Proceedings of the Seventeenth International Conference on
Civil, Structural and Environmental Engineering Computing
Edited by: P. Iványi, J. Kruis and B.H.V. Topping
Civil-Comp Conferences, Volume 6, Paper 15.1
Civil-Comp Press, Edinburgh, United Kingdom, 2023
doi: 10.4203/ccc.6.15.1

Maps Towards Autonomous Driving Ecosystem

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Abstract

The development of vehicle navigation maps used for vehicle transportation from the early days of paper maps to the modern use of satellite and mobile mapping technologies is not only ongoing but accelerating. Current maps have undergone significant changes in terms of format, content, and topology. They have evolved into 3D representations and now include dynamic content such as real-time road events and traffic updates. Different production technologies, such as aerial photogrammetry and mobile mapping, are used. The importance of standardizing the map content is also emphasized. Two main applications of map data, Standard-Definition maps (SD maps) for human interpretation and High-Definition maps (HD maps) for machine interpretation, are available today. The role of maps in the perception of the environment by vehicles is also discussed.

Keywords: autonomous driving, map ecosystem, simulation

1 Introduction

Navigation maps were published with the car maps folded and placed in the glove compartment. In 1930, with the development of the Italian Iter Avto, maps were introduced in cars, although the driver still had to do the positioning. The idea of Advanced Research Projects Agency using orbiting satellites for positioning was tested in 1960 with the Transit satellites; by 1968, 36 satellites were in operation. In 1978, the first Navstar GPS (Global Positioning System) satellites were launched into orbit, making the idea a practical reality. In 1980, the Japanese Electro Gyro-Cator was introduced as an integrated map-based navigation system with unique inertial-gyroscopic positioning. In 1985, the Etak Navigator digitally stored maps on magnetic tape. The first navigation company was founded as Karlin & Collins Inc. in the same year, later called Navtech and now HERE Technologies. By 1987, maps were stored on CD, the 1990s saw major mapping campaigns, and in 2000, the civilian revolution in satellite positioning began with the elimination of SA (Selective Availability), a jamming signal that affected GPS accuracy. [1, 2]

The maps used for vehicle navigation have undergone significant changes. Regarding map formats, the most significant improvement has been the digitization of analog (paper) maps. Another milestone was replacing the CAD-like storage model with databases, then with distributed or cloud-based databases. In terms of content, maps began as two-dimensional (2D) representations. Then, over time, maps gradually evolved into three-dimensional (3D) models. Early maps had a road-level representation that provided a limited description of the road infrastructure. In contrast, modern maps have moved to a lane-level representation that delivers a more comprehensive description of the road infrastructure. The initial environment presentation on maps was done using keyed pictograms of buildings, churches, gas stations, etc.

This was followed by accurate geometric descriptions using object models and three-dimensional point clouds, which provided a more detailed representation of built and natural objects. The most recent phase of map evolution includes dynamic content (4D), such as information on road closures, construction, weather conditions, traffic light status, and even the location of road users. This dynamic content allows for real-time updates and provides the user with more accurate and relevant information. [6, 9]

Map production uses various technologies. The traditional method of field geodesy involves visiting and measuring points, which is slow and expensive. Terrestrial Laser Scanning (TLS) is a faster and more efficient alternative, capturing millions of points per second with most of the work done in the office. However, it requires specialized hardware and data processing expertise. Aerial photogrammetry can cover larger areas at a lower cost, but is highly dependent on weather conditions and requires expertise. Satellite imagery is a similar alternative but serves limited detail and requires processing expertise. Drones are becoming popular for mapping tasks because they are easy to use and set up. However, they have limited coverage and variable accuracy. Mobile mapping, in which surveying equipment is mounted on a mobile platform such as a van, is the best solution regarding detail, geometric accuracy, and processing methodology. It uses cameras and laser scanners to collect data and can cost-effectively survey large road networks. However, the equipment is expensive to purchase, and most of the work is executed in an office environment. From a quality standpoint, mobile mapping is the best method for supporting self-driving. [6]

