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Urban Traffic Congestion Prediction System Based on Big Data

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Abstract: With the rapid advancement of urbanization, the problem of urban traffic congestion has become increasingly prominent, which has become an important constraint affecting the sustainable development of cities. In order to effectively alleviate traffic congestion, it is urgent to use advanced technological means to deeply tap the value and potential of traffic big data. In this paper, an urban traffic congestion prediction system based on big data is proposed. By extensively collecting heterogeneous traffic data from multiple sources, a set of adaptive reinforcement learning prediction model is constructed on the basis of which the traffic signal control problem is modeled as a Markov decision process, and the optimization goal is to minimize the average travel time of regional vehicles. The model uses DQN algorithm to train the signal timing strategy, and introduces dual network architecture, experience playback, priority sampling and other technical improvements to improve the stability and training efficiency of the algorithm.
Keywords: Traffic big data; Congestion prediction; Reinforcement learning; Deep Q network; Intelligent transportation

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With the acceleration of urbanization, the problem of urban traffic has become increasingly prominent, especially the problem of traffic congestion has become one of the bottlenecks restricting the sustainable development of cities. Traffic congestion not only reduces the efficiency of urban transportation system and prolongs the travel time of citizens, but also aggravates environmental pollution and energy consumption, which seriously hinders the realization of urban low-carbon development goals. Traditional traffic congestion control methods, such as road construction, traffic restrictions, etc., have been difficult to fundamentally solve the increasingly complex urban traffic problems. Through the integration of massive traffic data and the use of data mining, machine learning and other technologies, it is possible to gain in-depth insight into the space-time evolution law of traffic congestion and build an efficient and accurate traffic congestion prediction model [1]. This study aims to explore the application of big data technology in urban traffic congestion prediction, design and implement a set of urban traffic congestion prediction system based on big data, and provide a new theoretical perspective for alleviating urban traffic congestion, optimizing traffic travel, and promoting urban low-carbon development.

1. Collection and fusion of multi-source heterogeneous traffic big data

This study extensively collected multi-source heterogeneous traffic big data to comprehensively describe urban traffic operation status: (1) Roadside devices such as microwave vehicle detector and coil vehicle detector were deployed to collect real-time road traffic flow data, including key parameters such as vehicle flow, speed and vehicle density; (2) Obtain GPS floating vehicle data within the city through cooperation with traffic management departments to reflect real-time road condition information of the road network; (3) Access the API interface of the meteorological department to capture weather data regularly, including temperature, humidity, visibility, precipitation, etc., to analyze the impact of weather factors on traffic [2]. Considering the diversity of data, ETL (Extract-Transform-Load) tool is used for real-time data acquisition and multi-thread parallel processing, data is transmitted and decoupage based on distributed message queue Kafka, and data is analyzed and structured by Spark SQL to eliminate noisy data and outliers. Such as illegal GPS coordinates, sensor data beyond the reasonable range, etc. Build a Distributed File storage System based on Hadoop Distributed File System (HDFS) and deploy HBase columnar NoSQL databases to store high-dimensional and sparse traffic feature data. To meet the high concurrency writing and real-time query requirements of traffic flow data, NoSQL databases such as Cassandra and Redis are introduced to store time series data and cache hot spot data respectively.

2. Construction of traffic congestion prediction model

Based on reinforcement learning algorithm, this paper constructs a set of adaptive traffic congestion prediction and optimization model. The traffic signal control problem is modeled as a Markov decision process (MDP), and the traffic flow state is taken as the environment state space, the signal timing scheme as the action space, and the average travel time of regional vehicles is minimized as the optimization goal. Through continuous exploration and learning, the optimal signal timing strategy is found, so as to predict and alleviate potential traffic congestion:

Firstly, Q-learning algorithm is used to train the signal timing strategy. Q-learning is a value function model-free reinforcement learning algorithm, which approximates the optimal strategy by constantly updating the state-action value function (Q function). At its core is an iterative update of the Bellman equation:

$$Q(s_t, a_t) \leftarrow Q(s_t, a_t) + \alpha[r_{t+1} + \gamma \max_a Q(s_{t+1}, a) - Q(s_t, a_t)]$$

Where, st is the traffic flow state at time t, at is the signal timing action selected at time t, rt+1 is the reward obtained after executing the action (negative average travel time), α is the learning rate, γ is the discount factor.

