The scope of this column includes IoT technological achievements that cause social impacts and/or incorporate social factors. Each column will provide our knowledge and insights in most recent development, cutting-edge applications, latest deployment, and conceptual innovations, and of course, their implications on our society. I hope the columns will be meaningful in understanding how our society interacts, adopts, adapts to, and changes with IoT technological advancements.

Jun Zhang, Column Editor

Digital Twin: A Solution to More Effective Transportation Management

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Transportation safety, traffic congestion and transportation-induced air pollution are getting increasingly serious along with the urbanization process and the increase of vehicle ownership. There are over 1.35 million deaths caused by road traffic each year globally, which makes road traffic one of the major causes of death for people aged 5 to 29[1]. Traffic congestion results in a huge amount of time wasted as well as economic loss in metropolitan areas. In 2018, residents in New York City lost 133 hours in congestion on average and the monetary cost per driver is $1,859[2]. Similarly, traffic congestion costs residents in Beijing ¥12,588 on average[3]. The transportation sector is also a major source of energy consumption and air pollution, e.g. the transportation sector is responsible for about 28 percent of the U.S. total energy consumption in 2018[4] and 28.9 percent of U.S. total greenhouse gas emissions in 2017[5], and traffic congestion makes air pollution problems even worse[6].

To address the problems mentioned above, the Intelligent Transportation System (ITS) has been developed for years by applying information and communication technologies to provide better services to different stakeholders. Transportation management departments[7,8] implement various sensors (including loop detectors, cameras, radars, etc.) to collect data, build data platforms to store and process data, and publish traffic guidance information through electronic signboards, radio and other approaches. Drivers share traffic information among each other through crowdsourcing platforms (e.g. Waze) and instant massaging apps (e.g. WeChat), as well as conventional face-to-face communication. Vehicle makers are developing advanced driver-assistance systems (ADAS) consisting of on-board sensors to aid vehicle drivers while driving and minimize human errors by sending emergency alerts such as lane departure warnings and forward or backward collision warnings.

However, there are still questions remaining about how to collect comprehensive, accurate and timely transportation-related data, to efficiently process and analyze the data, and to effectively perform traffic control, especially to satisfy vehicle-to-everything (V2X) communications demands, which require high-accuracy real-time information.

What is Digital Twin?

Digital twin is a digital replica of a physical entity. "At its optimum, any information from the micro atomic level to the macro geometrical level that could be obtained from inspecting a physical entity can be obtained from its digital twin."[9] This concept provides a new direction for ITS development. For example, a digital twin road system will allow transportation management departments to inspect all pavement cracks and perform accurate pavement maintenance in time to avoid catastrophic pavement failure, to detect all pedestrians' movement to send warning messages to vehicles and reduce vehicle-pedestrian conflicts, and to obtain all vehicles' operation status even to take over control of a vehicle in an emergency situation to avoid fatal traffic accidents.

The Expressway Monitoring Advisory System (EMAS)[10] in Singapore is a preliminary demonstration of digital twin highway system, where it can detect traffic accidents, and ensure fast response to restore normal traffic flow. But the EMAS primarily relies on road-side sensors to detect traffic flow, instead of allowing vehicles to actively report their operation status, and there is a lack of effective two-way communication approaches between traffic participants and administrators in EMAS.

From the technical perspective, a digital twin system for intelligent transportation consists of three layers: node layer, network layer and cloud layer, as Figure 1 shows.

- The node layer includes all transportation-related infrastructures and vehicles. Nodes require digitization to be able to report real-time operation data and/or to execute instructions. For example, an intelligent traffic light with a communication module allows it to send its operational status to the transportation management platform and receive remote control instructions as well.
- The network layer is responsible for connection and data transmission between nodes and the cloud. The nodes with various characteristics require different network technologies. For example, a cellular V2X network is applicable for vehicle communication to satisfy mobility demands. Wi-Fi and NB-IoT are applicable for sensor-related communications considering the low monetary cost. Optical networking is applicable for connections between mobile edge computing (MEC) servers and the cloud because of the huge capacity of an optical network. Satellite communication is applicable for areas that lack terrestrial networks and with low node densities, such as ocean or desert area.
- The cloud layer is responsible for data processing, assisting decision making, traffic simulation, and sending instructions to nodes. Heterogeneous data reported from multiple sources are integrated and analyzed in the cloud. Real-time traffic conditions in the physical space will be reflected simultaneously in the cyberspace to allow people to have a comprehensive understanding about existing congestions and emergencies. The cloud will also assist decision making by modeling the potential impact of specific instructions. Eventually, programmed instructions will be sent to nodes to improve traffic in the real world. Besides the centralized cloud, there could also be MEC servers to provide extra local computing capacity, which are more suitable for low-latency computing tasks or to reduce network load caused by mass data transmission.

