Research on Intelligent Perception and Accident Prediction System of Smart City Traffic Information Supported by Spatiotemporal Big Data Mining and GIS Visualization

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Abstract: This research focuses on the intelligent perception and accident prediction system of smart city traffic information supported by spatiotemporal big data mining and GIS visualization. This paper analyzes the research background and significance, the current situation at home and abroad, and expounds the relevant theoretical basis, including spatio-temporal big data, GIS visualization and smart city transportation system architecture. The application of spatio-temporal big data mining in traffic is introduced in detail, such as data collection and integration, clustering, pattern and association rule mining, and the support of GIS visualization for intelligent perception of traffic information, covering traffic network, traffic flow, bus and event visualization. The smart city traffic information intelligent perception system is constructed, including sensor layout optimization, data transmission and storage, and intelligent perception algorithm design. A traffic accident prediction system based on spatiotemporal big data was established, risk factors were analyzed, models were constructed, and training and verification were carried out. Finally, we summarize the research results and look forward to the future research direction, aiming at promoting the development of smart city transportation.

Keywords: Spatio-Temporal Big Data Mining; GIS Visualization; Smart City Transportation; Intelligent Perception; Accident Prediction.

1. Introduction

In today's era of accelerating urbanization, the construction of smart cities has become an important trend of global development. As a city is a gathering place of economy, culture and population, the efficient operation of transportation system is crucial to the sustainable development of the city. However, with the continuous expansion of the urban scale and the sharp increase in the number of motor vehicles, traffic congestion, frequent traffic accidents, environmental pollution and other problems are becoming increasingly serious, which has brought huge negative impact on the life of urban residents and economic development. According to statistics, in some big cities, the average commuting time of residents is as long as tens of minutes or even hours. Traffic accidents cause a large number of casualties and property losses every year, and exhaust emissions caused by traffic congestion also seriously affect air quality. These problems not only reduce the quality of life of urban residents, but also restrict the economic vitality and competitiveness of the city.

In this context, with the help of advanced information technology to achieve the intelligent upgrade of the traffic system has become a top priority. Spatiotemporal big data mining and GIS visualization technology came into being, providing innovative ways to solve the smart city traffic dilemma. Spatiotemporal big data refers to massive data with time labels and geographic coordinates, reflecting the distribution and activities of people and objects in time and space dimensions. It comes from a wide range of sources, covering communication, transportation, social networking, remote sensing and other categories [1]. Among them, mobile signaling data contains a large number of users' spatio-temporal location information, swipe card data and GPS data accurately record residents' travel tracks, and check-in data from social platforms such as Weibo and wechat reflect users' activity locations. With large scale, fine granularity and wide coverage, these data contain rich temporal and spatial attributes and are valuable resources for analyzing behavioral activities [2]. Spatiotemporal big data is widely used in the field of urban transportation. The real-time positioning of vehicle GPS, RFID and other devices supports intelligent applications such as dynamic monitoring of traffic operation [3], event detection [4], and path planning [5]. The integration of multi-source data such as bus and subway can help clarify residents' travel patterns at different time and space scales, and provide new ideas for optimizing public transit network and adjusting transport capacity resources [6]. In the field of shared bicycles, bicycle track data is used to analyze riding behavior [7] and optimize bicycle scheduling [8]. In the field of online ride-hailing, order data helps to mine passenger demand [9] and vehicle capacity matching [10]. In general, spatio-temporal big data provides new ideas for analyzing traffic operation mechanism and optimizing traffic system governance. However, while spatiotemporal big data brings opportunities, there are also challenges such as uneven quality and unclear semantic expression. How to clean, integrate and analyze multi-source heterogeneous spatio-temporal data, and explore its spatio-temporal patterns and characteristic laws, is a research hotspot in the academic field [11]. A series of spatio-temporal data mining methods have emerged endlessly, such as spatio-temporal clustering [12] and spatio-temporal prediction [13], etc., laying a foundation for extracting regularity cognition from complex data. At the same time, the development of some visualization tools for spatiotemporal big data, such as TransBigData [14], also provides an intuitive perspective for mining spatiotemporal behavior patterns and discovering data insights.

