Top Level Newsletter: Connected Vehicle

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Vol 17.1 (this issue):
- The art and science of creating suitable maps for autonomous driving
- The challenges of validation of complex systems such as 5G automotive systems

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* Articles in IEEE Vehicular Technology magazine, March 2021: artificial intelligence (AI) applied to mobile networks, aerial vehicular networks and satellite communications, and automotive electronics.
* Articles from IEEE Communications magazine January 2021:
- "Communication Technologies for Robotics and Autonomous Systems"
- "Position Location for Futuristic Cellular Communications: 5G and Beyond.
*Article from IEEE Signal Processing magazine January 2021:
- 3D Point Cloud Processing and Learning for Autonomous Driving: Impacting Map Creation, Localization, and Perception
Vol 15.0: Concept of Fluid Flow for Vehicular Traffic Lanes, How to Validate Simulation Using Public Data Sets, and Object Detection Under Rainy Conditions for Autonomous Vehicles. The last two from IEEE Signal Processing - Autonomous Driving (part 2): "Learning and Cognition"
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Vol 4.0: Current Sensor Technology

This newsletter is intended to provide the IEEE member with a top level briefing of the subject under review. Instead of a cumulative approach, as adopted previously, it will now only feature new content. For older content, please access previous volumes.

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 400 words is usually set for each topic, 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. However, it is not the intent to make this a forest of hyperlinks. 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. The publication will be updated periodically. 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. Mapping for Autonomous Driving: Opportunities and Challenges, Kelvin Wong et al
IEEE Intelligent Transportation Systems Magazine (Volume: 13, Number 1, Spring 2021), pp 91-106

Abstract:
This article provides a review of the production and uses of maps for autonomous driving and a synthesis of the opportunities and challenges. For many years, maps have helped human drivers make better decisions, and in the future, maps will continue to play a critical role in enabling safe and successful autonomous driving. There are, however, many technical, societal, economic, and political challenges to mapping that remain unresolved. While fully autonomous driving may be some distance in the future, intermediate steps to realize the technology can be taken. These include developing an efficient and reliable storage and dissemination infrastructure, defining minimum data quality requirements, and

establishing an international mapping standard. The article closes with 11 open research challenges for mapping for autonomous driving.

Opening Lines: For many years, maps have helped human drivers make better decisions during the control and operation of a motor vehicle. These maps, both physical and digital, allow the driver to understand the relationship between their own vehicle and the surrounding environment, in addition to assisting in navigational and routing tasks. With the advancements in autonomous vehicles, maps play an even more crucial role—unlike humans, where simple abstract maps are complementary to the driver's own senses, experiences, and judgment, autonomous vehicles require far more detailed maps to aid their decision-making process. Maps can provide an important trusted baseline where the availability of sensors cannot be guaranteed. While opinions differ on the future state of autonomous vehicles, there is consensus that it will challenge transportation norms, infrastructure, and urban development—and that maps will play a critical role in enabling the technology.

Maps can do things that other sensors cannot. First, they have an "infinite range" and, therefore, can "see," even into occluded areas. Second, maps will never fail due to environmental conditions. Within the safety-critical application of autonomous driving, maps can be considered an additional sensor that cannot fail and provide a reliable source of redundancy. Lastly, maps contain highly refined data, which can involve many hours or days of preprocessing and human verification to reduce noise and uncertainty. In turn, this allows maps to provide accurate, meaningful, current and useful information in real time. With the higher accuracy requirements of autonomous driving, mapping-related data files can also be very large, introducing challenges in the transmission of updates in real time. Furthermore, the production of mapping of such quality can also incur a high cost.

…. For autonomous vehicles, maps can be created beforehand (often referred to as prebuilt, a priori, or offline maps) or in real time (online or simultaneous mapping). Prebuilt maps can contain much more detail and information than "conventional" maps created for humans, and, as such, are often referred to as "high-definition" (HD) maps. In this review, the focus will be on prebuilt and offline HD maps and the open research challenges surrounding the uses and production of such maps for autonomous driving.

