Top Level Newsletter: Connected Vehicle

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Vol 39: This issue includes:

1. Mapping for Autonomous Driving (repeated from Vol 17)
2. Recent Advances in Automated Driving Technologies

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.

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 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:

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

<u>Geometric:</u> 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.

<u>Semantic:</u> 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)

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2. Recent Advances in Automated Driving Technologies (Guest Editors, Basilio Lenzo et al)

IEEE Vehicular Technology: December 2022, Volume 17 Issue: 4. pp16-17

We live in the era of the advent of automated vehicles. These will bring dramatic changes in both the automotive industry and everyday life, revolutionizing the concept of passenger mobility. The issue of perception is crucial for an autonomous vehicle and presents important challenges, many of which still need to be addressed. In this context, the choice of sensors is pivotal, yet there is still no general consensus on what the potential "best" sensory equipment should consist of. Furthermore, perception-related information is then used to make timely decisions on path planning and vehicle dynamics control to ensure efficient and safe vehicle behavior. Here, machine learning algorithms are playing an increasingly important role, for example, in the generation of trajectories perceivable as "natural" by the car's occupants or in object recognition.

This special issue brings together researchers working in this field to share their latest developments on sensing and perception; path planning; and machine learning and control using data-driven learning or physics-driven algorithms, focusing on technologies directly applicable to autonomous vehicles. After a rigorous peer review process, four high-quality articles (out of 18) were selected for publication in this special issue.

The first article, "Trajectory Prediction Using Graph-Based Deep Learning for Longitudinal Control of Autonomous Vehicles: A Proactive Approach for Autonomous Driving in Urban Dynamic Traffic Environments," by Youngmin and Yi [A1], presents a method for the trajectory prediction of surrounding vehicles and proactive longitudinal control of autonomous vehicles in urban road environments. Their control method utilizes the prediction results of the target vehicle to give action requests in a proactive manner considering both safety and ride quality.

The second article, "Cellular Localization for Autonomous Driving: A Function Pull Approach to Safety-Critical Wireless Localization," by Whiton [A2], identifies five important requirements for cellular localization for safety-critical systems, with a particular focus on autonomous driving, and puts them in the context of industrial and academic trends and standardization. The article discusses how a cellular localization sensor that can provide position, heading, and velocity estimates with error overbounds in an external reference frame is a powerful tool for autonomous driving systems. The article was featured in this newsletter v 31.

The third article, “Integrated Sensor Fusion Based on 4D MIMO Radar and Camera: A Solution for Connected Vehicle Applications,” by Lei et al., presents an integrated sensor fusion solution based on multiple-input, multiple-output (MIMO) radar, camera, and on-device computing that can estimate objects’ range, velocity, azimuth angle, and elevation angle, which can be further used to estimate their length, width, and height. The proposed solution and its envisaged evolutions also have significant potential for applications on intelligent traffic management systems such as traffic signal control and roadway digital twins.

The fourth article, “Clothoid-Based Lane-Level High-Definition Maps: Unifying Sensing and Control Models,” by Cudrano et al., proposes two vision-based pipelines for generating lane-level high-definition maps using clothoid models. Such maps relieve vehicles from most of the scene parsing so that the resources required by scene understanding could be invested only on dynamical objects, which require higher alertness and faster reaction times, thus allowing them to focus on dynamical objects, trajectory planning, and control. An interesting experimental validation is provided, also demonstrating that the idea can be effectively used to generate lane-level maps in extra-urban scenarios.

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