3D Digital Twin of Intelligent Transportation System based on Road-Side Sensing

Yunpeng Guo*, Kai Zou, Shengdong Chen, Feng Yuan and Fang Yu

Institute of Software Application Technology, Guangzhou & Chinese Academy of Science, Guangzhou, China

*Corresponding author e-mail: guoyunpeng@gz.iscas.ac.cn

Abstract. Cooperative vehicle-infrastructure is one of the most import developing direction of future intelligent transportation system, while digital twin system can record, reproduce, and even deduce the physical system, which could be helpful for the development of cooperative vehicle-infrastructure. In this study, we proposed a 3D digital twin platform of intelligent transportation system based on road-side sensing, a core component of cooperative vehicle-infrastructure system. This platform consists of real road-side sensing unit, 3D virtual environment, and the ROS bridge between them, by receiving the sensing results of physical world in real-time, the virtual world can reproduce the compatible road traffic information, such as the type, 3D position and orientation of traffic participants.

1. Introduction
As the urban population growing, the city traffic-related issues become more and more serious, and in consequence of this, the development of Intelligent Transportation System (ITS) as a common solution is adopted by most of the governments in this world. ITS promotes the traffic safety and efficiency by applying artificial intelligence and information technology, which can be divided into two parts, one is “smart vehicle” and the other is “intelligent road”. “Smart vehicle” has developed for decades and had made a great deal of improvements as a result, including the traditional Advanced Driving Assistance System (ADAS) and the newly emerged Autonomous Driving, however, it still faces practical problems, like performance limit, high cost of manufacture, difficulties in supervision. In the other hand, with the technology of Internet of Things (IoT) developing, the number of IoT devices installed in cities grows fast [1], which makes “intelligent road” possible. Cooperative Vehicle-Infrastructure System (CVIS) is the senior stage of ITS, CVIS enables vehicles to sense environment better by combining road-side sensing ability and accomplishing the vehicle to road communication, therefore, it enhances the vehicle driving performance and streamlines the vehicle hardware configuration, as well as letting the regulators handle traffic accidents more effectively [2].

The earliest concept of Digital Twin was proposed by Professor Grieves in 2003, used as Product Lifecycle Management (PLM), which was named “Mirrored Space Model” [3]. While the word “Digital Twin” was first put forward by United States’ National Aeronautics and Space Administration (NASA) officially, which was used for setting up the computing model of aircraft structure [4]. Currently, Digital Twin is conceived as one of the most promising technologies [5], and is applied in many fields, such as industry design [6], manufacture [7], smart city [8], and intelligent driving [9]. The general definition
of Digital Twin contains three components: the physical entity, the digital model, and the interaction between them [10]. The digital model has a high functional homogeneity to the physical entity, while the interaction guarantees the synchronization of working status between digital model and physical entity, all these enable the digital twin system to record, reproduce, and even deduce the physical system.

In this paper, we designed a 3D digital twin system based on road-side sensing of CVIS, which can visualize the traffic on road in real-time. Different to [11], we use a lidar as the road-side sensor, and besides the type of traffic participant, the system also displays the position and orientation of traffic participant in 3D. The remainder of this paper is organized as follows. Section two describes the structure of our proposed system, section three looks into the details of constructing our digital twin system, including a static modeling and a dynamic visualization of objects, in the end, a conclusion of this work and future studies is presented in section four.

2. System Structure
The development of ITS digital twin can be divided into 3 phases [12], and currently we are in the first phase, the main content of phase 1.0 is to provide services beyond visibility for drivers and supervisors by gathering road information with sensors. For CVIS, sensors are mainly for road-side sensors, like lidar, camera, while road information is generally regarded as traffic participants in particular area, such as vehicles, pedestrians, and obstacles.

Digital model is one of the three key components of Digital Twin, which has two kinds of representations, one is an abstract expression of physical model theoretically, and the other is coupled with a visualization form on the base of the former one. Apparently, the latter has richer information and is easier to understand, especially when it is in 3D form, which suits the way humankind to recognize the world better.

Figure 1 shows the structure of our proposed digital twin system. The sensing device in real world collects road information, for example, point cloud data or image data, then the road information is passed to detection algorithm where derives the recognition results, containing the object type (vehicle/pedestrian/obstacle) and its 3D pose, the object information is sent to virtual world through communication module via ROS bridge, after the rendering of 3D engine, there is a digital clone of detected object with a same pose in virtual world.