Uses of Maps for Autonomous Driving: Information from maps supports many functions of autonomous driving, including self-localization, vehicle control, motion planning, perception, and system management. Maps for autonomous vehicles can provide static and dynamic information, such as road grade, curvature, and speed limits as well as traffic speed, traffic congestion, and temporary road works.

One of the leading uses of maps is self-localization—the process of identifying where your vehicle is in relation to the surrounding environment. By using range- or camera-based sensors, it is possible to localize yourself on the prebuilt map, using lane markings, landmarks, pole-like objects, lidar intensity, or

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the overall geometry of the surrounding environment [88], [89]. It has been suggested that even the underlying geology coupled with a ground-penetrating radar can be exploited for the purposes of localization. Maps can also help predict the blocking, reflection, and diffraction of satellite signal availability for GNSS positioning. Once the ego-position is obtained, the prebuilt map can provide information that enables the system to make vehicle control decisions, such as lane change maneuvers, some of which are not possible with only sensor-based methods. Furthermore, maps can provide additional robustness and foresight for motion planning, allowing the vehicular system to "see" ahead of what is within the sensor range. It can also help with distinguishing dynamic objects and detecting obstacles. There are three main categories of mapping information that an autonomous driving system uses:

Topological: Topological maps can provide information on the connectivity between geometry features. In the case of autonomous driving, this is usually the network of roads.

Geometric: Beyond the topology of roads, it is important to consider the geometry or shape of other environmental features. Accurately representing the geometry of the objects and features around the vehicle is critical to many functions of autonomous driving.

Semantic: semantic information can provide the "meaning" of features. Semantic information for autonomous driving includes road speed limit, lane information, and road classification. It can also provide relational information, such as how lanes work together, where vehicles can and cannot turn, and where vehicles must stop.

Storage of Maps: Maps for autonomous vehicles contain far more detail than traditional maps, such as lane dimensions, distance from pedestrianized areas, and curb height. These autonomous vehicle maps require enormous computational and storage power to create and handle in real time. For example, a 3D point cloud for a 300- × 300-m area may consist of more than 250 million points, with a single vehicle estimated to produce anywhere from 11 to 152 TB of data per day. Map storage systems for autonomous vehicles must be able to: 1) handle massive volumes of incoming and outgoing data and 2) handle multiple formats simultaneously. Although traditional data storage methods can support this to certain extents, they are currently unable to meet all of the requirements of autonomous driving. The development of solid-state drives (SSDs) has provided a low-latency and high-capacity data storage option. In 2018, SSDs were available in sizes up to 100 TB, but 120–512 GB were more common. As autonomous vehicle maps grow from local to regional to national scale, the storage required to hold the mapping data will only increase. One approach is for data reduction through compression.

Production of Autonomous Driving Maps: Data for creating maps can be captured in many ways, from satellite to aerial to terrestrial sources. These sources may capture a wide variety of data, from high-resolution red, green, blue imagery to 3D point clouds to thermal imagery.

For autonomous driving, the focus is on operating in the road environment. As such, mobile mapping systems (MMSs) are often a popular choice, as they map at the road-level perspective. MMS are specialized vehicles equipped with high-end sensors (e.g., lidar scanners and stereo cameras) and positioning sensors (GNSS and inertial measurement unit/inertial navigation system), which can generate highly detailed 3D point clouds of features, such as building facades, roadside infrastructure, and trees. Simultaneously, high-resolution images can be captured using a single or multiple cameras and using wide-angle or fisheye lenses to cover the full 360° field of view. These sensors can be used together to capture dynamic environments, traffic-related information, traffic signs, and road surface conditions

In recent years, however, there has been a shift away from using a single specialized vehicle equipped with expensive sensors to deploying many and multiple vehicles with cheaper and lower-end sensors. Through this cooperative approach, multiple vehicles working simultaneously as a team can produce many local maps, which are then merged into a single global map.

