Top Level Newsletter: Connected Vehicle

(Published by IEEE Orange County Section)

December 2023
Volume 46.0

Editor-in-Chief: Kay Das, IEEE Life Member,
Systems Research Development and Innovation

Vol 46: Contains an article on digital twins and two articles on sensor technology (audio and radar) for autonomous vehicles.

1. The Interplay of Digital Twin and 6G Wireless Networks
2. Turning the Vehicle into a Giant Microphone
3. The Rise of Radar for Autonomous 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.

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. The Interplay of Digital Twin and 6G Wireless Networks (by Lina Bariah et al)

Published in: IEEE Communications Magazine, (November 2023, Volume 61, no 11,, Section: Guest Editorial Page(s): 70 to 71).

Abstract:
Embracing the principles of network virtualization and digitization as a main pillar in the upcoming wireless generation has motivated the emergence of the digital twin (DT) paradigm as an enabler for 6G networks. The key concept of the DT technology is to create a digital replica of the physical components and functions of wireless networks, with the aim to realize ultra-reliable, low latency communication, while ensuring high energy-efficiency in resource-constrained networks.

It is envisaged that DT will be the seed for the efficient deployment of intelligent, fully automated, zero-touch networks, in which artificial intelligence (AI) algorithms will be leveraged at the digital realm to enable virtualized network monitoring and operation. Despite its promising advantages, to reap the full potential of the DT technology in 6G networks, the cyber twin is envisaged to leverage AI algorithms, with novel data-driven paradigms, high performance computing, optimization theory, matching theory, as well as efficient cyber-physical interaction schemes, among others, to realize the necessary adaptation/reconfiguration at the physical twin with an imperceptible time-lag. In order to achieve the needed quality-of-service (QoS) for the successful implementation of a high-fidelity DT paradigm in 6G, a new level of stringent requirements pertaining to connectivity, reliability, latency, and data rate are imposed on future wireless generations. This Feature Topic (FT), which has attracted a large number of high-quality articles, aims to be a stepping-stone on advancing the research on DT for 6G, and to promote the development of high-fidelity Telecom Digital Twin.

As the Telecom industry is continuously, and rapidly, evolving in response to new technologies, it is challenging to sketch a unified architecture for a network DT.

Editor’s Notes:
The article by X. Lin et al puts a reference architecture for 6G DT network, based on ITU-T recommendation Y.3090, comprising physical, twin, and network application layers.
The article by N. Apostolakis *et al*. presents a case-study to demonstrate the potential of DT in improving the performance of virtual radio access network, in which the capability of the developed DT was quantified according to its ability to accurately replicate the physical environment, generate synthetic data similar to the real one, and to interact to the cyber-physical variations.
The article by H. Gao *et al*. focused on the various methods for capturing the propagation features of radio environments through exploiting the DT, including ray-tracing, radio channel sounding, and statistical modeling.

A total of nine articles on the subject of DTs are included in the journal ranging topics such as the interplay of DT and open RAN (O-RAN), and how each compliments the other, in order to achieve full network virtualization and autonomy. (433 words)

DOI: https://doi.org/10.1109/MCOM.2023.10328185

Article 2. Turning the Vehicle into a Giant Microphone (by Kami Buchholtz)

Published in SAE International Automotive Engineering April 20023 (pages 11-12)

When an emergency vehicle is approaching but its blaring siren isn't heard by nearby motorists, all are put at risk. Engineers at Harman International have developed novel sensor technology that detects both the sound and its direction, in effect piping that screaming siren into vehicles so equipped, to alert the driver.

"What we're in essence doing is turning the vehicle into a giant microphone," Mitul Jhala, senior director of automotive embedded audio for Harman, explained in an SAE Media interview. Harman's sound and vibration sensor functions as a vehicle's external "listening ear" to detect sound frequencies from 20 Hz up to 6 kHz. The sensor can "distinguish siren tones via post-processing algorithms, so it can tell whether the sound is a police, fire, or ambulance siren," Jhala said. He noted specific tones vary for the U.S., European and Asian markets. This sensor can be used alone or alongside Harman's new external microphones.

Using multiple external microphones to create a multi-element array, post-signal processing algorithms, such as beam forming, can be used to determine the siren's direction. "Localization is very useful when it's not possible to see the emergency vehicle because it's behind a building or there's another visibility obstruction," Jhala said. The distance range for siren detection is approximately 1968 ft (600 m), depending on factors such as whether the emergency vehicle is stationary or moving.

