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Progress and Thoughts Toward High-Precision Road Navigation Map

Liu Jingnan[1], Wu Hangbin[2], Guo Chi[1], Zhang Hongmin[1], Zuo Wenwei[1], Yang Cheng[3]

1. Wuhan University, Wuhan 430079, China
2. Tongji University, Shanghai 200092, China
3. EMG Technologies (Beijing) Co., Ltd., Beijing 100070, China

Abstract: With the rapid development of the Internet, new industries, such as "Internet Plus" intelligent transportation and unmanned systems based on location, have gradually increased in number. The development of these industries requires high-precision location data; however, the 5 m accuracy of traditional navigation maps is insufficient to meet this demand. Therefore, a high-precision road navigation map is proposed. A high-precision road navigation map can provide more detailed road information, and can reflect the situation of the road accurately. Compared to traditional maps, a high-precision road navigation map has three advantages. First, it includes more map layers. Second, the content of the layers is finer. Third, a new map structure is created. However, the rich information content of high-precision maps leads to the generation of large amounts of data. Traditional centralized big-data-processing modes are unable to meet the computing needs required for processing such large amounts of data. Consequently, a big-data-processing model of "crowdsourcing + edge computing" is proposed to solve the problem of high-precision map calculations. Currently, high-precision road navigation maps are advancing rapidly, but some problems need to be solved in the development process.
Keywords: high-precision road navigation map; "Internet Plus" intelligent transportation; unmanned systems; crowdsourcing; edge computing

1 Introduction

A traditional navigation map is generally used for cartographic information queries and navigation by humans, who are the main service targets. Based on the visual identification ability and logical thinking of humans, much road information in traditional maps is simplified [1]. With the development of the Internet, many new services and industries based on location have emerged, such as the "Internet Plus" intelligent transportation system (ITS) and unmanned systems. The Internet Plus intelligent transportation implementation plan has been released, which aims at promoting the development of ITSs. It was proposed by the National Development and Reform Commission (NDRC). The maps provide services to not only humans, but also machines (gradually), because these services are based on the Internet. Therefore, there are more requirements for the accuracy, content structure, and computing mode of the map.

1.1 Map accuracy

The accuracy of an ordinary navigation map is approximately 5 m, which can describe the locations and structures of roads, but without any other detailed information. Therefore, vehicles cannot obtain their exact locations. However, the absolute accuracy of a high-precision navigation map can be less than 1 m, and its relative accuracy can reach 10 to 20 cm, which includes more detailed information, such as lanes, lane lines, center lines, and restriction information, as shown in Fig. 1.

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Corresponding author: Guo Chi, Wuhan University, Associate Professor. Major research field is navigation and location service. E-mail: guochi@whu.edu.cn
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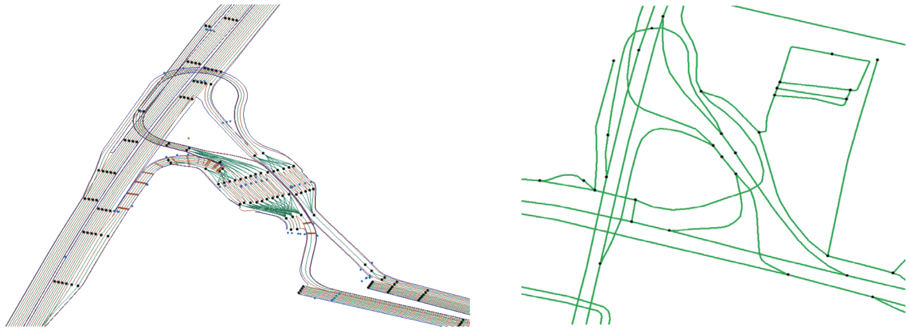

High-precision road navigation map (lane level) Ordinary navigation map (road level)

Fig. 1. Comparison of a high-precision road navigation map and an ordinary navigation map.