![Figure 1. Structure of proposed system.](image_url)

In this paper, we use a lidar as the sensing device, on contrast to camera, lidar is less effected by environments, and what’s more, lidar is able to get accurate 3D position and orientation of detected object, which is crucial for constructing a 3D digital twin of traffic participants. As for the 3D engine,
we use LGSVL [13] as our simulation platform, which is an open source software based on Unity, it has a high-fidelity rendering performance and supports Digital Twin well.

3. Procedures toward Digital Twin

The digital models of CVIS involves different kinds of elements in traffic scenarios, mainly are pedestrians, vehicles, roads, and environments, according to whether it is dynamic responsive, these elements can be divided into two categories: static digital model and dynamic digital model. The static digital model includes roads, buildings, greenbelts, stationary road infrastructures like traffic poles, and so on, the dynamic digital models includes pedestrians, vehicles, weathers, variant road infrastructures like traffic lights, and others.

3.1. 3D Modelling of Digital Models

In this paper, we refer to digital model as 3D model, the modeling of 3D models includes building its geometry, appearance and material. We choose the open source software Blender as our modelling tool, figure 2 shows the final output of virtual environment around the road-side unit, rendered by LGSVL.

![Figure 2. Virtual environment around road-side unit.](image)

Here we use a lidar to detect objects on road, the result of object type contains vehicle, pedestrian, and non-motor-vehicle, where vehicles are distinguished as big vehicle and small vehicle. 4 models are modeled in Blender to represent the 4 kinds of object types respectively, which are shown in figure 3.

![Figure 3. 3D models of different kinds of object types, from left to right are: big vehicle, small vehicle, pedestrian, non-motor-vehicle](image)

3.2. Generation of Dynamic Digital Models based on Road-Side Sensing Results

By collecting the point cloud data scattered on traffic participants, and then processing with the recognition model based on deep learning, the road-side unit can get the object type, 3D position, and 3D orientation of traffic participants, all this information will be published in a form of ROS topic after being structured, LGSVL receives the information by subscribing this topic thereafter, and then parses
it, obtains the type, position, and orientation, finally sends these to the rendering pipeline. The whole process is shown in figure 4.

Figure 4. Data flow of dynamic digital models.

There is one frame of point cloud data in a single period of data processing, and every frame is marked with a timestamp, which is helpful for storing and reusing of data. As lidar keeps running, the digital models of traffic participants get dynamic response. In order to fulfill the transmission of recognition results of point cloud data, the results should be structured, we defined message types separately in ROS and LGSVL, the contents are described in figure 5, in which, orientation is expressed with quaternion.

```c
message_type DigitalTwin_msg
{
  time  Timestamp;
  detectedObject[ ] Objects;
}

message_type detectedObject
{
  int Type;
  vector3 Position;
  vector4 Orientation;
}
```

Figure 5. Data flow of dynamic digital models.

Generally, lidar uses right-handed coordinate system, but LGSVL uses a left-handed coordinate system, so as to make the virtual traffic participants have same position and orientation with their real-world ones, we need to convert the data parsed from ROS topic, from right-handed coordinate system to left-handed coordinate system. Define the position and orientation in lidar coordinate system as:

\[
P_{\text{lidar}} = (x_{\text{lidar}}, y_{\text{lidar}}, z_{\text{lidar}}), \quad O_{\text{lidar}} = (x_{\text{lidar}}^{o}, y_{\text{lidar}}^{o}, z_{\text{lidar}}^{o}, w_{\text{lidar}}^{o})
\] (1)

Define the position and orientation in LGSVL coordinate system as:

\[
P_{\text{lgsvl}} = (x_{\text{lgsvl}}, y_{\text{lgsvl}}, z_{\text{lgsvl}}), \quad O_{\text{lgsvl}} = (x_{\text{lgsvl}}^{o}, y_{\text{lgsvl}}^{o}, z_{\text{lgsvl}}^{o}, w_{\text{lgsvl}}^{o})
\] (2)

There is a relationship between (1) and (2):
\[
P_{\text{gsvl}} = \begin{bmatrix} -1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & -1 & 0 \end{bmatrix} \quad P_{\text{lidar}}, \quad o_{\text{gsvl}} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \quad o_{\text{lidar}}
\] (3)

In figure 6, (a) shows a visualization result of traffic participants in ROS, recognized from one frame of lidar point cloud data, while (b) is the corresponding rendering result in LGSVL. Obviously, the objects in LGSVL have same types and poses with those in ROS, and what’s more, the demonstration in LGSVL is much more realistic and abundant with contents.

Figure 6. Visualizations of traffic participants.