To prevent wind interference, a single sound and vibration sensor would be mounted on the B-side of the exterior panel between the interior panel trim and the exterior panel. The optimal placement location for external microphone(s) depends on the vehicle type, as different vehicle profiles mean different aerodynamics, which equates to different noise profiles. "We've done testing on small cars, hatchbacks, minivans and SUVs with microphones integrated on different locations, such as the rooftop's shark-fin antenna or the front bumper, with single- and multi-arrays," Jhala said.

Exposure to harsh conditions, especially wind turbulence and water, required a microphone design unlike anything the automotive industry's microphone technology leader has done in the past. "It took lots of engineering hours to design a unique, conical-shaped grille pattern for the microphone," said Jhala. The resulting grille pattern includes drainage holes to protect against a direct water hit to the electronics. "There is also a protective membrane in front of the microphone itself that serves as a secondary layer of water and environmental protection," he explained.

ACOUSTIC VEHICLE MONITORING
When technology development started in 2019, Harman's sound-and-vibration sensor and the external microphone products were intended as an alert system for autonomous vehicles. But it soon became apparent that human drivers could also benefit from acoustic sensing of the vehicle exterior. One of the use-case examples is emergency-vehicle detection.

Another example is speech commands, such as 'open liftgate', or 'close liftgate'," Jhala said. When used separately or together, the sound and vibration sensor and external microphone solutions also enable acoustic vehicle monitoring. For instance, an alert can be sent to a cell phone if vehicle glass breakage is detected by the sound and vibration sensor.

Acoustic emergency-vehicle alerts and other notifications can be communicated to drivers via a vehicle's infotainment screen, gauge cluster, or head-up display. "It's also possible to alert drivers with an audible transmitted through the vehicle's audio system," he said. The first passenger-vehicle application of the design-validated sound and vibration sensor or the external microphone product is expected in the U.S. market in late 2023. Asian and European market applications are expected in 2024 or later. *(591 words)*

Article 3 : The Rise of Radar for Autonomous Vehicles: Signal Processing Solutions and Future Research Directions (by Igal Bilik et al)

Published in IEEE Signal Processing Magazine September 2019 (pages 20 -31)

Introduction
Autonomous driving is one of the megatrends in the automotive industry, and a majority of car manufacturers are already introducing various levels of autonomy into commercially available vehicles. Autonomous conveyances need to substitute for a human driver in both sensing and decision making. The main task of the sensing suite in autonomous vehicles is to provide the most reliable and dense information on the vehicular surroundings. Specifically, it is necessary to acquire information on drivable areas on the road and to report all objects above the road level as obstacles to be avoided. Thus, the sensors need to detect, localize, and classify a variety of typical objects, such as vehicles, pedestrians, poles, and guardrails. Since the major benefits of autonomous vehicles are expected in urban environments, the variety of obstacles' appearance and the short response time required pose the major challenges to the sensing suite. Comprehensive and accurate information on vehicle surroundings cannot be achieved by any single practical sensor. Therefore, all autonomous vehicles are typically equipped with multiple sensors of multiple modalities: radars, cameras, and lidars.

Because cameras resemble human driver vision, they can be the most natural sensors for autonomous driving. They are low in cost and have a small form factor, providing dense and rich information on the environment, along with the color and texture of objects. However, cameras have significant shortcomings: they are sensitive to illumination and weather conditions, have to be mounted behind an optically transparent surface, and do not provide direct range and velocity measurements. On the contrary, radars are robust to adverse weather conditions, are insensitive to lighting variations, provide long and accurate range measurements, and can be packaged behind optically nontransparent fascia.

The first attempts at automotive radar applications were reported a few decades ago. However, the mass deployment of radars in commercial vehicles began only recently. The autonomous driving megatrend is the major factor in automotive radar mass production. The technological progress of the 77-GHz RF CMOS with integrated digital CMOS and further packaging advances enable low-cost radar-on-chip and antenna-on-chip systems. The continuously shrinking vehicular radar form factor enables novel on-platform integration possibilities and, consequently, new applications. Historically, automotive radars were classified into long-range radars (LRRs), short-range radars (SRRs), and side-blind zone radars (SBZAs). This was driven by a variety of applications and performance requirements, such as operation range, field of view (FOV), and object of interest. Thus, LRR is mainly used for adaptive cruise control and, therefore, is required to detect, localize, track, and classify vehicles at longer ranges, with a narrow FOV. SRR needs to provide information on a vehicle's surroundings at ranges of up to 100 m, with an FOV of more than 120°, where the reference target can be any object above the road level. The simplest automotive radar, SBZA, is required to detect only objects within the lanes adjacent to the host vehicle.