1.2 Map structure

A high-precision navigation map can reflect the patterns of roads accurately, because it includes more-detailed layers and more data about roads. The high-precision map includes not only coordinates of high precision, but also roads with exact shapes. Meanwhile, information about the gradient, curvature, heading, and height of every lane can be added to the high-precision map. In addition, the lane lines (dashed line, solid line, single line, and double line), lane line color (white or yellow), road isolation belts, texture of the isolation belts, road arrows, content of the road markings, and locations must be described in detail.

1.3 Computing mode

The data volume of the high-precision map is 10^5 times as much as that of the ordinary one. Therefore, the current centralized big-data processing, which is based on cloud computing, cannot meet the needs of the high-precision map. With the development of the Internet of Things (IoT) and 5G communication, a type of cloud cooperative computing method, edge computing, has been proposed. Meanwhile, the task distribution mode of crowdsourcing has been applied in several industries. Therefore, the data processing of a high-precision navigation map can use a "crowdsourcing + edge computing" mode.

2 Related work

With the rapid development of ITSs and autonomous driving, current ordinary navigation maps cannot meet the high-level requirements for content, accuracy, and integrity [2]. High-precision maps that aim at roads have been proposed and gradually accepted [3,4].

Currently, there are many studies applying high-precision map data in assisted driving and autonomous driving. For example, some researchers studied information behavior and vehicle location based on high-precision maps [5,6]. Some used high-precision map data in assisted driving and autonomous driving to conduct studies. Furthermore, a method to guide the trajectory in an autonomous-driving lane based on high-precision map data has been reported [7,8]. There have been many studies on methods for high-precision maps, such as data collection along specific routes by equipping vehicles with GPS-RTK [9]. Another method extracts road information by using laser radar and wide-angle cameras; the accuracy could reach 10 cm after vehicles have been equipped with Global Navigation Satellite System (GNSS) capabilities. However, this method is expensive [10]. Some researchers also developed a method that uses low-cost sensors to build lane-level maps, locate by GPS/INS tight coupling, and obtain related map information from orthophoto maps [11].

In China, the number of companies engaged in the mapping and production of high-precision electronic maps has been increasing gradually. For Google and Daimler, a high-precision electronic map is an important aspect in developing autonomous vehicles [12]. In 2015, Audi, BMW, and Daimler jointly invested 3.1 billion dollars in purchasing Nokia's Here map, preparing for the research and development of high-precision maps. High-precision maps were used in specific situations; for example, the BMW 3-series, Track Trainer in 2011, and Audi RS7 in 2014 completed the race in Laguna Seca and Hockenheim with the use of high-precision maps. Since 2016, many Internet companies, such as Google, Uber, Baidu, and Alibaba, have been obtaining map data by purchasing related companies and combining their own algorithms and cloud computing to produce high-precision maps. Meanwhile, automobile companies began to rely on the map services provided by third parties. At the beginning of 2017, Mobileye signed agreements with Volkswagen, BMW, and Nissan, in which Mobileye provided map production, and the automobile companies were responsible for providing more map data for Mobileye.

3 Requirement analysis and modeling

Based on the application of the Internet Plus intelligent transportation and typical application scenes for the unmanned-system industry for the next 20 years, high-precision navigation maps are divided into six layers to set up a demand model, as shown in Fig. 2.

3.1 Internet Plus intelligent navigation

With continuous construction of urban environments, many new traffic management measures, for instance, high-occupancy vehicle (HOV) lanes and reversible lanes (Fig. 3), have been implemented to improve the efficiency of road utilization and alleviate road congestion. An HOV lane is a lane on main roads that can only be used by vehicles carrying three or more passengers in heavy traffic conditions. A reversible lane is a variable lane in which traffic may travel in either direction, relying on certain conditions, to improve traffic flow during rush hours. These new traffic management schemes are implemented mainly through lanes, and high-precision navigation maps can accurately reflect lane information and provide people with intelligent navigation services.

3.2 Internet Plus intelligent traffic management

There are many difficulties in road-traffic law-enforcement administration, particularly in law-enforcement evidence collection and emergency response. A high-precision map can provide a new technological means for resolving the difficulties in traffic law-enforcement administration.