Considering the complexity of the actual traffic environment and the high dimensional characteristics of the state space, deep reinforcement learning (DRL) technology is further introduced, and deep neural network is used as an approximate representation of Q function to improve the generalization ability and convergence speed of the algorithm. A DQN algorithm based on dual network architecture is designed, which includes an estimation network and a target network. The estimate network is used to greedily select actions and update Q values, and the target network is used to compute target Q values, periodically copying parameters from the estimate network. The loss function of DQN is defined as:

$$L(\theta) = \mathrm{E}(s, a, r, s') \sim \mathrm{D}[(r + \gamma \max a' Q(s', a'; \theta^-) - Q(s, a; \theta))^2]$$

Where θ is the parameter of the estimated network, θ- is the parameter of the target network, and D is the experience playback cache. The estimation network was trained by mini-batch gradient descent algorithm to minimize the mean square error between the predicted Q value and the target Q value. On the basis of DQN, Prioritized Experience Replay is prioritized and samples are prioritized in the experience replay cache according to the size of TD error of samples. Improve the utilization efficiency and training speed of important samples.

In terms of model training, a set of micro-traffic Simulation environment is built, and realistic traffic flow data is generated by SUMO (Simulation of Urban MObility) software. Multi-dimensional features such as road network topology, traffic flow and signal timing are extracted to build an interactive interface between reinforcement learning agents and the environment [2]. Distributed training of the model through GPU server, fast iteration and optimization of DQN model. The DQN class defines a three-layer fully connected neural network as a Q function approximator, and the DQNAgent class encapsulates the core logic of the DQN algorithm, including the mechanism of experience playback, ε-greedy exploration, target network, etc. By constantly interacting with the environment and updating the Q network, the agent gradually learns the optimal signal control strategy.

3. Experimental results and analysis

In order to comprehensively evaluate the performance of the traffic congestion prediction model based on reinforcement learning proposed in this paper, a micro-traffic simulation environment was constructed and SUMO traffic simulation software was used to generate realistic traffic flow data. In the simulation environment, the performance differences between reinforcement learning model and traditional fixed-period signal control and traffic responsive control methods are compared [3]. The trained reinforcement learning model is deployed to the real traffic scene, and several typical intersections in the central area of a city are selected as test points to collect continuous real-time traffic flow data and signal timing data. The state features of the model are updated every 15 minutes by means of a sliding window, and the traffic congestion prediction results within the next 1 hour are generated. Two typical cases are taken as examples:

3.1 Case 1: The core road of the downtown business district

This section is located in the downtown bustling business district, surrounded by a large number of shopping malls, office buildings and restaurants, traffic demand is strong, especially during weekends and holidays, often serious traffic congestion. The reinforcement learning prediction model was deployed at four intersections of this section to continuously monitor traffic conditions for a week. The results show that by dynamically adjusting the signal timing scheme, the model can effectively alleviate traffic congestion, increase the average speed by 16.02%, reduce the number of vehicle stops by 19.65%, and shorten the queue length by 22.33%. At the same time, the model also sends congestion warning and travel advice to the driver in advance according to the real-time road conditions and prediction results, and guides the vehicle to choose a reasonable driving path to further alleviate the traffic pressure.

3.2 Case 2: Expressway toll station exit

Toll station is an important node of the highway, because the vehicles will gather in a short time, it is easy to cause traffic congestion. A toll station exit of an expressway is selected as the test point, and the traffic flow and queuing condition of the toll station are predicted by the reinforcement learning model. The model predicts the traffic load of the toll station in the next half hour according to the traffic flow, vehicle type distribution, weather conditions and other factors in the upstream section of the toll station, and adjusts the number of toll Windows opened and the guidance strategy of ETC lanes in advance. The experimental data show that during the continuous one-month test period, the traffic efficiency of the toll station is increased by 12.83%, and the average queuing time of vehicles is shortened by 25.17%, which effectively reduces the frequency and intensity of congestion.

4. Conclusion

To sum up, the traffic congestion prediction model based on reinforcement learning constructed in this paper has achieved good prediction results under different traffic scenarios, which can effectively alleviate congestion and improve traffic efficiency. Through the analysis of typical cases, the practicability and scalability of the model are further verified, and new ideas and methods are provided for intelligent traffic management. In the future, we will continue to optimize the model algorithm, expand the coverage of data sources, and deeply integrate with traffic simulation, traffic guidance and other technologies to build a complete set of traffic congestion prediction and mitigation solutions, contributing to alleviating urban traffic pressure and improving residents' travel experience.

References:

[1] Wang Lankai, Chen Cong. Exploration of Big Data Analysis and prediction Model in Transportation planning [J]. Theoretical Research on Urban Construction (Electronic Edition), 2024, (14) : 151-153.

[2] Yan Jianqiang, Zhang Lin, Gao Gao, et al. Research on Urban Traffic congestion Prediction: A case study of Xi 'an City [J]. Computer Engineering and Applications, 1-13.

[3] Lu Qing-Li. Prediction of urban Main road traffic congestion level based on deep learning [J]. Microcomputer Applications, 2019, 40 (07) : 238-241.

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