Roadside Unit Deployment of Cooperative Vehicle-Infrastructure System Based on Digital Measurable Image Method

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Abstract. As the trend of the new generation of intelligent transportation systems, the application of the cooperative vehicle-infrastructure system (CVIS) is important to reduce traffic congestion and accidents. For the cooperative vehicle-infrastructure system, the roadside unit (RSU) is a new application without enough deployment experience. Meanwhile the deployment of traditional mechanical and electrical infrastructure is generally based on experience and is easy to change the design. This paper analyzes the key technical parameters of RSU and the Digital Measurable Image (DMI) method in context of the CVIS. After collecting field data from a smart highway pilot project (the Deqing-Fuyang expanded Huzhou section in Chang-Shen Highway) and matching the DMI method with highway mileage pile numbers, an RSU deployment scheme based on DMI data was completed. It provides significant support for smart highway demonstration projects with cooperative vehicle-infrastructure intelligent management and control applications.

Keywords: Cooperative vehicle-infrastructure system (CVIS); Roadside unit (RSU); Digital measurable image (DMI); RSU deployment.

1. Introduction
At the end of 2019, China's highways amounted to 5,012,500 kilometers and expressways amounted to 149,600 kilometers, ranking the first in the world, laying a good foundation for intelligent operation management and services [1]. In recent years, China put great effort to the development of smart highways. By focusing on issues such as frequent congestion and traffic accidents caused by fatigue driving, everyone has shifted their focus to the use of cooperative vehicle-infrastructure technology. Using vehicle-to-backstage, roadside-to-backstage and V2I (vehicle-to-infrastructure) management to improve highway traffic capacity, reduce fatigue driving of operating vehicles, and reduce traffic accidents. Cooperative vehicle-infrastructure system (CVIS) is based on wireless communication, sensor detection and other technologies to obtain vehicle and road information. It realizes intelligent coordination and cooperation between vehicles and infrastructure through V2V (vehicle-to-vehicle) and V2I communication, and achieve the goals of optimizing the use of system resources, improving road traffic safety, and alleviating traffic congestion [2][3][4].

The roadside unit (RSU) system is a subsystem of the CVIS. In America, accelerating deployment is one of the ITS program categories. As new ITS technologies and systems evolve into market-ready products, the ITS Program must address questions associated with adoption and deployment. As defined in [5], adoption includes the phase after testing, when technologies are ready for initial implementation in the “real world.” Ensuring a smooth transition from initial adoption to widespread deployment
requires special attention and detailed programs. Thus there are challenge for RSU deployment in the "real world" as well. [6] describes the minimum requirements of a DSRC (Dedicated Short Range Communication) RSU that will be used for the “New York City Connected Vehicle Deployment Pilot Project”. [7] depicts the RSU deployment configurations such as RSU mounted on a Mast Arm, RSU installed inside a roadside electronics cabinet and RSU mounted on a roadside Pole Base. However, it didn't describe the deployment strategies for multiple RSUs. In Europe, [8] does not prescribe the exact position and specifications of the RSU, but remain on the level of dissemination areas, i.e. areas of the road network where messages can be received by the potentially targeted vehicles. According to [9], the main reasons for not being more precise, are the situation and equipment variables, it is up to, for example, the contractor to choose the most suitable solution, related equipment type (e.g. antenna type(s)) and exact positions. In China, although there are various requirements and standards for cooperative intelligent transportation system, the lack of RSU deployment or placement guidelines is still a problem. In [10], it provides equipment requirements and technical specifications for RSU. [11] provides the application layer specification and data exchange standard. [12] concludes the development of C-V2X industry.

Above all, which technical methods or model algorithm should be used for RSU deployment are not mentioned according to the literature review. Therefore, this paper uses the digital measurable image (DMI) method to carry out research on RSU deployment, and conducts experiments on demonstration roads. It solves the problem of poor accuracy and no scientific basis for determining the location of mechanical and electrical equipment deployment solutions rely on experience. It also provides important support to intelligent management and service of the cooperative vehicle-infrastructure system.

2. System Composition and Key Parameter Analysis of Roadside Unit

The RSU subsystem is composed of a communication unit, an edge computing node and a power supply and chassis. It realizes the communication and multi-source data access with On-board Unit (OBU), monitoring facilities, platform systems, etc. It has localized edge computing, strategic organization processing, publishing and other functions. Figure 1 illustrates the composition of RSU.