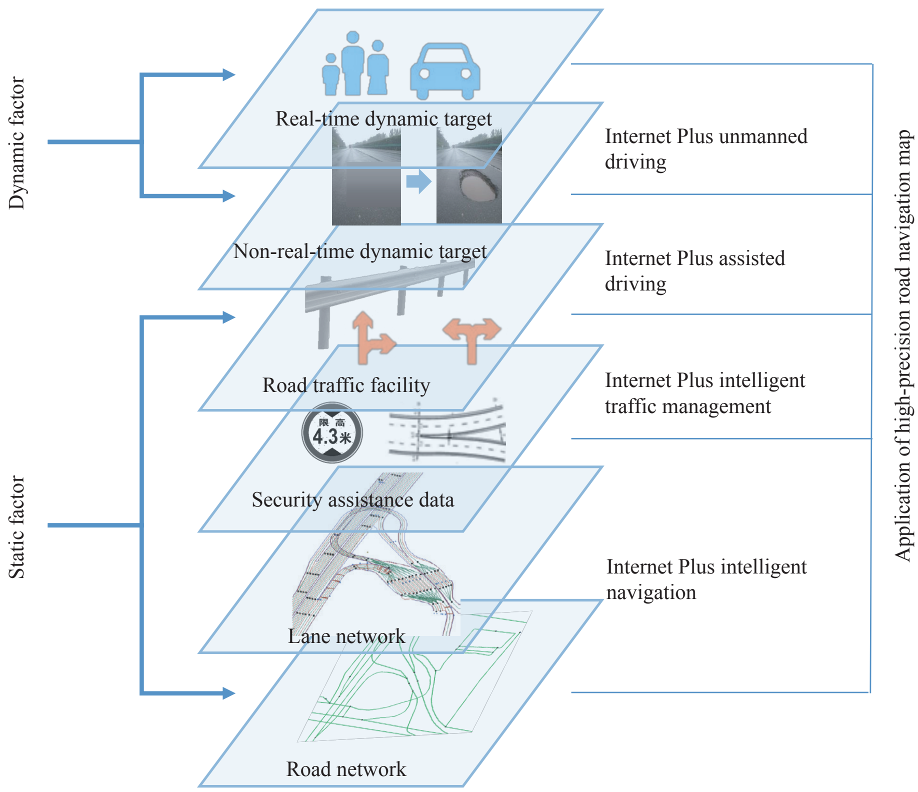

Fig. 2. Application analysis of high-precision road navigation map.

Fig. 3. HOV lane (left), reversible lane (right).

3.2.1 Law enforcement of traffic police

Law enforcement evidence collection of lane-level illegal behaviors is a difficult problem in road law enforcement. Lane-level illegal behavior is when, with respect to the ground level or other moving targets, the relative position of the moving target moves within one lane level, and the behavior of the moving target violates traffic regulations [13]. For example, the vehicle does not drive under the provisions of the traffic lane. Because of the problems in data collection and on-site restoration, it is difficult to collect evidence for law enforcement. Fortunately, high-precision navigation maps can show accurately which lane the vehicle is driving in. Therefore, lane-level illegal behaviors can be judged accurately, meeting the needs of law enforcement evidence collection.

3.2.2 Auto insurance claims

Auto insurance claims have been plagued by insurance fraud for a long time, and this has cost considerable manpower and material resources. Insurance personnel can only survey the evidence after an accident, and cannot judge the whole process of the accident. Because the high-precision map contains detailed lane information, it can accurately reflect the driving state of the vehicle and restore the whole process of the accident on the map. Thus, the high-precision map can help insurance personnel to judge the accident accurately.

3.3 Internet Plus assisted driving/unmanned driving

Unmanned driving requires maps to possess geometrically smaller granularity to provide detailed information on each lane of the road. In the topological network, it is also necessary to express connections among lanes accurately. High-precision maps contain multiple levels of geometric topological data, which can meet the requirements of different levels in assisted driving and autonomous driving. In addition, high-precision maps contain two types of dynamic factor. One is the semi-real-time dynamic factor, which is mainly used for global path planning in autonomous driving. The other is the real-time dynamic factor. This refers to dynamic obstacles, which are used to realize local path planning in autonomous driving systems.

