Digital Twin Platform for Road Traffic Using CARLA Simulator

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***Abstract*—Digital twin has been attracting much attention for reproducing real space data in the virtual environment, which allows for running the simulations as close to real situations as possible. In other words, the digital twin is one of the effective technology to predict future situations. Meanwhile, direct communication among devices based on location information has been proposed as an intelligent transport system (ITS). ITS aims to solve various problems of road traffic such as traffic accidents. A location-based peer-to-peer technology proposed in the previous study tried to construct a logical network with neighbor peers to realize information sharing among them. However, the conventional method just gives an opportunity for the direct communication between peers but does not consider road information, movement characteristics of objects when constructing networks or warning dangers, or even the prediction of future situations. In this paper, therefore, we propose a digital twin platform for road traffic with real-time information of road objects such as vehicles and pedestrians as well as the road information using CARLA simulator as a virtual environment. We also evaluated the real-time performance on CARLA simulator to clarify the availability of the proposed method.**

***Index Terms*—digital twin, CARLA, intelligent transport systems, location information**

I. Introduction

In recent years, digital twin technology has been attracting attention for reproducing various data collected from the real space into a virtual space toward the realization of smart cities [1]–[6]. With a large amount of data collected from the sensors and devices in the real space, computer simulations can be performed in a virtual space that is close to the real world [7], [8]. Therefore, digital twin is expected to be increasingly in demand for use in future forecasting and data analysis in manufacturing and urban development industries.

On the other hand, thanks to the development of mobile communication networks, various novel services have been considered for networking and communicating between users in the neighborhood. Among them, direct device-to-device (D2D) or peer-to-peer (P2P) communication between devices based on location information has been proposed as intelligent transport systems (ITS) [9]–[13]. The ITS aims to solve various problems of road traffic such as traffic accidents and road congestion. In the previous study, a P2P virtual overlay network is constructed among neighbor peers using location information obtained by a global positioning system (GPS). Although the conventional method realizes direct communication between the devices logically, it does not consider road information or movement characteristics of objects when constructing networks or warning dangers: It is difficult to use for accurate prediction of future situations.

This paper proposes a digital twin platform to imitate lifelike road traffic introducing the information of vehicles and pedestrians in the real world by using location-based P2P communication. The proposed digital twin can maintain the vehicles' and pedestrians' locations and their movements, and will thus enable more accurate future predictions and improve the convenience of ITS. In this paper, we utilize the CARLA, a world-famous open urban driving simulator [14], as a platform to create a virtual space.

II. Related Work

A vehicle-to-pedestrian warning system using location-based P2P network has been proposed [10], [12]. This method creates a predictive movement area using location and moving speed information of each vehicle or pedestrian. The prediction area of pedestrian's movement is assumed to be circular since pedestrians can move in any direction. On the other hand, we assume that the prediction area of vehicle's movement is a sector extending in the forward direction since vehicles are likely to move straight ahead. Based on the overlapping of these prediction areas, the system sends warning notifications to users. However, this system does not consider road information or movement characteristics of objects when warning the dangers. It is thus difficult to predict the future situations accurately.

CARLA was proposed as an open source simulator for advanced driver assistance systems and autonomous vehicles [14]. Fig. 1 shows an overview of the CARLA simulator. CARLA runs 3D vehicular traffic simulation by communicating between the client and the server through an interface called the CARLA API. The CARLA server is responsible for everything related to the simulation, such as physics calculations and updating actors like vehicles and traffic lights. On the other hand, the CARLA client consists of several modules to control the actors in the simulation and to set or change the simulation conditions. Therefore, the CARLA enables vehicular traffic simulations that are close to the real space.

A collision avoidance method for intersection accidents using 5G edge computing environments in cellular vehicle-

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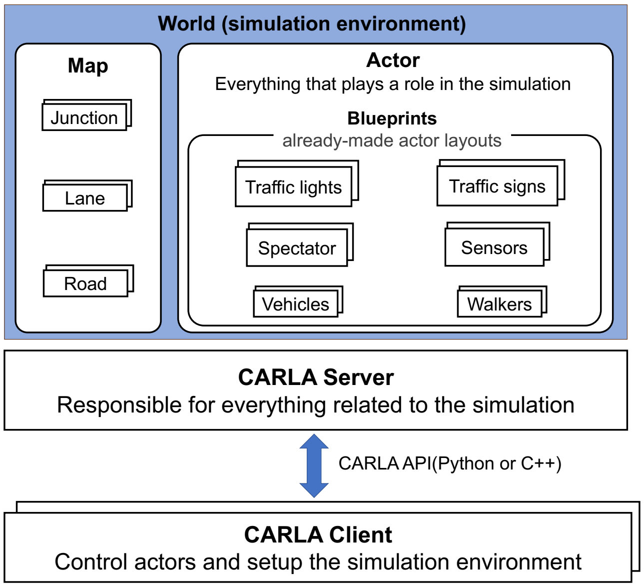

Fig. 1. An overview of the CARLA simulator.