This research focuses on the intelligent perception and accident prediction system of smart city traffic information supported by spatiotemporal big data mining and GIS visualization, which has great theoretical and practical significance. At the theoretical level, it helps to enrich and improve the theoretical system in the field of intelligent transportation, deeply explore the application mode and algorithm optimization of spatio-temporal big data in traffic scenes, and promote the cross-integration of multiple disciplines such as data mining, machine learning, and geographic information science. Practical significance is more significant. On the one hand, it can help the traffic management department achieve accurate and intelligent management, real-time perception of traffic conditions, early warning of congestion and accident risks, reasonable allocation of traffic resources, optimization of traffic signal control, so as to effectively alleviate traffic congestion, reduce traffic accidents, and improve road traffic efficiency. On the other hand, it provides real-time and accurate traffic information for residents to make travel decisions, plan optimal routes, save travel time, reduce travel costs, and reduce vehicle exhaust emissions to help urban environmental protection and sustainable development. In short, the research has an immeasurable role in promoting the construction of an efficient, safe, green and intelligent smart city transportation system.

2. Application of Spatio-Temporal Big Data Mining in Smart City Transportation

2.1 Application of Spatio-Temporal Big Data Mining in Smart City Transportation

The collection of multi-source traffic data is the key to build spatiotemporal big data. Traffic sensors, such as ring coil sensors, microwave radar sensors and video cameras, collect vehicle flow, speed, road occupancy and other parameters and road scene pictures through electromagnetic induction, electromagnetic wave detection and image recognition technology. With the development of intelligent connected vehicles, its GPS devices and sensors can record vehicle trajectories and driving states, providing information for traffic planning and road maintenance. Social media platforms gather people to share road conditions, which can be mined by natural language processing and image recognition technology to make up for the shortage of traditional sensors. The meteorological data provided by the weather station is closely related to the traffic operation, and the integrated analysis can predict the impact of bad weather.

In the face of multi-source heterogeneous data, data integration is very important. Data cleaning uses filtering algorithms, duplicate data identification and missing value processing to ensure accurate and complete data. Data conversion Unified data format, including time format, spatial coordinate system, and normalization, standardization processing. Data fusion Through spatio-temporal registration and fusion algorithms, in-depth mining of data association, such as the combination of sensors and vehicle GPS data to generate more accurate speed, to provide a basis for traffic decision-making.

2.2 Space-Time Cluster Analysis

Spatiotemporal clustering algorithm plays a significant role in the field of smart city transportation. Taking Beijing as an example, through the integration of traffic flow, speed and road geographic information data, the algorithm can accurately identify the morning and evening peak traffic congestion and timely sections, such as the East third Ring road and the West Second Ring road congestion. Based on the spatial and temporal proximity and similarity criteria, the algorithm clusters the congested sections into hot spots, providing scientific basis for traffic facilitation.

In terms of traffic accident analysis, collecting historical accident data, including location, time, type and weather conditions and other information, the spatio-temporal clustering algorithm can mine the spatio-temporal regions with high incidence of accidents, such as complex intersections, the surrounding areas of construction sections and specific periods of rain and fog weather. This will help traffic management departments to implement accurate safety early warning and optimize road facilities. In addition, the algorithm is also applied in transportation planning and public transit network optimization, which can reasonably plan road and bus layout and improve the efficiency of transportation resource allocation according to the results of the clustering analysis of the big data of residents' travel time and space.

2.3 Spatio-Temporal Pattern Mining

Spatio-temporal pattern mining aims to extract rules from massive traffic data and provide basis for traffic management, planning and travel decision-making. In the time dimension, the traffic flow law is analyzed by week, day and hour. The traffic flow increases sharply in the morning and evening peak hours on weekdays, the road between the urban access channel and the business district and residential area is congested, the purpose of travel is diversified on weekends, and the road flow around the leisure place changes differently. For example, Beijing's weekday commuter roads are busy in the morning and evening peak hours, and the road traffic peak hours around the scenic spot are different on weekends. During the daily cycle, most cities have morning and evening peaks, and some areas are briefly busy at noon due to dining. For example, the morning peak traffic in Guangzhou tends to be stable after rising hour by hour, while the noon, afternoon and evening peaks have their own characteristics, which are related to the rhythm of urban life.