![Figure 1. System Composition of RSU.](image)

The core of the communication unit is to realize vehicle-to-road communication, and the choice of communication mode is closely related to the location of RSUs; The core of the edge computing node implements localized information access processing and publishing functions, and communicates with the communication unit. The power consumption determines the demand for power supply specifications. The size of communication units, edge computing nodes, and power supply modules determines the choice of chassis specifications, which are closely related to the location of RSUs,
including the communication foundation, power supply foundation, and other embedded reservations. The communication unit is a sensing terminal for the interactive application of RSUs, and its communication distance and coverage range are the core influencing factors of point layout.

3. Analysis of Roadside Unit Deployment Factors

Through the analysis of the key parameters of RSU, the main factors for the deployment of RSU include the location characteristics of the cooperative vehicle-infrastructure road section, the reserve of the power and communication infrastructure for the electrical and mechanical facilities, the deployment of peripheral monitoring equipment, the communication coverage of communication unit, highway alignment, and highway infrastructure, etc.

In the course of the project research, in order to verify the communication performance of the cooperative vehicle-infrastructure system under different communication environments, distances, and vehicle speeds, it was deployed at the intersections, gates, and F-Pole facilities of intelligent roads at the Comprehensive Test Field of the Research Institute of Highway, MOT (Ministry of Transport of the People’s Republic of China). Based on 4 sets of LTE-V (Long Term Evolution-Vehicle) and DSRC RSU equipment, it tests DSRC and LTE-V communication delay and packet loss rate under different cooperative vehicle-infrastructure application scenarios, and consider the communication distance, vehicle motion status, obstacles and other factors. Figure 2 Shows the RSU test installation locations.

![Figure 2. Installation and deployment of RSUs.](image)

Analysis of the test data:
1. The two LTE-V/DSRC communication modes have serious packet loss over 1000 meters, and the packet loss rate is greater than 5%, which affects normal data communication.
2. In the open area, the two LTE-V/DSRC communication modes cannot receive data beyond 1200 meters, the delay increases and the data cannot be received;
3. The two LTE-V/DSRC communication modes have unstable signal strength over 800 meters, and the average field strength is less than -90dBm;
4. The two communication methods have obvious obstructions on the turning sections and areas with obstructions such as trees.
5. Considering the influence of environmental interference factors, combined with the communication delay and packet loss rate, the signal coverage of the roadside unit is better between 400m~500m, so the average distance of the roadside units is recommended to be 800m~1000m, in case of occlusion, it can be more intensive.

4. Research on Data Acquisition Methods of Digital Measurable Image

Digital measurable image data acquisition equipment relies on high-precision, high-reliability satellite signal receiving chips to achieve geographic location-based video image acquisition during high-speed driving and precise coordinate acquisition of any location on the all-weather highway, combined with advanced inertial navigation technology, it guarantees the acquisition of coherent, linear and accurate position information in the unstable environment of satellite signals at the same time. The intelligent management of highways based on measurable live action images uses the ground near-field stereo photogrammetry technology to analyze and calibrate the spatial position coordinates of consecutive adjacent images, and then uses space geometric calculations to extract highway facility objects, including highway main roads, toll stations, service areas, bridges, tunnels, entrances and exits, monitoring equipment, various signs and markings, variable message signboards, lighting facilities, isolation zones, reflective facilities, guardrails, etc., and form spatial information that matches business
attributes. The application provides an efficient technical support environment for digitizing highway facilities. The process of digital measurable image data collection is shown in Figure 3.

**Figure 3.** Digital measurable image data acquisition and processing flow.

The data acquisition method based on the digital measurable image method realizes the intelligent management of the three-dimensional visible space location environment of the highway, and provides a fast and efficient spatial reference for the selection of new installation points along the highway. The digital reproduction of the scene also provides the surrounding environment data support and pass-through analysis support for the RSU deployment scheme, which can visually manage the process of positioning RSUs, thereby generating data results and rationalizing the selection and display of corresponding schemes.