An exceptional feature of transportation maps is their topology. The discipline of topology studies properties of objects that are invariant under any continuous geometric transformation or deformation. Maps are constructed from points and their connections. Connections can be used to create open chains (like lines) or closed shapes (like polygons). Because of the transition from street-level to lane-level maps, the former line (arc-node) topology is no longer sufficient, so a polygon (polygon-arc) topology is additionally required. This paradigm shift is crucial for data processing and map algorithms dedicated to HD maps. The need for topology checking and fixing algorithms is strongly recommended. [7, 8, 11]

The diversity of possible developments and the usability of data from many map providers require that map content is stored and transferred in a standardized format. In this spirit, international groups have been formed to bring map data collection, storage, and communication onto a common platform: physical and exchange formats have been specified and standardized. The former plays a prominent role in data storage, and the latter in the integration of data from different providers.

2 Potential roles of maps in transportation

As mapping technologies have evolved, it has become clear that there are two main applications. If the primary use is human, the map (data) is interpreted by people, and then it must fully support human environmental and pictorial perception; a Small/Standard-Definition map (SD map) is needed. On the other hand, if the primary use is not for computers, the map (data) is processed by a machine ("vehicle"), then a High-Definition map (HD map) is required. The latter is characterized by high accuracy, high reliability, and a highly updated data set [12]. Therefore, a crucial difference between SD and HD maps lies in the data geometric and temporal resolution, size, representation, and relation to other system components. No special environmental sensing is expected for human use, whereas in automotive use, other onboard sensory systems must be considered and managed in an integrated way.

In order to understand the role of maps, the vehicle must first be broken down into larger units (Figure 1). Among these components, the observations of the environment represent the perception of the infrastructure and the objects moving on it, followed by the interpretation of the data received, i.e., the identification, recognition, and movement characteristics of the objects (vehicles, pedestrians, bicycles, etc.) [4]. In addition, the vehicle control process, as a complex one, selects the appropriate intervention based on the information from the map. In addition, the communicating vehicle receives additional information from other road users or the infrastructure.

In a vehicle controlled by a human driver, all decisions and interventions are performed by the human driver. The vehicle can reach higher and higher SAE (Society of Automotive Engineers) levels of automation through the presence of assistants to achieve elementary and complex operations; Levels 0 to 2 are dominated by humans, while Levels 3 to 5 are by machines. The entirely self-driving vehicle is at Level 5. [10]

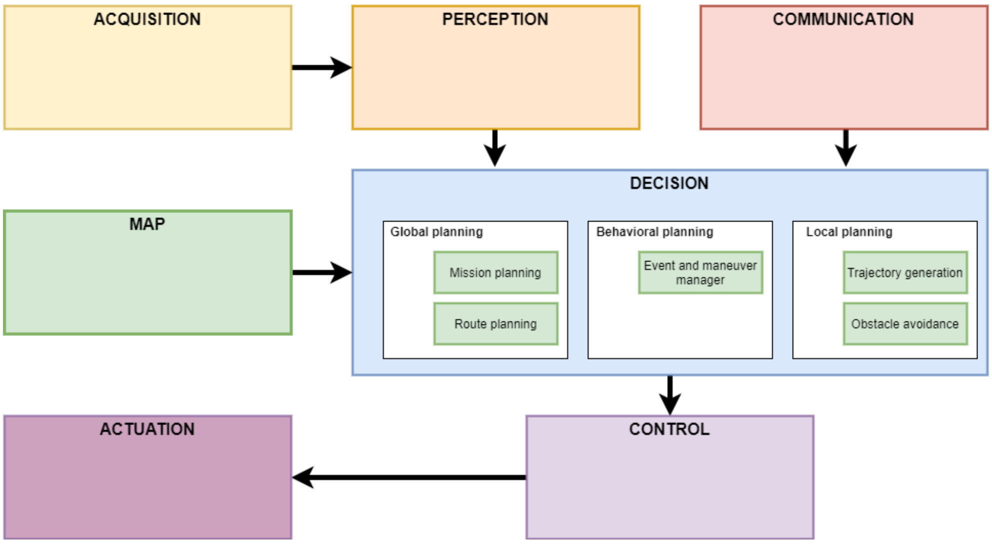

Figure 1: Functional component blocks in a vehicle

The role of maps in this development context can be threefold:

1) Use HD maps with cheaper, simpler, less accurate sensors.

