car or truck. Hence, simulations of the vehicle, including its powertrain, are also required.

To establish a strong coupling between vehicular simulations and the real-world hardware setups of vehicles, a method known as *hardware-in-the-loop* (*HiL*) simulation is needed. However, existing cross-domain approaches touch only some of the relevant areas. For traffic and communication simulation, bidirectional coupling is a common practice. HiL and traffic simulations have been coupled before. More recently, it became possible to connect simulated and physical vehicular communication components. In previous work, we showed a concept for combining traffic and communication simulation with an HiL system. Powertrain component testing that uses HiL setups has already been demonstrated for combustion engines and electric motors. Our previous research included the coupling of powertrain components on separate test benches. To the best of our knowledge, existing HiL setups for vehicular networks have never been used to holistically investigate a combination of all these domains. We therefore developed an X-in-the-loop validation platform that combines traffic, communication, and vehicle simulation with actual powertrain components. (655 words)

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5. Deep Learning-Based Wireless Resource Allocation for Vehicular Networks, by Le Liang et al

Published: Proceedings of the IEEE (Volume: 106, Issue 2, Feb. 2020, pp341-356)

Abstract: It has been a long-held belief that judicious resource allocation is critical to mitigating interference, improving network efficiency, and ultimately optimizing wireless communication performance. The traditional wisdom is to explicitly formulate resource allocation as an optimization problem and then exploit mathematical programming to solve the problem to a certain level of optimality. Nonetheless, as wireless networks become increasingly diverse and complex, for example, in the high-mobility vehicular networks, the current design methodologies face significant challenges and thus call for rethinking of the traditional design philosophy. Meanwhile, deep learning, with many success stories in various disciplines, represents a promising alternative due to its remarkable power to leverage data for problem solving. In this article, we discuss the key motivations and roadblocks of using deep learning for wireless resource allocation with application to vehicular networks. We review major recent studies that mobilize the deep-learning philosophy in wireless resource allocation and achieve impressive results. We first discuss deep-learning-assisted optimization for resource allocation. We then highlight the deep reinforcement learning approach to address resource allocation problems that are difficult to handle in the traditional optimization framework. We also identify some research directions that deserve further investigation. (193 words)

DOI: https://doi.org/10.1109/JPROC.2019.2957798

6. Toward Reliable and Scalable Internet of Vehicles: Performance Analysis and Resource Management, Yuanzhi Ni et al

Published: Proceedings of the IEEE (Volume: 106, Issue 2, Feb. 2020, pp324-356-340)

Abstract: Reliable and scalable wireless transmissions for Internet of Vehicles (IoV) are technically challenging. Each vehicle, from driver-assisted to automated one, will generate a flood of information, up to thousands of times of that by a person. Vehicle density may change drastically over time and location. Emergency messages and real-time cooperative control messages have stringent delay constraints while infotainment applications may tolerate a certain degree of latency. On a congested road, thousands of vehicles need to exchange information badly, only to find that service is limited due to the scarcity of wireless spectrum. Considering the service requirements of heterogeneous IoV applications, service guarantee relies on an in-depth understanding of network performance and innovations in wireless resource management leveraging the mobility of vehicles, which are addressed in this article. For single-hop transmissions, we study and compare the performance of vehicle-to-vehicle (V2V) beacon broadcasting using random access-based (IEEE 802.11p) and resource allocation-based (cellular vehicle-to-everything) protocols, and the enhancement strategies using distributed congestion control. For messages propagated in IoV using multihop V2V relay transmissions, the fundamental network connectivity property of 1-D and 2-D roads is given. To have a message delivered farther away in a sparse, disconnected V2V network, vehicles can carry and forward the message, with the help of infrastructure if possible. The optimal locations to deploy different types of roadside infrastructures, including storage-only devices and roadside units with Internet connections, are analyzed. (231 words)

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