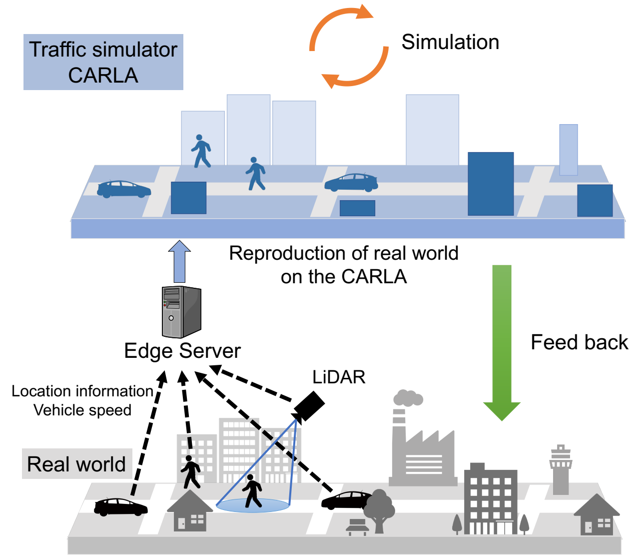

Fig. 2. Overview of the proposed method.

to-everything (C-V2X) has been proposed [15]. This method predicts a collision by calculating the possibility of the position of a vehicle considering the vehicle's acceleration and deceleration instead of calculating the position based on a linear prediction. In addition, to confirm the effectiveness of this method, the performance of collision detection when a vehicle enters an intersection was evaluated by a real-time traffic simulation using the CARLA. First, the simulation server sends the location and moving speed information of each vehicle virtually generated in the CARLA to the physical edge server using a real local 5G communication environment. Then, the edge server predicts the probability of a collision using the collision detection algorithm. Simulation results showed that all collision risks were notified in advance and collision detection between vehicles was achieved. However, the conventional method uses vehicle's information obtained from the simulation but does not consider the use of data collected in the real space.

III. Proposed Method

This paper proposes a digital twin platform for road traffic to maintain the information of vehicles and pedestrians using the CARLA simulator. The CARLA is used as a driving system of virtual space to produce digital twin with virtually maintaining the information about vehicles and pedestrians collected from the real space.

Fig. 2 shows an overview of the proposed method. In the method, a digital twin platform is constructed by the following procedure:

1) Road information in the real space is reproduced into the CARLA using an editor to create 3D scenarios.
2) Vehicles and pedestrians in the real space that are using location-based services, such as location-based P2P system [9], regularly send their location information obtained by GPS and moving speed information calculated based on the location information to the CARLA client.
3) The CARLA client converts the users' location based on the GPS to the coordinates in the CARLA simulator.
4) The CARLA client sends the converted data to the CARLA server.
5) The CARLA server generates the vehicles and pedestrians at the corresponding locations.
6) Traffic simulations are executed on the CARLA that is as close to the real space as possible, using the collected real space data.
7) The simulation results related to the future prediction will be returned to the real space.

The proposed method supposes that the information of vehicles and pedestrians in the real space is acquired and sent to the CARLA by using the following two types of devices: devices owned by users and devices installed in the public. In the former case, users' mobile devices such as ones installed in vehicles and ones held by pedestrians are used as capturing devices. These devices easily obtain their location information using the built-in GPS and calculate the moving speed (and even movement trajectory) based on time-series location information data. The devices then send these information to the CARLA, which will accurately reflects the obtained objects in the virtual space. In the latter case, on the other hand, devices publicly installed such as video camera and light detection and ranging sensors (LiDAR) are used as capturing devices. In particular, we focus on LiDAR sensors that capture only point cloud data, less containing privacy information. A LiDAR sensor installed in the city measures the distance to an object in the real space and sends the point cloud data to the edge server. The edge server then analyzes

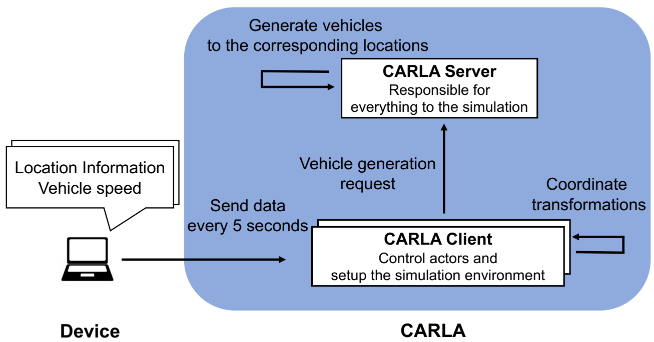

Fig. 3. Simulation model.