4 Structure and calculation of high-precision road navigation maps

4.1 Structure of high-precision road navigation maps

The road map reflects the actual road; it depicts a specific category through a specific layer and then superimposes the layers to express the road surface. The navigation map displayed on the terminal is obtained by superimposing 10 or 20 layers of images with different resolutions. When a user zooms in/out of the map, the program chooses tiled maps with various resolutions (using the grid to simulate entities) according to the scaling, and pieces together a complete map. The same is true for high-precision road navigation maps, which include more layers than ordinary electronic maps and more-detailed descriptions in each layer.

High-precision road navigation maps consist of four types of data, namely, data of road networks, data of lane networks, data of road traffic facilities, and safety auxiliary data. The map structure formed by these four types of data displays different information because of the corresponding accuracies of the map. A sample of the basic structure and its information display is shown in Fig. 4.

The road network is mainly composed of a road baseline

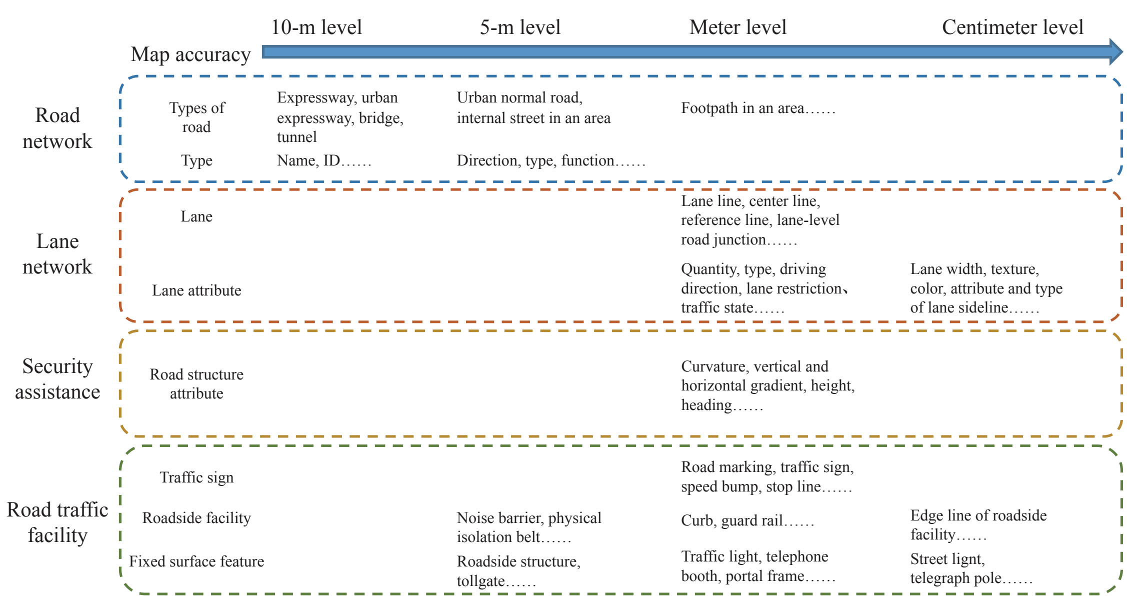

Fig. 4. Map structure and its content diagram.

network, describing the geometric shape of the roads and the relationship between the road network and road facilities. A road network diagram of a high-precision map includes layers of the road baseline, the road baseline junction, and intersections, as shown in Fig. 5.

The lane network records the relevant properties of each independent lane in the road network, and it is used for lane-level road display, positioning, path planning, and driver assistance. It includes features such as layers of lane-level roads, lane-level road junctions, lane-level road attributes, and road surface markings, as shown in Fig. 6.