## 5. The Roadside Unit Deployment Scheme Based on Digital Measurable Image Method

### 5.1. Basic Information of Smart Highway Demonstration Project

The Hangzhou Expressway West-Line Pilot Section of Zhejiang Province is a newly-built expressway, which is a diversion road of the Hangzhou Crossing Section of the G25 Chang-Shen National Expressway. One of the main functions is to ease the traffic pressure on the west line of the Hangzhou Expressway and improve investment environment for Hangzhou and the areas along the project line. It will promote the formation of a reasonable spatial layout of cities in the Hangzhou Metropolitan Economic Circle and the rapid development of the regional economy. The total length of the pilot project is about 148.8 kilometers. There are 23 interchange hubs, 17 toll stations, 3 service areas, 4 maintenance areas, and 4 tunnel management stations. There are 137 bridges with a total length of 42.76 kilometers and 27 tunnels with a total length of 32.43 kilometers. The density of bridges and tunnels are relatively high (50.53%), especially for Hang-Shao Section’s 25-tunnels and 5-tunnel-groups. There are multiple intertwined road networks, typhoons, heavy rains, and frequent foggy weather and bridge decks are susceptible to icing. Mixture of passenger vehicles and freight, high proportion of trucks, large traffic volume is expected, and the main traffic composition is expected to be passenger vehicles (over 50%), followed by small goods trucks (above 25%) are expected to have an average daily traffic volume of more than 30,000 pcu/d by 2025. With the West Line around the city, the public has higher requirements for mobility services.

### 5.2. Data Collection and Information Matching for Demonstration Road Sections

The digital measurable image equipment is used to collect about 148.8 kilometers of real-world scene data on the demonstration highway section. As shown in Figure 4, it is the field collection vehicle and digital measurable image acquisition equipment.
During the data collection process, a set of known station points is selected as the anchor point group \( \{GP_1, GP_2, \ldots GP_n\} \), \( n \) is the number of selected station points, and the station value corresponds to \( \{Stake_1, Stake_2, \ldots Stake_n\} \), and perform static observation and positioning of the spatial position at the same time, correspondingly generating an anchor point spatial coordinate group \( \{(log_1, Lat_1), (log_2, Lat_2), \ldots (log_n, Lat_n)\} \). After the data collection is completed, a fast video real-world image solution is performed based on the driving track coordinate sequence to generate real-world data with three-dimensional spatial position attributes. The solution function interface is shown in Figure 5 and Figure 6.

5.3. Deployment Principle
Based on the collected digital measurable image data, the existing electromechanical foundations that are not open to traffic, and the location of monitoring facilities, the RSU deployment principles are formulated as follows:

(1) According to the actual surveyed terrain and the direction of high-speed lines, combined with the existing reserved foundation, reorganize the layout points. The signal coverage of the RSU is better between 400 meters and 500 meters, and the average distance between the demonstration sections is 621 meters;

(2) Consider scenarios such as early warning of confluence areas, early warning of tunnels, service in service areas, etc., and arrange locations in Wukang Junction Interchange, Moganshan High-tech Interchange, Moganshan Service Area, Changchengwu Tunnel, and the Changchengwu Tunnel entrance according to the application scenario;

(3) Distribute points according to the upward and downward directions and structures;
(4) RSUs locations are differentiated in accordance with edge computing and RSU communication base stations.

5.4. Deployment Scheme

According to the deployment principle and actual field investigation and analysis, based on the analytic data of the measurable real-world image data, the station numbers of RSUs are estimated. A total of 38 intelligent RSUs are deployed. The vector data extracted based on the measurable real-world image data. The placement and locations of RSUs are shown in Figure 7.

![Figure 7. RSUs Deployment Scheme.](image)

6. Conclusion

Aiming at the lack of scientific, reasonable, and efficient deployment methods of the RSU of the cooperative vehicle-infrastructure system in the smart highway pilot project, this paper first studies the system composition and main functions of the road-side intelligent stations of the cooperative vehicle-infrastructure system, then verifies the coverage of two LTE-V/DSRC communication modes in different vehicle-infrastructure collaborative scenarios by experimental test. This paper proposes the main factors affecting the deployment of RSU and the deployment principles. Based on the advantages of digital measurable image technology in highway actual scene collection, processing and analysis, an RSU deployment plan was proposed. The field data collection was performed on a 148.8km demonstration section of the Hangzhou Expressway West-Line Pilot Project. This paper presents an accurate RSU deployment scheme by matching the digital measurable image method with highway mileage station number. It provides important support for the construction of a smart highway cooperative vehicle-infrastructure system. In the future, it can be used to optimize the adjustment of RSU deployment based on the actual application results and local-level traffic management and control effects. It can also perform highway operation and maintenance management, systematically and comprehensively, based on the digital measurable image method.

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