Design of a Visual Traffic Management System for Smart Cities Based on Digital Twin Technology

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Abstract. With regard to the current socio-economic situation, the traditional means of road traffic management can no longer adapt to the current speed of global information development. Intelligent traffic management, which responds to the practical needs of the history of intelligent traffic management, is an imperative reform initiative. The aim of this paper is to study the design of a visual traffic management system for smart cities based on digital twin technology. The framework of the system based on digital twin technology is constructed, and the system functions mainly include information login system, rapid traffic modelling module, traffic prediction management module, traffic control management module, and case application analysis of the system. Starting from the problems of traffic state prediction and traffic congestion control, and combining with the actual traffic history data of some areas of L station in M city, the results show the applicability and feasibility of the digital twin technology in traffic congestion prediction and control in this paper.

Keywords: Digital Twin Technology · Smart City · Traffic Management · Visualisation System

1 Introduction

Information technology has been developing considerably and has gradually entered the lives of the general public, while transport issues have become more and more important because of the overall increase in the economic level of society [1]. The speed of development of the transport industry has a direct impact on the prosperity of the country, making it easier for people to travel and for materials to be transported, reducing the travel load on the public and actually increasing the quality of work. However, the increasing level of the industry has brought with it a variety of problems, particularly in the area of transport. Regardless of the economic level of the country, this issue is of great importance and plays a key role in economic development.

Kalpit Sharma proposes a new dynamic congestion pricing and electric vehicle charging management system for connected vehicles in an urban smart city environment. The proposed system rewards drivers who choose alternative congestion free roads and congestion free charging stations. They propose a token management system as a virtual

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currency in which vehicles are awarded these tokens if they use alternative non-congested ways and charging stations and pay for charging with tokens [2]. In response to the lack of traffic dynamics caused by the rapid growth of urban traffic, Nyothiri Aung designed and implemented an urban intelligent traffic management system based on data mining techniques. The multi-layer architecture features of the intelligent traffic management system, the collection of traffic data, the linkage of the system and the functions of each module are introduced. The system constructs a traffic flow model library through data mining technology, and the system constructs a traffic flow type database through data mining technology, and on this basis, predicts the short-time traffic flow of urban traffic, analyses the spatial distribution pattern of traffic congestion in urban traffic flow and urban road traffic flow, realises the intelligence of urban traffic management and relieves the pressure of urban traffic congestion [3]. The traffic digital twin represents a digital version of a physical object or process of traffic, such as a traffic signal controller, thus enabling bidirectional real-time data exchange between the physical twin and the digital twin. To compensate for this shortcoming of conventional ATSC with connected vehicle data, Moahd K has developed a digital twin-based ATSC (DT-based ATSC) which takes into account the waiting times of vehicles approaching the target intersection as well as the waiting times of these vehicles at the immediately upstream intersection. The driving experience of the traveller is improved by reducing and redistributing the waiting time at the intersection [4]. Therefore, it is of practical importance to study visual traffic management systems for smart cities based on digital twin technology.

In this paper, the construction of a visual traffic management information integration system based on digital twin technology can effectively deal with mass and sudden events and major traffic incidents. It realises the event-oriented collaborative command and dispatch, network-oriented remote command and dispatch, and resource-oriented integrated command and dispatch functions of traffic management command and dispatch. The technology selection and realisation process in the whole system development process has good reference significance for the further development of the system in the future.

2 Research on the Design of a Visual Traffic Management System for Smart Cities Based on Digital Twin Technology

2.1 Digital Twin Technology

Digital twin uses sensor and physical attribute parameter data, after extraction and fusion to map entities in physical space to virtual digital space from the perspective of multi-physical features and connections, to achieve digital representation of physical entities in virtual scenes [5, 6]. The core of the digital twin is the model and data, with the model as the most intuitive visual representation of the digital twin and the data as the driving conditions to support individual movement and change; at the same time, the theoretical and technical support is inseparable from the construction of digital twin models and products [7, 8]. According to some of the existing methods in the application of digital twin technology, combined with the key technical points of the Internet of Things and

Big Data, the technical guidelines carried by digital twin technology are summarized, mainly including the following points:

(1) physical entities are real and virtual objects are a true and objective reflection of physical entity mapping in digital space, both of which have a common life cycle.
(2) The digital twin structure must include at least the physical entity, the virtual model and the interactive system that constitutes the data fusion between the two, and have the characteristics of real-time and consistency [9].
(3) The digital twin mapping in the virtual environment needs to have the ability to provide a multi-faceted and comprehensive description of the physical entity, either in terms of functional characteristics or electrical characteristics of the device or other physical properties it possesses.
(4) The interaction of data is continuous, i.e. the digital twin model reflecting the physical entity can continuously change during its life cycle, and the results fed back to the real world are also in a dynamic process of change, both of which can form a closed-loop structural form.