Security auxiliary data and the data of road traffic facilities are used for describing the lane security data and other traffic facilities in the lane. This is to assist with lane-level positioning, and to display such information as curvature, heading, and vertical and horizontal gradient.

The data of road traffic facilities include such information as traffic signs, roadside facilities, and fixed surface features.

4.2 Computational model

Because high-precision road navigation maps contain more road information, their data volume is larger. The data volume of a traditional navigation electronic map is approximately 1 kB per kilometer, whereas that of a high-precision map is approximately 100 MB per kilometer, which is 10^5 times that of the traditional navigation map. With the complex and diverse data types in high-precision maps, the significant increase in the data volume, and the need for real-time data processing, the centralized big-data-processing method focused on a cloud-computing model cannot meet the requirements of high-precision map data calculation. Thus, it is necessary to establish a new computing model. The crowdsourcing + edge computing model proposed can be successfully applied as a high-precision-map computing model.

The data collection process of high-precision maps is difficult, and it requires the vehicle to run across every road to collect data, and then upload the data and map the results. On the one hand, data collection takes considerable time; on the other hand, the process consumes more resources. The repetition of the process results in large amounts of duplicate information, because the high-precision map updates data periodically with changes in road information. These problems can be solved by means of crowdsourcing, and the users of high-precision maps can also be mappers. Data collection devices are installed on vehicles that use high-precision maps by means of crowdsourcing. The devices collect data while they are using the high-precision map when vehicles are driving, and then they upload the acquired data. This method can meet the need for urban street information, which has to be updated once a week to reflect the roads' structures and new traffic patterns. Mapper, a US firm, has applied this approach to obtain map data.

With the rapid development of the IoT and 5G, a new computing mode, edge computing, which is different from traditional cloud computing, has been proposed. Edge computing is a computing model that performs calculations at the network edge.

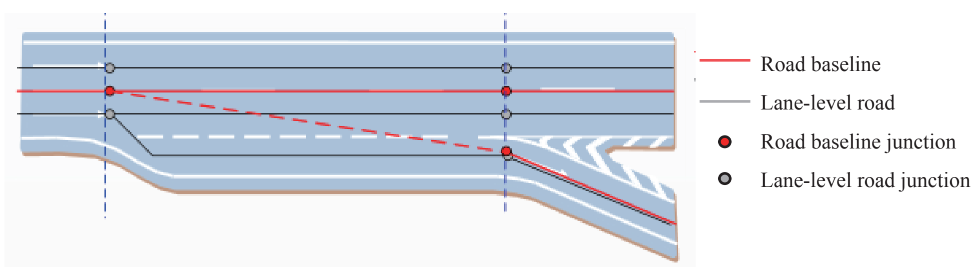

Fig. 5. Road network diagram of high-precision road navigation map.

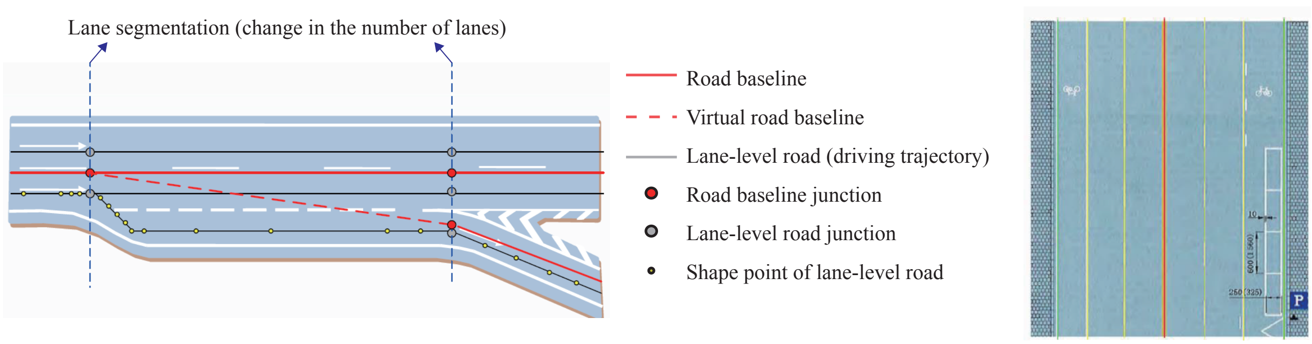

Fig. 6. Lane network diagram of high-precision road navigation map.