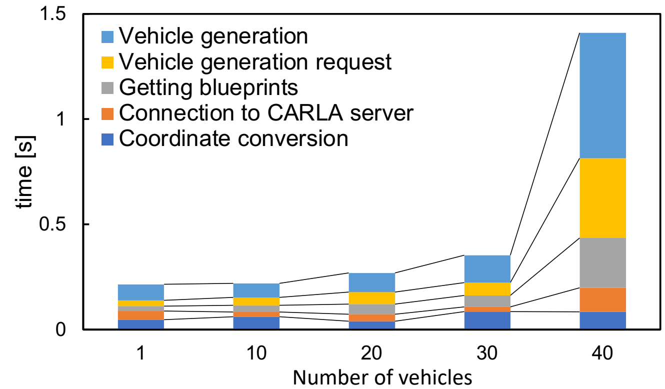

Fig. 4. Simulation result.

the collected point cloud data to detect objects such as vehicles and pedestrians and to identify their location information [16]. The moving speed information of each object is also calculated based on time-series identified location information. Finally, these information is sent to the CARLA, which will accurately reflect the obtained objects in the virtual space. In this way, through two types of devices, vehicles and pedestrians in the real space can be reproduced into the CARLA's virtual world regardless of whether the user has a device or not.

Thus, the CARLA simulator can be used as a virtual environment of digital twin to make accurate future predictions considering geographical information of real objects. Moreover, accurate future prediction results will then be fed back to the real space to realize the ITS with high usability.

IV. Evaluation

To confirm the real-time performance of the proposed method, we evaluated the operation response of the CARLA simulator when the number of vehicles generated in the CARLA's virtual space changed. The response time was measured as the period from the moment when vehicle information arrived at the CARLA client to the moment when the vehicle object was generated at the corresponding location. We used RoadRunner [17] and OpenStreetMap [18] to reproduce the real road information into the virtual space. RoadRunner is an editor for designing 3D scenes for automated driving simulations. Road network in the real space can be created by importing map data obtained from OpenStreetMap into RoadRunner.

Fig. 3 shows the evaluation environment for the simulation. Simulations were performed using one desktop PC running the CARLA simulator and another laptop PC sending data assumed to be a vehicle. The laptop PC sends the location and moving speed information, which is assumed to be acquired by GPS or converted from point cloud data, to the CARLA client every five seconds. The CARLA client receives the data and performs a conversion from the coordinates in the real space to those in the CARLA's virtual space. Then, the CARLA client connects to the CARLA server and obtains the blueprints of vehicles used in the CARLA. After that, the CARLA client sends a vehicle generation request to the CARLA server. Finally, the CARLA server generates a vehicle at the corresponding location.

Fig. 4 shows the simulation results when generating up to 40 vehicles. In this experiment, it is assumed that the data collected from a LiDAR sensor installed to detect real-space objects has already been transformed into the coordinates, and the time required for this process is not considered in the simulation. The results show that real-time performance can be maintained up to about 30 vehicles; the operation response is suppressed within 0.4 seconds. However, when more than 40 vehicles are generated, the time to generate vehicles increases rapidly due to the CPU load and other issues on the desktop PC. It can also be seen that, as the number of vehicles increases, the time for the CARLA clients to make vehicle generation requests (the yellow part) and the time for the CARLA server to generate vehicles (the light blue part) increase. On the other hand, it can be confirmed that the time required for the coordinate conversion is not affected significantly regardless of the number of vehicles generated.

V. Conclusion

In this paper, we proposed a digital twin platform for road traffic using the CARLA simulator. The simulation results revealed that the real-time performance of the proposed method can be kept up to a specific number of vehicles. Therefore, it is concluded that the proposed platform made a step toward the realization of accurate future predictions considering road information and also the certain improvement of the convenient ITS.

For future work, we plan to utilize some LiDAR sensors to capture real vehicles and pedestrians and to reflect the detected objects who do not possess their own devices into the CARLA's virtual space. In addition, we will also consider the feedback contents in the digital twin infrastructure according to the results of this simulation, as well as scenarios for the use of the proposed system considering the accuracy of position information obtained by GPS.

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