2.2 Functional Requirements

(1) Traffic flow data query

    Traffic information collected by traffic signals and road information collection devices is stored uniformly on a central database server, where operators can easily query and analyse charts and prints [10].
(2) Vehicle Management Data Query

    The system can be connected to a vehicle management repository and contains many important information about daily traffic management in the vehicle management repository. As a result, dispatch and surveillance personnel can improve their ability to control and access information.
(3) Driver management data query

    The system can be connected to a driver management database which contains a variety of information about drivers, including important traffic management information such as name, ID number and licence number.

3 Investigation and Study of a Visual Traffic Management System for Smart Cities Based on Digital Twin Technology

3.1 System Development Environment

The Vue.js framework is a bottom-up, layer-by-layer application that enables fast, clean, efficient and unified interaction of information in the front and backend. This paper is based on the Vue.js framework to develop the web front-end system, and with the help of open source frameworks such as ElementUI and Echarts to make the development process easier and also facilitate integration with third-party libraries or existing projects.

3.2 Calculation of Bus Operation Status Parameters

Based on historical bus operation data, a total of three state parameters - line operation efficiency, passenger congestion ratio and congested mileage ratio - are calculated from three perspectives: line, station and passenger, providing a theoretical basis for data monitoring application scenarios in the digital twin traffic management system.

(1) Line operation efficiency

When the vehicle full occupancy ratio calculated using Eq. (1) is lower than the low occupancy ratio threshold, the vehicle is in a low occupancy driving state. In this paper, the low load mileage rate during the peak period is used to indicate the operating efficiency of the line; the higher the low load mileage rate, the lower the operating efficiency of the line. The calculation formula for the low load mileage rate is:

$$R_s = \frac{\sum_i^I LS_i}{\sum_i^I S_i} \tag{1}$$

where: Rs - denotes the low load mileage rate; I - denotes the total number of departures in the statistical period; LSi - denotes the low load vehicle miles travelled for trip i; Si—denotes the vehicle mileage travelled for trip i.

(2) Passenger congestion ratio

Crowding time ratio is the ratio of the crowding time of all crowded passengers to the total travel time of all passengers, which is calculated by the formula:

$$R_t = \frac{\sum_i^{Pc} CT_i}{\sum_i^P T_i} \tag{2}$$

where: Rt - denotes the proportion of congestion time; Pc - denotes the number of passengers who experienced congestion during the count period; P - denotes the total number of passengers during the count period; CTi—denotes the congestion time of passenger i; Ti—denotes the travel time of passenger i.

(3) Proportion of crowded miles

is the ratio of congested miles travelled by passengers who experienced congestion to the total miles travelled by all passengers:

$$R_m = \frac{\sum_i^{Pc} CM_i}{\sum_i^P M_i} \tag{3}$$

where: Rm - denotes the proportion of congested miles; Pc - denotes the number of passengers who experienced congestion during the enumeration period; P - denotes the total number of passengers during the enumeration period; CMi --- denotes the congested mileage of passenger i; Mi --- denotes the mileage travelled by passenger i.

4 Analysis and Research of a Visual Traffic Management System for Smart Cities Based on Digital Twin Technology

4.1 Framework of the System Based on Digital Twin Technology

In this paper, the overall framework of the system is determined based on the five-dimensional model of the digital twin as shown in Fig. 1:

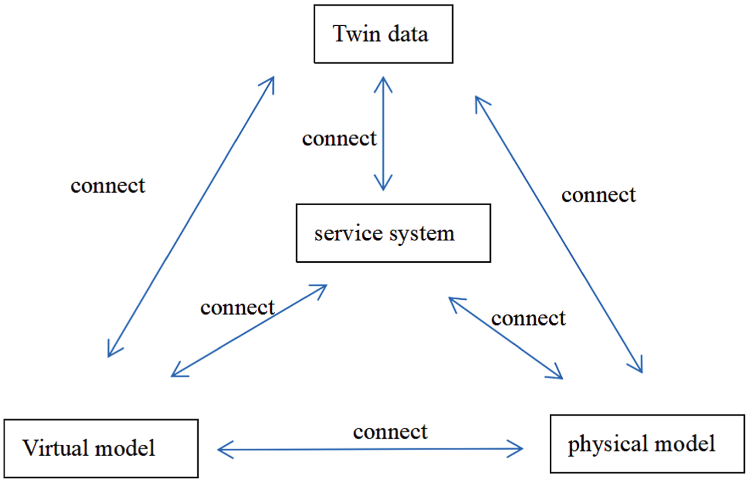

Fig. 1. The overall framework of the system based on digital twin technology

The following is an introduction to each part of the model:

(1) Physical model

The physical model is a physical representation of the whole transport system and its subsystems to a realistic scenario. In the digital twin model, the physical entities are portrayed against each other in virtual space. In addition to the intersection of information on the number of vehicles, traffic roads, road CNC equipment, etc. and the traffic operation process, the physical model in this paper also requires the collection of environmental data as well as dynamic data on the equipment: 1) environmental data: road scenes, vehicle specifications, equipment status, road status; 2) dynamic data: sensor information, controller information, CNC equipment information.