4. Conclusion and Future Work
In this paper, we proposed a 3D digital twin system based on road-side sensing of CVIS, which has dynamic response capability by using the sensing results of road-side unit. As a further study, we use a lidar as the sensing device, successfully accomplished mapping the traffic participants from real-world into a virtual world, with their types, positions, and orientations staying the same, and the final result shows our system has a better visualization performance compared to ROS. Due to the mistakes in object recognition, there are sudden changes in object type and orientation, which is clearly to be observed when it is visualized in 3D, as a solution, we are considering removing the error recognition by filtering the received data in LGSVL later. Furthermore, we will introduce more road-side sensors and build more dynamic digital models, which will lead to more interaction content, as making one more step toward digital twin city.

Acknowledgments
This work was financially supported by Guangdong Research and Development Plan Program in Key Areas (Project Number: 2019B090912002) and Special Project on Cooperation of Guizhou Science and Technology (Project Number: ZNWLQC [2019] 3012-1).

References
[1] O. E. Marai, T. Taleb and J. Song, "Roads Infrastructure Digital Twin: A Step Toward Smarter Cities Realization," in IEEE Network, vol. 35, no. 2, pp. 136-143, March/April 2021, doi: 10.1109/MNET.011.2000398.
[2] M. Tsukada, M. Kitazawa, T. Oi, H. Ochiai and H. Esaki, "Cooperative awareness using roadside unit networks in mixed traffic," 2019 IEEE Vehicular Networking Conference (VNC), 2019, pp. 1-8, doi: 10.1109/VNC48660.2019.9062773.
[3] GRIEVES M W. Product lifecycle management: the new paradigm for enterprises [J].International Journal of Product Development, 2005, 2(1-2): 71-84.
[4] TUEGEL EJ, INGRAFFEA AR, EASON TG, et al. Reengineering aircraft structural life prediction using a digital twin[J]. International Journal of Aerospace Engineering, 2011
DOI:10.1155/2011/154798.

[5] T. Erol, A. F. Mendi and D. Doğan, "Digital Transformation Revolution with Digital Twin Technology," 2020 4th International Symposium on Multidisciplinary Studies and Innovative Technologies (ISMSIT), 2020, pp. 1-7, doi: 10.1109/ISMSIT50672.2020.9254288.

[6] Y. Yang, W. Meng and S. Zhu, "A Digital Twin Simulation Platform for Multi-rotor UAV," 2020 7th International Conference on Information, Cybernetics, and Computational Social Systems (ICCSS), 2020, pp. 591-596, doi: 10.1109/ICCSS52145.2020.9336872.

[7] L. Xia, J. Lu and H. Zhang, "Research on Construction Method of Digital Twin Workshop Based on Digital Twin Engine," 2020 IEEE International Conference on Advances in Electrical Engineering and Computer Applications (AEECA), 2020, pp. 417-421, doi: 10.1109/AEECA49918.2020.9213649.

[8] L. Raes et al., "DUET: A Framework for Building Secure and Trusted Digital Twins of Smart Cities," in IEEE Internet Computing, doi: 10.1109/MIC.2021.3060962.

[9] Z. Wang et al., "A Digital Twin Paradigm: Vehicle-to-Cloud Based Advanced Driver Assistance Systems," 2020 IEEE 91st Vehicular Technology Conference (VTC2020-Spring), 2020, pp. 1-6, doi: 10.1109/VTC2020-Spring48590.2020.9128938.

[10] J. Wu, Y. Yang, X. Cheng, H. Zuo and Z. Cheng, "The Development of Digital Twin Technology Review," 2020 Chinese Automation Congress (CAC), 2020, pp. 4901-4906, doi: 10.1109/CAC51589.2020.9327756.

[11] A. Lee, J. Kim and I. Jang, "Movable Dynamic Data Detection and Visualization for Digital Twin City," 2020 IEEE International Conference on Consumer Electronics - Asia (ICCE-Asia), 2020, pp. 1-2, doi: 10.1109/ICCE-Asia49877.2020.9277250.

[12] W. Ji et al., “Technology Connotation and Application Prospect of Digital Twin Intelligent Transportation System”, 15th Chinese Intelligent Traffic System Annual Congress (ITSAC), 2020, pp. 1-11, doi: 10.26914/c.cnkihy.2020.028417.

[13] G. Rong et al., "LGSVL Simulator: A High Fidelity Simulator for Autonomous Driving," 2020 IEEE 23rd International Conference on Intelligent Transportation Systems (ITSC), 2020, pp. 1-6, doi: 10.1109/ITSC45102.2020.9294422.