Open Research Challenges:

Challenge 1—What Should We Map?

Challenge 2—Mapping Traffic Laws and Regulations

Challenge 3—Improvement of Navigation Information Integrity Through Redundancy

Challenge 4—Intelligent Driving Style

Challenge 5—Defining Minimum Data Quality Requirements

Challenge 6—Defining a Universal Mapping Format

Challenge 7—Collaborative Mapping

Challenge 8—Efficient, Effective, and Reliable Storage and Dissemination of Autonomous Driving Maps

Challenge 9—Building Maps at the National or International Scale

Challenge 10—Update and Maintenance

Challenge 11—Preserving Privacy in a Shared and Connected Environment

(1321 words)

2. Digital Twin for 5G and Beyond, Huan X. Nguyen et el

(IEEE Communications Magazine, Vol 59 Issue 2, Febuary 2021), pp 10-15

Editor's note: Validation remains a big challenge to all new systems, not least the connected vehicle, IoT and 5G developments. Here is an article that introduces the concept of a Digital Twin, DT

Introduction: Thanks to recent and notable improvements in technologies such as the Industrial Internet of Things (IIoT), wireless sensor networks, deep learning algorithms, cloud-based platforms, and high-performance computing, a new data-driven paradigm, digital twin (DT), has emerged and is currently receiving increasing attention. *The DT represents a high-fidelity digital mirror of the physical entity where the former evolves synchronously with the latter throughout their entire life cycle*. Operators rely on DT data and a virtual prototype to enhance preventive maintenance programs, pioneer next generation business models, rapidly improve product development, and maximize a product's sustainability and efficiency in the field. DT helps create comprehensive digital models of physical environments with full support for two-way communication between the digital model and the physical object to enable real-time engineering decisions.

One can build one-way data-driven/analytics-based DTs by connecting assets to an Internet of Things (IoT) platform on the cloud. However, these simulation-based DTs are often not as accurate as we want in real life. Thus, one should use physics-based DTs to get an emulated model of the asset as it goes through environmental impact, thereby producing a much more accurate prediction. The very initial concept of DT dates back to when NASA used basic twinning ideas during the 1960s for their space programs (e.g., Apollo 13). However, only around 40 years later did the concept start being developed through different names such as virtual space, digital mirror, digital copy, and then finally the term "digital twin." Only as recently as 2017 has the DT become one of the top strategic technology trends, widely investigated in many industries, including manufacturing, energy, industrial assets, and structures, such as a dual fault diagnosis method based on DT for high diagnosis accuracy in predicting the trend of production throughput, and a DT-based real-time monitoring system in for mechanical structures to improve the safety of the work environment using IoT and augmented reality.

With the support of artificial intelligence, development of digital transformation through the notion of a digital twin has been taking off in many industries such as smart manufacturing, oil and gas, construction, bio-engineering, and automotive. However, digital twins remain relatively new for 5G/6G networks, despite the obvious potential in helping develop and deploy the complex 5G environment.
General Electric developed their Predix IoT platform denoted as a DT that has the capability of ingesting large volumes of sensory data, running analytic models, and performing business rules at the same time, allowing detection of abnormal phenomena and improving plant reliability. Siemens integrates its DT solutions into smart operations at key stages throughout the product life cycle, from product design and production to operation. Microsoft also enables DT support through its ubiquitous IoT platform that models the interaction between people, spaces, and devices. The adoption of DT technology by tech leaders opens up new opportunities of DT integration for more advanced engineering applications.