In spatial dimension, traffic flow in different functional areas has its own characteristics. During the day, the commercial area has a large flow of people and vehicles, concentrated parking demand, and congested surrounding roads around the entrance of shopping malls and parking lots. The traffic in the residential area is tidal in the morning and evening, and the entrance and branch roads of the residential area are often congested. Industrial zone during the working day transport of goods frequent, need to take into account truck traffic and safety, prone to local congestion. In the case of spatio-temporal pattern mining of bus passenger flow in a city, by analyzing multi-source information, the bus company adopts scheduling strategies such as off-peak departure and route adjustment according to the spatio-temporal distribution law of passenger flow, so as to achieve accurate matching of bus resources and passenger flow demand, improve operational efficiency and service quality, and alleviate road traffic congestion.

2.4 Association Rule Mining

Association rules mining is of great significance to understanding the operating mechanism of traffic system and predicting the evolution of traffic situation. Weather is closely related to traffic accidents, such as heavy rain weather, low-lying urban roads and mountain curves and other areas of the accident risk increased significantly. Taking the road section along the river in a southern city during the summer rainstorm season as an example, the mining of association rules can identify the high frequency correlation between rainstorm and accident, according to which the traffic management department can strengthen the deployment of police, set up warning signs or take control measures.

The traffic flow of the road section is correlated with the congestion degree of the surrounding area. In the commercial core areas of first-tier cities, when the traffic volume of the main road is saturated in the evening peak on weekdays, the surrounding auxiliary roads and alleys are easy to cause congestion and spread due to insufficient diversion capacity. By comprehensively mining traffic flow data, road topology and historical congestion records, the mapping relationship between traffic threshold and congestion area can be determined, and the traffic management department can predict the direction of congestion diffusion, adjust the timing of signal lights, guide the diversion of vehicles, and avoid the deterioration of congestion. Association rule mining helps traffic management departments make accurate decisions, scientifically allocate resources, prevent and control accident risks, and promote the refined and intelligent development of smart city traffic management.

3. GIS Visualization Supports Intelligent Perception of Smart City Traffic Information

3.1 Transportation Network Visualization

GIS technology can visually present the urban traffic network in the form of map. On the two-dimensional plane map, the road layout and the location of traffic facilities are accurately depicted through vectorization processing. For example, the Beijing traffic map clearly shows the connection between the ring line, the main road and the urban functional area. Roads of different levels are distinguished by different lines, and the nodes are clear at a time, providing basic support for traffic planning and control.

For dynamic information such as traffic flow and speed, GIS visualizes it by means of real-time data access and dynamic rendering technology. The traffic flow and speed of Shanghai traffic map are represented by color gradient or flowing lines, according to which the managers can understand the congested sections and bottleneck nodes, and dispatch the police force in time. Travelers can plan their routes ahead of time to avoid congestion. In addition, GIS can accurately locate and mark special events such as traffic accidents and road construction. When an accident occurs, the system pops up a warning icon and displays detailed information. The affected area of the surrounding road section is presented in the form of a buffer zone, which facilitates the timely implementation of diversion control measures. The road construction area is marked with construction progress and other information to help adjust the traffic organization plan and ensure smooth road passage.

3.2 Visualization of Traffic Flow Dynamic Monitoring

GIS technology can monitor traffic flow in real time and present it visually, which provides a strong basis for traffic management decision-making. Taking an intersection in Shenzhen as an example, the data of vehicle flow and speed are collected by geomagnetic sensors and video cameras and transmitted to the GIS system, which dynamically draws the traffic flow chart at minute intervals. In this way, the manager can accurately understand the tidal changes of the traffic flow at the intersection. For example, when the congestion in the direction of entering the city is intensified in the morning peak, the timing of the signal light can be adjusted or the tidal lane strategy can be adopted to optimize the traffic flow distribution and alleviate the congestion. When dealing with traffic anomalies caused by large-scale activities or emergencies, GIS traffic visualization can also assist managers to quickly develop diversion control measures to ensure the orderly operation of urban traffic.