The downstream data at the edge for these calculations are cloud services, the uplink data are for high-precision map services, and the edge in edge computing is any computing and network resource of the path from the data source to the cloud-computing center [14,15]. This calculation method builds an open platform integrating the core competencies, such as network, computing, storage, and applications at the network edge that is close to the data source. Further, it provides edge intelligent services nearby, meeting the critical requirements of industry digitization: agile links, real-time business, data optimization, application intelligence, security, and privacy protection. For the high-precision map, because of the increase in data volume and the demand for being real time in edge computing, the original computing tasks must be transferred from the cloud center to the network edge devices. This is to improve the performance of data transmission, make it real time, and lower the computing load of the cloud-computing center. The calculation model reference-frame of the developed high-precision map is shown in Fig. 7.

5 Thoughts toward the high-precision road navigation map

5.1 Standard system framework

An increasing number of enterprises and institutions engage in high-precision road navigation map surveying and mapping, but their technical levels, adopted equipment, operational approaches, forms of data processing, and results differ. In addition, different enterprises and institutions adopt different standards. All these differences bring problems to the management and sharing of the high-precision maps; therefore, strengthening the establishment of a high-precision road map's standard system framework is crucial. The framework for high-precision electronic maps is the basic unit to form a standard system of high-precision electronic maps. It consists of four parts: basic standard for maps, standard for cloud integration, standard for application service, and standard for testing and evaluation, as shown in Fig. 8.

5.2 Privacy and security

For national security, many countries have numerous regulations on the information collection and drawing of public maps, including accuracy, surveying and mapping areas, institutions, personnel, and other restrictions. Accordingly, policies on high-precision data protection and public map information collection must be further standardized, striking a balance among ensuring information security, encouraging the technological development of high-precision maps, and finding solutions.

5.3 Opening of coordinate system

Traditional navigation maps have conventional encryption methods, such as review of the electronic map version and adding offset. However, a contradiction between these methods and high-precision maps exists. Therefore, we can embrace innovative thinking in the future development of high-precision maps. Moreover, because the practical application of navigation and positioning services is local, an attempt can be made to improve the positioning accuracy and solve the problems of security with the relative coordinate system.