It is expected that 5G will enable $12.3 trillion global economic output and support 22 million jobs by 2035. Manufacturing is expected to see the largest share of 5G-enabled economic activity (3.4trillion out of 12.3 trillion, i.e., 28 percent), while information, communications, and technology (ICT) is second with $1.4 trillion. The potential advantages from 5G are significant, but realizing them remains a challenging task. Despite all the promises, customers and investors remain skeptical of the technology maturity. There are prohibitive complexities with hybrid network deployment challenges, with multi-vendor scenarios and with security risks. Minimizing the risk for life-critical manufacturing and robotic doctor applications is essential, especially with the evolving security risks. Some market challenges with open questions exist:

1. How do we speed up the deployment of new (but complex) 5G technologies?
2. How do we provide flexible testbed facilities with high availability?
3. Who is willing to invest in the expensive 5G deployment with uncertain returns?

Thus, there is demand for a virtual solution that could create a digital model to replicate as accurately as possible the 5G ecosystem and help tackle all the above obstacles to satisfy the 5G needs. Using DT for 5G networks has recently gained significant interest, including from the leading telcos (e.g., Ericsson and Huawei), being a new topic where sensor/network data, traffic data, data mining, data visualization, and data interpretation are integrated into one system to facilitate the live replica of a process or whole 5G network. The DT has the potential to assess the performance, predict the impact of the environment change, and optimize the 5G network processes and decision making accordingly. Consequently, this study presents a concept of cloud DT for 5G networks aiming to perform continuous assessment, monitoring, and proactive maintenance through the closed-loop data from physical entities to the virtual counterparts and vice versa. Within the 5G DT, the digital 5G model will run alongside the physical 5G network to perform operational predictions and enforce optimized decisions into the living network and associated services.

5G Automotive Specifics: The latest developments in both the automotive and communications industries, especially related to the rollout of 5G networks, the Internet of Vehicles, and adoption of cellular vehicle-to-every-thing (C-V2X) connectivity, are fueling significant transformations on the roads in terms of autonomous driving where 5G connected vehicles will negotiate traffic, motorways, roundabouts, and so on, without human intervention behind the steering wheel. Thus, 3rd Generation Partnership Project (3GPP) Release 16 targets Industry 4.0 and C-V2X services.

The deployment of 5G aims to enable effective connected cars communication as well as fully automated driving that could increase road safety and improve traffic management. The provisioning of ultra-reliable low-latency communication (URLLC) through 5G will enable the support for these connected cars services as well as a new set of related applications (traffic prediction, intelligent navigation systems,

cooperative collision avoidance systems, etc.). The highly dynamic nature of vehicular networks along with the heterogeneity of wireless infrastructures for connected cars and the variety of vehicular applications (e.g., safety, traffic management, infotainment, etc.) make the resource management and low-latency communication requirements a significant challenge. It is expected that thousands of millions of miles of expensive driving setup is required for testing and validating the connected autonomous vehicles. Consequently, one promising solution in the automotive sector is the use of DTs to create the virtual model of a 5G connected vehicle. The DT could analyze the overall performance of the 5G connected vehicle and enable the delivery of personalized services. AI is used to predict the vehicle's performance under various dynamic conditions, identify problems, and apply solutions, making the driving experience safer for the user. However, before taking the solution out on the public roads, it has to be tested thoroughly through emulations. The Spirent 5G DT aims to emulate the 5G network for testing the behavior and performance of the connected vehicles within a controlled realistic environment using a 3xD drive-in simulator. The 5G emulator would enable the car manufacturer understand how the vehicle behaves under different road specific scenarios (e.g., parking, pedestrians, road traffic, weather conditions) as well as under various 5G connectivity specific scenarios (handover, network traffic load, radio propagation, etc.). As the automotive industry relies on 5G to power core functionalities, this level of testing could speed up the adoption and integration of autonomous vehicles in a safe, reliable, and secure manner. The advantages of 5G DT integration within the automotive industry include efficient use of road capacity in real time, reduction of carbon emissions, reduction of road accidents, as well as limiting the need for emergency services in case of accidents. However, some significant questions still remain open, such as: In a critical scenario, should the autonomous car value the life of its passenger over a pedestrian's? (1269 words)

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