3.3 Public Transportation Information Visualization

The visual application of GIS technology in the field of public transportation greatly facilitates the residents' travel and improves the service quality and operation efficiency of public transportation. In terms of public transportation system, GIS can accurately present the direction of bus routes and station layout. For example, the Beijing bus map displays the track and station information in detail. Passengers can check the real-time location and arrival time with the help of mobile phone APP or electronic bus stop card, and select the optimal route based on real-time road conditions in travel planning to save travel time.

In the subway system, GIS presents the lines and stations in three dimensions to show the transfer relationship. The subway network of Beijing is complex, and the subway map drawn by GIS accurately describes the route direction and station sequence, and displays the train operation status and real-time passenger flow distribution through dynamic effects. At large transfer stations in the evening peak, the GIS system monitors passenger flow changes and presents the congestion degree of the carriage and platform with color or thermal map, so that the operation department can adjust the departure interval and arrange personnel accordingly, balance the distribution of passenger flow, and improve the ride comfort and operation safety order. Some cities also integrate and visualize bus and subway information, build an integrated travel planning platform, comprehensively consider a variety of factors for users to plan the optimal travel path and animation display, promote the coordinated development of public transport, and guide citizens to travel green.

3.4 Visualization of Traffic Events

GIS technology plays a key role in traffic event visualization and provides strong support for traffic emergency management. When a traffic accident occurs, the GIS system quickly marks the exact location of the accident on the map with eye-catching ICONS to highlight it, and at the same time displays information such as the type, time and severity of the accident. The affected area of the surrounding roads is visually displayed through buffer analysis, and different color buffers represent different traffic obstruction degrees, providing a basis for timely diversion and diversion measures. For example, in a traffic accident on a main road in Nanjing, the GIS system assisted the traffic management department to respond quickly, dispatch traffic police and plan diversion routes to avoid the large-scale spread of congestion.

For the visualization of road faults, the GIS system connects with the data of the municipal maintenance department to mark the fault point in real time, and specify the fault type, reporting time and estimated repair time in detail. Maintenance personnel can obtain information to repair with the help of mobile terminals to improve road maintenance efficiency and driving safety. In terms of traffic control visualization, GIS clearly marks the start and end point, time and mode of the control section in advance, and dynamically displays the change of the control area, so that travelers can know the road condition and plan their route in advance, and at the same time assist the traffic management department to optimize the control plan and reduce the negative impact on traffic.

4. Construction of Intelligent Perception System for Smart City Traffic Information

4.1 Sensor Layout Optimization at the Sensing Layer

The sensor layout of the sensing layer needs to consider many factors comprehensively. The main road with a large traffic flow, such as Chang 'an Street in Beijing and Yan 'an Road in Shanghai, should encrypt the sensor layout density, take the ring coil sensor as an example, shorten the setting interval during peak hours, accurately collect data, and provide support for traffic signal intelligent control. The type of intersection affects the layout strategy. Cameras and geomagnetic sensors are deployed at the entrance and exit lanes at intersections to monitor vehicle behavior in an all-round way and identify traffic conflict points. In addition to the entrance and exit of the roundabout, monitoring points are set inside the roundabout to grasp the vehicle trajectory and speed changes to prevent congestion and accidents.

Different road levels, sensor layout focus is different. To monitor the continuous changes of speed and flow on urban expressways, microwave radar sensors can be used and installed at a certain distance. Secondary arteries and branches connect residential and commercial areas with frequent vehicle traffic, focusing on the deployment of geomagnetic sensors and RFID tags to provide data for regional traffic microcycle management. Taking Hangzhou as an example, Tianmushan Road, Moganshan Road and other main roads optimize the sensor layout according to the traffic flow, intersection distribution and the characteristics of the surrounding functional areas. Annular coil sensors and high-definition cameras are installed in the morning peak direction out of the city, and geomagnetic sensors and intelligent cameras are installed in an all-round way at intersections to improve the accuracy of traffic data acquisition and lay the foundation for traffic management decisions. Improve the efficiency of urban transport operations.