The reduced radar size and advanced capabilities have opened the door for completely new radar application segments. Thus, ultrashort-range radar (USRR) was recently introduced for autonomous parking and side-looking applications at a wide FOV of 120° and ranges of up to 30 m . The multimode radar, where the same hardware configures its operation (antenna configuration, waveform, radar echo processing, and so forth) to various operational modes, is another automotive radar trend.

Vehicular radars are required to provide sensing capabilities starting from zero range and, therefore, are continuous wave (CW) and, because of low-cost requirements, employ linear-frequency modulation (LFM). Other waveforms, such as phase modulation and step frequency, were also introduced for automotive radars.

The most dramatic transformation of the vehicular radar system is now occurring because of its role shift from a sensor that detects to one that images. Autonomous driving requires high-resolution sensing capabilities, and thus automotive radars must provide high-resolution information on the vehicle environment in the range–Doppler–azimuth–elevation domains. Range resolution is inversely proportional to the radar bandwidth. In 77-GHz radars, the available bandwidth is 4 GHz, which provides sufficient range resolution. Doppler resolution is limited by the coherent observation time and depends on the transmitted waveform, receiver processing, and target dynamics. Angular resolution is contingent upon the antenna aperture and thus is determined by the number and geometry of the transmit and receive channels, limited by the radar cost and packaging size. Automotive radars are required to operate in dense urban environments with distributed objects. Therefore, the applicability of conventional super resolution methods, such as multiple signal classification (MUSIC) and minimum-variance distortionless response (MVDR), relying on spatial sparsity, is limited. The requirements for high-angular resolution in both azimuth and elevation, using a small number of channels, turns the MIMO radar concept into an attractive alternative to the full sensor array. Thus, the majority of state-of-the-art automotive radars use some variant of MIMO radar In automotive radar applications, a novel interpretation of the target and clutter notions is required because all of the dynamic or static objects above the road level are targets of interest, and detailed information on them is needed for autonomous driving. This operational scenario poses additional challenges for the radar processing and limits the applicability of conventional radar techniques to automotive radar.

This work overviews the conventional fast LFM–CW automotive radar signal processing flow, emphasizes its limited applicability to vehicular radar scenarios, and proposes a few novel approaches for key performance improvements. In particular, novel range–Doppler processing, detection, clustering, and dynamic range (DR) enhancement methods are required, specifically designed for high-resolution automotive radar. Thus, one of the challenges in vehicular radar operation is the discernment of small objects (e.g., child pedestrians) as well as large ones (e.g., semitrailers). Conventional implementation of detection methods, such as constant false-alarm rate (CFAR), are suboptimal in the automotive environment since objects occupy multiple range–Doppler–azimuth–elevation cells. Therefore, novel detection methods for target recognition that use information from adjacent range–Doppler cells are required.

High-resolution automotive radars can generate multiple detections from the same object. Thus, data association methods are required. Detections originated by the same object have similar properties and, therefore, can be associated into clusters. Data similarity is determined by specific criteria and metrics, such as distribution in the range–Doppler–azimuth–elevation space.

Automotive radar operation challenges

The main role of the sensing suite in autonomous driving is to be a substitute for human driver vision and thus provide reliable information on a moving vehicle's surroundings to enable a prompt reaction to the dynamically changing scene and threats to the vehicle being driven. The autonomous sensing capabilities are well beyond those of human eyes, compensating for the limited artificial intelligence in comparison with human cognition.

The radar, along with cameras, plays a central role in autonomous vehicles oriented toward mass production. Automotive radars have multiple advantages over cameras and lidars, such as long operation ranges, immunity to lighting and weather influences, ability to operate behind optically nontransparent fascia, and direct measurement of targets' radial velocity. Therefore, radars have been given a key role in autonomous vehicles. Both the advantages and challenges of automotive radars stem from the properties of their associated electromagnetic waves and their wavelength, which is determined by regulations. The main issue for automotive radar systems is to provide high-resolution information about multiple dynamic targets in an extremely cluttered automotive scene with a high update rate. *(1217 words).*

DOI: https://doi.org/10.1109/MSP.2019.2926573