(2) Virtual model

Usually use VISSIM related software to simulate modeling, analysis and optimization of physical entities in the virtual environment to create a spatial scene consistent with the entities in the real environment. Realise the virtual model and the real model movement - consistent.

(3) Connection

In this paper, the system for each module part of the components need to be connected to each other, to achieve a purpose of effective data transmission. To realise a barrier-free information transfer in the system, an efficient digital mapping between the physical model, the virtual model, the twin data and the service system, a data-driven real-time simulation and an analysis and real-time feedback of the experimental results. Therefore, effective connectivity is of great importance for the implementation of the system.

(4) Twin data

The twin data provides the primary data support for the digital twin module and incorporates the basic methods of data collection, data processing and fusion to unify the data in the system in the real and imaginary space.

(5) System services

Simulation experiments are conducted in the virtual space using the collected data to predict and control traffic operations in the virtual environment, and provide users with data statistics and analysis functions in an intuitive manner to help alleviate urban traffic congestion and make timely judgments.

4.2 System Function Demonstration

The implementation of the traffic management system based on digital twin technology mainly includes an information login system, a rapid traffic modelling module, a traffic prediction management module, and a traffic control management system. The initial interface of the system is designed to provide access to different users, and its purpose is to well protect the user's right to use and personal privacy. After a successful user login, the system enters the Rapid Traffic Modelling Management module.

The first part uses historical traffic data to obtain some samples for the training of the traffic prediction model, which mainly includes the number of vehicles, congestion time and other relevant data for the basic variables of the whole traffic operation; the second part is for the modelling of the whole traffic congestion section and the setting of the model parameters, such as the whole The second part is the modelling of the entire congested section and the setting of the model parameters, such as the queue length and duration of the congestion process, as well as the selection of the relevant rules and simulation objectives. In the second part, the traffic state prediction model and the congestion control model are optimised in turn.

In this paper, traffic data obtained from monitoring points on the roads in some areas of the L station in M on 30 September 2022 is used as an example. Table 1 shows the proportion of passenger congestion under the data monitoring module, and the passenger congestion on each route is shown in Fig. 2. Data-driven full-cycle status monitoring and dynamic control of the actual bus system can effectively improve the overall level of bus operation services.

Table 1. Data Monitoring

line	Direction of travel	Percentage of crowded people (%)	Congestion time ratio (%)	Congestion distance ratio (%)
Bus No.215	upstream	15	27	10
Bus No.215	down	25	30	18
Bus No.7	upstream	18	22	34
Bus No.7	down	26	25	26
Bus No.66	upstream	24	30	30
Bus No.66	down	33	24	21
Bus No.3	upstream	16	19	16
Bus No.3	down	35	15	19

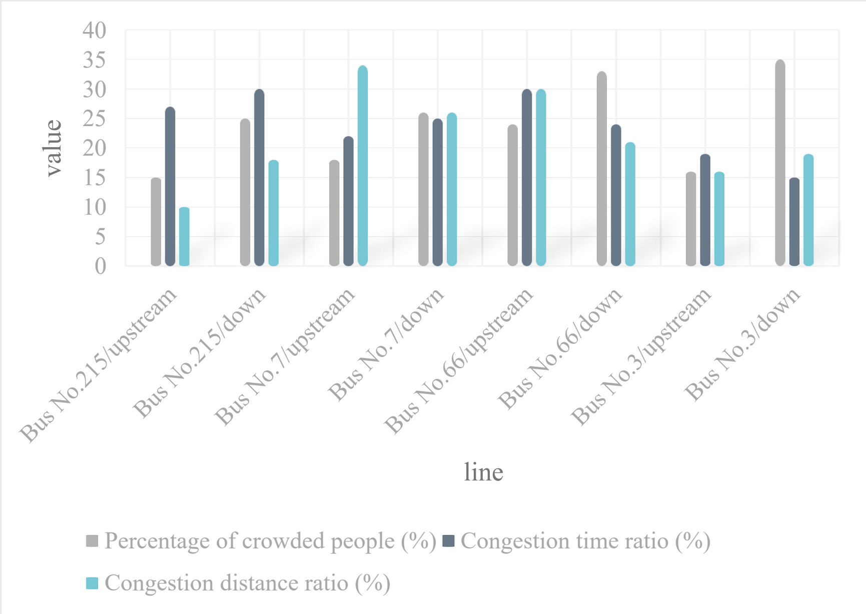

Fig. 2. Monitoring Data on Roads in Some Areas

5 Conclusions

The traffic management system has made great contributions to the smart city and is of great research significance. In this paper, a traffic management system based on digital twin technology is implemented from a system development perspective with the integration of various subsystems. The basis for future application and further analysis and improvement of the system is laid. The construction of the traffic management system is only a prototype of the system and there is still some distance to go before the system can be implemented. In view of the above shortcomings, the next work in this paper will focus on the diversity of data and the integration of multiple models to achieve a more complete traffic situational awareness, while more data types will also enable a richer visualisation of the components.

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