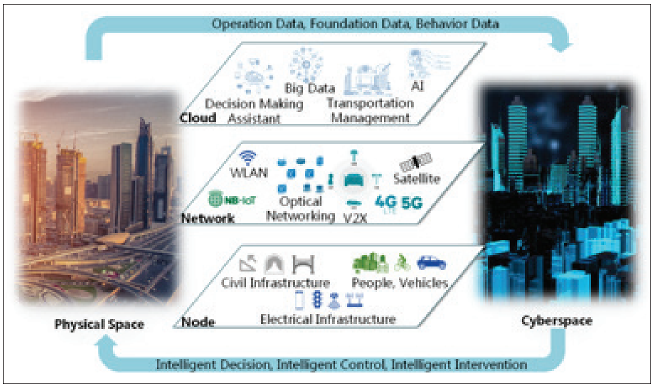


FIGURE 1. Digital Twin System for Intelligent Transportation.

The essence of a digital twin system is to build a closed-loop control system through global entity identification, accurate status perception, real-time data analysis, decision-making modeling, and effective instruction execution, in order to realize transportation system simulation, monitoring, diagnosis, prediction and control/intervention.

Ongoing Research Projects at Zhejiang Lab

Zhejiang Lab was established in 2017 with an initiative by the Zhejiang provincial government to integrate the research capabilities of Zhejiang University and the industrial capabilities of Alibaba. Zhejiang Lab aims to deliver original and innovative research in intelligent perception, intelligent computation, intelligent networks and intelligent systems.

Transportation is an important application scenario for technology innovation, and there are three ongoing research projects at Zhejiang Lab (Figure 2) that are related to intelligent transportation: transportation infrastructure digitization, V2X network, and traffic control cloud platform.

Transportation Infrastructure Digitization: Transportation infrastructure digitization requires deploying massive amounts and various types of sensors along with backhaul networks. Different traffic scenes have different data collection requirements, such as to detect spilled objects on highways, pedestrians at intersections, vehicle plates at toll stations, and structural shift of tunnels and bridges. To collect this information requires different sensors considering their collectable information, applicable working scenarios, data granularity, monetary cost, and other factors. What's more, the communications among sensors and the cloud brings great challenges for backhaul network design to satisfy capacity, coverage and reliability demands. It is also necessary to have an edge IoT platform to be responsible for sensor access, data integration and formation, cross sensor communication, and to bridge the sensor network with the cloud.

Zhejiang Lab aims to take the advantages of existing wireless technologies, such as LoRa, NB-IoT, Bluetooth, Wi-Fi and 4G/5G, and develop a total technical solution for sensor deployment, networking and the edge IoT platform for transportation infrastructure digitization.

V2X Network: V2X is a bridge between vehicles and the surrounding environment. V2X network has even stricter requirements than the infrastructure-to-cloud network in terms of transmission rate, timeliness and reliability to ensure vehicle safety.

Zhejiang Lab is working on building a convergence network to provide efficient, adaptive and coordinated communications services for cooperative vehicle infrastructure system (CVIS) applications. In order to improve network coverage and to satisfy vehicle mobility, Zhejiang Lab is researching a resource

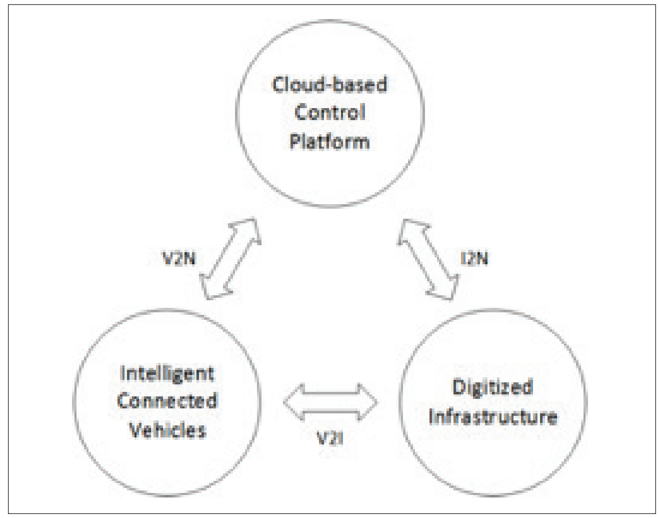


FIGURE 2. Relationship among ongoing research projects in Zhejiang Lab.

management scheme, and we hope to use distributed antennas to allow a more flexible network topology.