2) SD maps are used, but all sensors are "high-end".

3) Use simple sensors alongside the SD map, but strong artificial intelligence replaces human decision-making.

The first mode is map sparse – many adopters hope to adopt higher automation rapidly. The second approach expects a breakthrough from intensified hardware development while paving the way for the third. The third option is effectively the machine realization of the human competencies needed for vehicle control – most likely through AI-based solutions for integrating human competencies beyond the AI-based solution of separately decomposable subtasks [4, 5]. The latter is moving intensely in the direction of Artificial General Intelligence (AGI).

Vehicle assistants with navigation support – especially Advanced Driver Assistance Systems (ADAS) – use the map as a sensor [19]. For example, the Adaptive Front-lighting System uses map information to better illuminate curves and intersections, while Predictive Lighting controls the vehicle lighting based on topography. The Intelligent Speed Assistant compares the map information with the messages of locally detected traffic signs and road markings and takes them into account for speed control. [3, 13]

The Predictive Gear system selects the right gear based on the route's elevation profile, resulting in fuel savings and increased uptime. The Fuel Efficiency Advisor only makes suggestions, while Hill Descent Control intervenes to adjust the vehicle's settings. The Eco-Driving and Eco-Routing assistants consider road gradient, number and type of approaching intersections, pedestrian crossings, speed limits and bumps, speed cameras, traffic data, and weather information elements available in the dynamic map database system. The examples go on and on.

In 2015, another revolutionary idea emerged: vehicles equipped with sensors should be not only users but also creators of the map database. This idea led to the creation of the SENSORIS standard in 2017, which transformed vehicles with environmental monitoring and communication into "rolling mapmakers": map maintenance services receive and process maps, incorporating changes detected on the road into the map database so that continuous updates are available. Obviously, a higher level of automation (expected to be AI-enabled) is inevitable in this activity [5].

3 Simulation supported by maps

With a focus on extreme speed and cost efficiency, vehicle development has long recognized that computer simulation can give a competitive edge and be a powerful tool to support development work. Today's simulations not only test the individual components of a vehicle but can also analyze the operation of the vehicle as a whole or its sensors and assistants. To achieve this, the digital twin of the environment, i.e., 3D HD maps must be fed into the computer simulator. [15, 16]

Map formats have been extended to include formats suitable for simulation. The most important of these is the OpenX family of standards, where OpenDRIVE describes the geometry of the road and its surroundings in detail, OpenCRG provides the road surface in centimeter resolution, and OpenSCENARIO ensures realism by describing the traffic. Of course, this family of standards is complemented by other additional elements to support the full spectrum of product development [14, 20, 21]

However, simulation has an interesting side effect. Allowing vehicles and their assistants to be studied in situations that are rare or difficult to create in reality also reveals the characteristics and properties of maps. For example, if the positioning based on a map is incorrect due to inaccurate map data, the application built on top of it may indicate an anomaly or at least show a warning. The quality of the map database can thus be verified and certified through simulation.

Therefore, it is necessary for automotive development and applied research to focus intensively on providing a map background for simulation. Development begins with simulation, continues in the laboratory and on the test tracks and proving grounds, and finally, to a limited extent, on the public road. In this process, a map of the synthetic environment can be created, as well as a map of the test track and lastly the road infrastructure. The map creation is therefore much more complex than simply creating a digital database from a survey of reality. [17, 18]

4 Conclusions

The evolution of navigation maps has significantly changed from analog to High-Definition maps for autonomous vehicles containing dynamic content. The role of maps in transportation has evolved from a tool for human interpretation (SD maps) to a crucial component for autonomous vehicles.

Information technology, communication, and other metrological developments are quickly incorporated into map technologies and put into practical use [4]. The advancements in methodology have not only improved the accuracy and detail of the maps but have also made the production process faster and more cost-effective [12]. Various technologies are now used for map production, with mobile mapping being the best process for supporting self-driving. The development of these newly released maps is still ongoing, including dynamic content and real-time updates.

The fact that the vehicles are not only beneficiaries of the map data but also contribute to its verification and updating, thanks to the observations of the onboard sensors, can also be interpreted as an unusual but very straightforward perception method. Standardizing map formats and exchange protocols has also made integrating data from various providers easier.

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