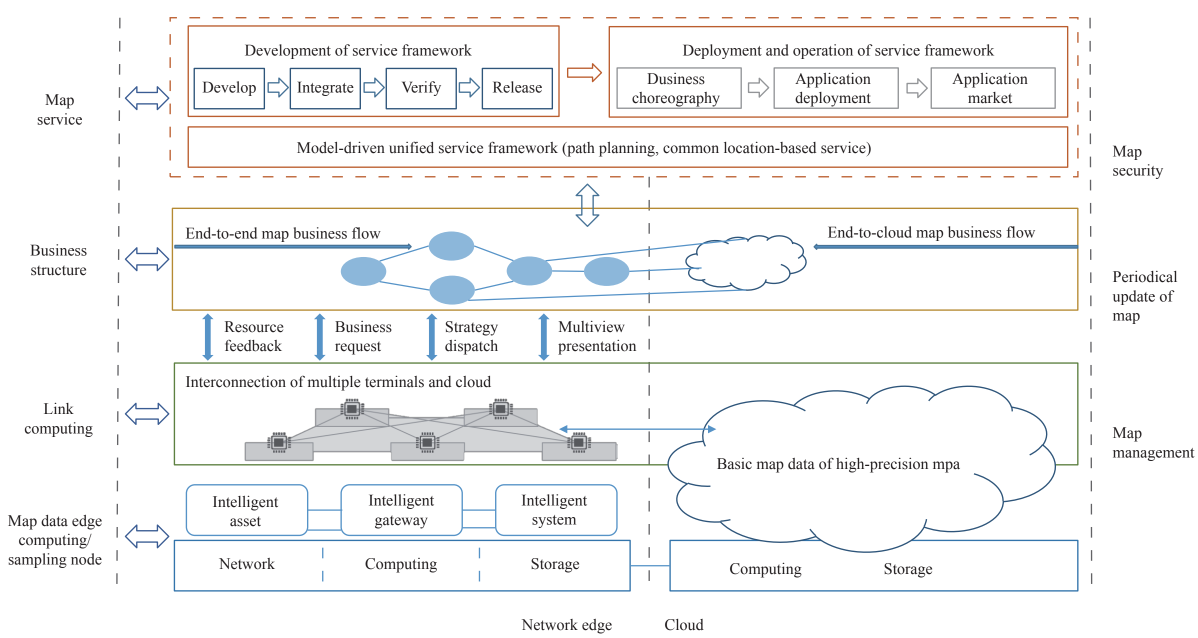

Fig. 7. Edge calculation model reference-frame of high-precision map.

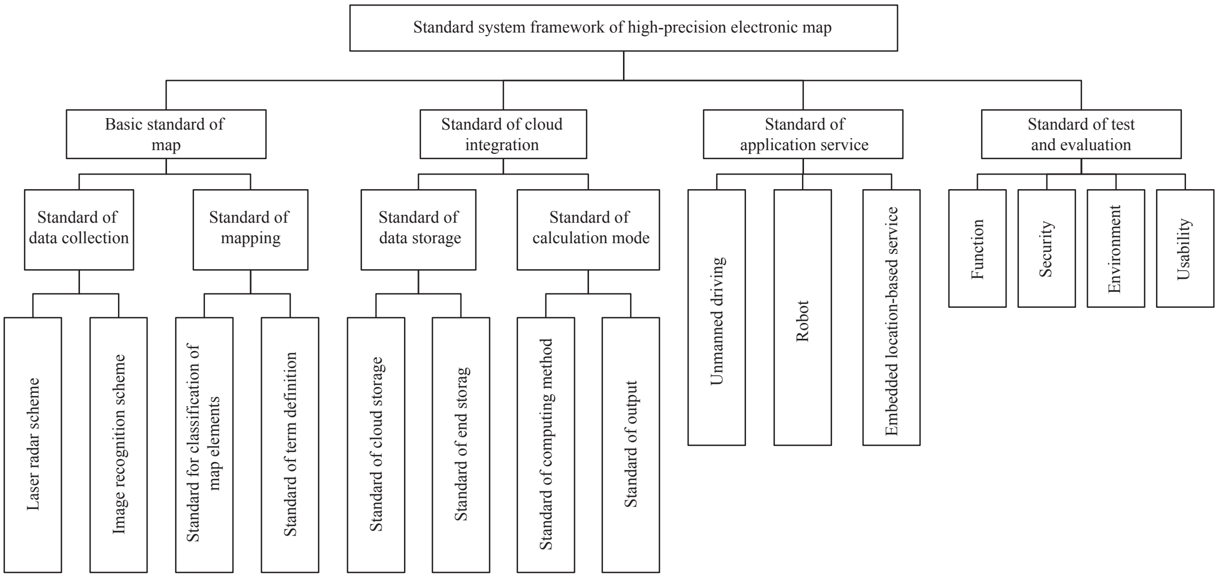

Fig. 8. Standard system framework of high-precision electronic map.

5.4 Timely and accurate data updating

The traditional navigation map can ensure the accuracy of navigation services because of timely and accurate data updating by the commercial map companies. In addition to the geometric information of roads and lanes, the update process for high-precision maps entails substantial data updating, which includes transportation elements. Moreover, the high-precision map itself contains substantial amounts of data. If the data are updated by the original collection method every time, this will result in excessive amounts of redundant data and high costs. Therefore, it is more convenient, more reliable, and less expensive to obtain large amounts of real-time data from users by means of crowdsourcing in the future development of high-precision maps.

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