To satisfy the ultra-reliable and low latency communication requirements of CVIS applications (such as platooning and remote driving), Zhejiang Lab is studying V2X communications control and traffic channel enhancement technology, including link adaptation, fast coding hybrid automatic repeat request (HARQ) and more. We plan to introduce artificial intelligence algorithms into the link adaptation so that roadside units and user equipment can fully perceive the channel changes under the cooperative management of MEC, so as to improve the reliability and data transmission rate.

What's more, Zhejiang Lab will explore millimeter-wave technologies to achieve a V2X network with ultra-high throughput in order to satisfy the data transmission demands of applications like video transmission.

Traffic Control Cloud Platform: Vehicles and sensors are nodes in the digital twin system, and a traffic control cloud form will be responsible for integrating multi-source data, scheduling and distributing computing and storage resources, and performing data analysis and decision-making. Considering the characteristics of vehicles moving at high speed, V2X communication and traffic guidance requires edge-computing technology to satisfy the low-latency feedback requirement in order to ensure safety and system functionality. However, if edge-computing servers are isolated from each other, the uneven distribution of users might cause a lack of edge-computing resources in some regions while idling edge-computing servers in other regions.

Thus, Zhejiang Lab is designing a cloud-edge collaboration architecture to provide reliable and efficient computing services. The cloud center uses network orchestration and virtualization technology to manage and schedule computing resources on MEC servers. Computing power adaptation techniques will also be used in the cloud to allocate computing tasks to different computing resource slices according to service types and requirements.

What's more, the massive sensors and vehicles in the digital twin system are expected to generate enormous amounts of data, and unstructured data (e.g. video) requires preprocessing to be interpreted as structured information for further analysis. Therefore, the cloud-based control platform adopts stream processing technologies to handle the foreseeable enormous amount of data. Data fusion technologies are used to process the heterogeneous fragmented data. Spatio-temporal databases are designed to manage data, and models are created to visualize the spatial and temporal distribution of entities and analyze the interaction between entities. With global access of data, intelligent applications can be deployed in the cloud to assist decision-making and to simulate future traffic situations.

Demonstration Project in Deqing County

Deqing County of Huzhou City, Zhejiang Province is constructing a county-wide connected and autonomous vehicles (CAVs) testbed system to allow manufacturers to test their CAVs on the public roads of Deqing County. The testbed system consists of road-side sensors, V2X communication devices, MEC servers and a test control cloud platform.

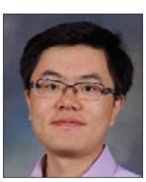
The road-side sensors including cameras, microwave detectors, millimeter wave detectors, LiDAR detectors, and infrared heat detectors. These sensors have been deployed on a 3.6 km long road segment to precisely report on-road vehicles' location, pedestrian appearance, and to track their moving trajectories.

All on-test CAVs are equipped with on-board units (OBUs), inside/outside cameras, and vehicle status recording devices. OBUs allow communication between vehicles and road-side units (RSUs), as well as the cloud platform, e.g. OBUs will report vehicle speed, acceleration, pedal position, steering wheel angle, gear information, etc. to the cloud platform, and OBUs will receive traffic information, pedestrian warnings, test instructions, etc. from RSUs and the cloud platform.

MEC servers collect data from regional road-side sensors, publish pedestrian appearance warnings through RSUs to satisfy the low latency demand, and report processed sensor data to the cloud platform. The test control cloud platform gets a full picture of the traffic flow by integrating all road-side sensor data and OBU reported data.

The test control cloud platform will send test instructions to test CAVs based on the vehicle's surrounding traffic environment such as to send a school zone warning and evaluating test CAVs' response such as response actions and response time. The test control cloud platform can also adjust the traffic signal plan according to the detected traffic situation to reduce traffic congestion and achieve global optimization.

Biographies



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Footnotes

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