4.2 Data Transmission and Storage Management

Wireless communication technology is very important in data transmission. 5G achieves high-speed real-time transmission of traffic data by virtue of high bandwidth, low latency and wide connectivity. Video data collected by high-definition cameras on urban main roads can be transmitted to the traffic command center in real time, and vehicle networking communication between vehicles and road infrastructure also relies on 5G technology. At the same time, wireless communication technologies such as Wi-Fi, Bluetooth and ZigBee play a role in specific scenarios. Wi-Fi is often used in transportation hubs and parking lots to provide users with network access; Bluetooth is used for short-distance vehicle communication and intelligent parking device connection; ZigBee is suitable for traffic sensor network data aggregation transmission, such as intelligent street light system integrated ZigBee module to collect environment and traffic flow information.

In the face of massive traffic data, distributed storage technology emerges. Taking the Chengdu traffic management department as an example, it carries the construction of intelligent transportation based on a large-scale distributed storage platform, which can accommodate a large amount of unstructured and structured data, including high-definition camera video and traffic bayonet pictures. The platform has the horizontal expansion ability to meet the data storage needs, but also provides speed performance, support violation identification and map search and other AI applications, through the metadata service cluster technology and hierarchical storage strategy, to achieve rapid data retrieval and reading and writing, lay a solid foundation for the deep mining of traffic data and intelligent application, and promote the refined and intelligent development of smart city traffic management.

4.3 Intelligent Perception Algorithm Design

Intelligent perception algorithm relies on machine learning and deep learning technology to extract valuable information from traffic data. Machine learning-based traffic flow perception algorithms, such as support vector machines (SVM), predict future traffic flows by mining historical data and combining feature vectors such as date types and weather conditions. In the core business district of first-tier cities, the SVM model can predict the change of traffic flow based on past data and real-time factors, and assist the traffic management department to adjust the timing of signal lights and police deployment.

In terms of traffic event perception, decision tree algorithm analyzes the multivariate data collected by traffic sensors, such as speed change and other information, builds a model to judge the type of event, and issues early warnings in time. Deep learning algorithms have obvious advantages in the field of traffic information perception. Taking Guangzhou as an example, convolutional neural network (CNN) and long short-term memory network (LSTM) are integrated to build a congestion perception model, CNN analyzes road surveillance images and videos, and LSTM processes traffic flow time series data. The combination of the two can realize high-precision real-time perception of traffic congestion conditions and predict the section and degree of congestion in advance. Provide accurate route planning suggestions for citizens to travel and help urban transportation operate efficiently.

5. Smart City Traffic Accident Prediction System Based on Spatiotemporal Big Data

5.1 Analysis of Accident Risk Factors

The occurrence of traffic accidents is affected by a variety of risk factors, so it is very important to analyze from the four dimensions of human, vehicle, road and environment. Among the human factors, the driver's behavior and state play a decisive role in driving safety. Fatigue driving, drunk driving, driving without a license and mood swings all increase the risk of accidents. Fatigue driving is easy to cause accidents in long-distance transportation and night driving scenes. Drunk driving severely impairs the driver's ability to control; Driving without a license lacks the necessary skills and knowledge; Mood swings can interfere with driving.

Vehicle performance is directly related to driving safety. Braking, steering system failures and tire wear affect vehicle handling stability, especially under special road conditions. Missing or inoperative safety configurations do not effectively protect drivers and passengers. Poor vehicle maintenance, parts aging damage not replaced in time also buried hidden dangers for the accident.

Road design and condition affect accident probability. Unreasonable lines such as sharp bends, steep slopes increase the difficulty of operation, easy to cause collision accidents. Unclear traffic signs lead to illegal driving and conflict. Problems such as potholes and water not only affect comfort, but also interfere with vehicle handling, reduce adhesion, and cause loss of control.

Environmental factors cover a wide range, and weather conditions have a prominent impact. Heavy rain, snow, fog and strong winds respectively make roads slippery, icy, low visibility and affect driving stability, increasing the risk of accidents. When the light changes day and night, if the driver does not adapt to or does not use the light correctly, it is easy to cause accidents. During special holidays and large-scale activities, traffic flow increases sharply, congestion intensifies, drivers are easy to make mistakes, and the risk of accidents increases. The analysis of these risk factors provides scientific basis for the construction of accident prediction model, and helps traffic management departments to prevent in advance.

5.2 Construction of Prediction Model

In the field of smart city traffic accident prediction, a variety of models have been applied, each with its own characteristics. The decision tree model is intuitive, easy to understand and interpretable, and can quickly judge the accident risk according to the characteristics of weather, road type and time period, but its ability to deal with complex nonlinear relations is limited. The neural network model has strong self-learning ability and can simulate nonlinear mapping relationships, such as multi-layer perceptron (MLP) processing data through multi-layer neurons, but the training is complicated, easy to fall into local optimal solutions, and the data amount is high.

Deep learning models have significant advantages when dealing with spatiotemporal big data, such as Long short-term memory networks (LSTM), which are designed for serial data and can capture the time dependence of traffic flow. Taking Chongqing as an example, its terrain is complex, the traffic flow is large and varied, and the construction of the accident prediction system based on LSTM has achieved remarkable results. Deploy sensors on key road sections in cities to collect multi-source data, and integrate meteorological, construction and holiday information to build spatio-temporal large data sets. The LSTM model mined the time series rules and spatial correlation characteristics of the data, and considered the impact of traffic flow changes in different periods, mountain terrain, functional region and other factors on the accident. After training and optimization, the model performs well in practical application. For example, a complex interchange section had frequent accidents due to ramp problems. After the introduction of the model, the real-time analysis of the surrounding traffic data was used to predict the high-risk period of accidents in advance, and the management department optimized the traffic control strategy accordingly, reducing the accident rate and alleviating traffic congestion, providing support for the intelligent transportation construction in Chongqing and providing reference for other cities.

In order to ensure the accuracy and reliability of the model, data division, parameter optimization and index evaluation are the key links. The classical tripartite method of training set, verification set and test set is often used for data partitioning. Take the traffic accident data of Wuhan as an example, randomly divided according to the proportion of about 70%, 15% and 15%. The training set is used for model learning and parameter fitting, the validation set periodically validates and adjusts hyperparameters to prevent overfitting, and the test set evaluates the model's performance on unknown data.

Parameter tuning is very important in model training. Different models have different key parameters, such as the number of hidden layers, the number of nodes, the learning rate and the activation function in the neural network. Taking LSTM as an example, in the practice of traffic accident prediction in Wuhan, multiple tests found that when the hidden layer is set to 3 layers, the number of nodes in each layer is 128, the adaptive learning rate strategy (such as Adagrad) is adopted, and ReLU is selected as the activation function, the model has the best performance, which can effectively capture the characteristics and relations of the accident data and improve the prediction accuracy.

It is necessary to use scientific index to evaluate model performance. The accuracy rate reflects the proportion of correct samples predicted. Accuracy measures the proportion that is predicted to be positive and is actually positive; Recall rates look at the percentage of actual accident samples that were correctly predicted; F1 score comprehensive accuracy and recall rate; Mean square error (MSE) and mean absolute error (MAE) can also be used to measure the deviation between the predicted value and the true value. In the verification of the Wuhan model, the accuracy rate of the optimized LSTM model is above 85%, the accuracy rate is about 80%, the recall rate is close to 83%, and the F1 score is stable at about 82%, which is significantly improved compared with the non-optimized model, and can provide a reliable basis for traffic management departments to prevent accidents and ensure road traffic safety.

6. Conclusion

This research focuses on smart city traffic information intelligent perception and accident prediction system, and has achieved remarkable results in theory, technology application, system construction and empirical testing. The theory explains the principle and correlation of related concepts; In the application of technology, spatio-temporal big data mining and GIS visualization effectively empower traffic; At the level of system construction, intelligent perception and accident prediction system perform well; The empirical results show that the constructed system improves urban traffic. In the future, it is necessary to deeply integrate multi-source data, strengthen real-time analysis and prediction capabilities, integrate new technologies to improve GIS visualization, overcome intelligent perception and accident prediction problems, and collaborate on multi-disciplinary innovation to promote the development of smart city transportation and create a better travel environment.

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