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Research on Dynamic Spatial Evolution Model of Traditional Villages Based on Deep Learning

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Abstract: In the process of modernization, the spatial form of traditional villages is undergoing significant changes, and their cultural values and ecosystems are facing severe challenges. Based on deep learning technology, this paper explores the dynamic spatial evolution of traditional villages, combines convolutional neural network (CNN) and long short-term memory network (LSTM), constructs a time series prediction model, and uses generative adversarial network (GAN) to simulate the spatial pattern of villages under future policy scenarios. The results show that the building density increases year by year, while the green space coverage decreases significantly, and the two are negatively correlated. The CNN-LSTM model has high prediction accuracy, and the scenario simulation generated by GAN provides scientific basis for policy making. This paper provides technical support and optimization path for the protection and sustainable development of traditional villages.

Key words: deep learning; traditional villages; spatial evolution; time series prediction

1. Introduction

Traditional villages are important carriers of Chinese history and culture, and their unique spatial patterns carry profound social, cultural and natural information. However, with the acceleration of modernization and urbanization, traditional villages face challenges such as increased building density and declining green space coverage, which not only threatens their historical landscape, but also puts pressure on ecosystems and sustainable development. Most of the existing studies rely on GIS and remote sensing image technology for static analysis, but there are shortcomings in revealing the dynamic evolution law and predicting the future trend. Deep learning, with its advantages of processing high-dimensional, non-linear and complex dynamic data, provides a new path for the study of village spatial evolution. Through deep learning model, this paper analyzes the spatial evolution law and simulates future scenarios to provide scientific basis for protection and development.

2. Research Basis and Technical Methods

2.1 Research status of dynamic evolution of traditional villages

Research on the spatial evolution of traditional villages mainly focuses on pattern changes and driving factors analysis. Common methods include GIS and remote sensing technology, identifying spatio-temporal trends by extracting spatial elements such as village buildings, green space and roads, and social survey and statistical data to analyze the impact of population flow and policy changes on village spatial patterns from a socio-economic perspective. These traditional methods have some limitations, mainly in the lack of dynamic feature mining, most of them remain in the description of

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static pattern, difficult to reveal the long-term evolution law; The ability of quantitative prediction and scenario simulation of future spatial evolution is limited, and it is difficult to provide scientific support for dynamic conservation and planning.

2.2 Introduction of deep learning technology

Deep learning technology has shown strong advantages in the processing and prediction of complex dynamic data, especially in the field of image analysis and time series prediction, which is widely used and excellent. In the study of spatial evolution of traditional villages, the following key technologies provide important support: convolutional neural network (CNN) can efficiently extract spatial features such as building density and green space distribution in remote sensing images; Long short-term memory network (LSTM) is suitable for the analysis of time series data, and can accurately capture the dynamic trend of village spatial change. Generative adversarial networks (GANS) generate future scenarios to simulate changes in village spatial patterns under different policy conditions and provide quantitative basis for scientific decision-making. These technologies open up a new path for the mining of dynamic laws and the prediction of future trends.

3. Data Processing and Model Construction

3.1 Data preparation

The data sources of the study include multi-period remote sensing image data from 2000 to 2020, as well as village-related boundary, road distribution and socio-economic development statistics, which form the basis for the analysis of the spatial dynamic evolution of traditional villages. In terms of feature extraction, three key indicators are selected: building density, that is, the percentage of construction area in the total area of the village, which is used to measure the degree of village building intensification; The coverage rate of green space, that is, the percentage of green space in the total area of the village, reflects the distribution of ecological resources[1]. Road accessibility measures the convenience of traffic inside and outside the village through the connectivity index of the road network. The above data and characteristics provide important support for in-depth analysis of dynamic spatial evolution law and future trend prediction.

3.2 Data preprocessing

In the data preprocessing stage, two key methods, cleaning and standardization and time series sorting, are adopted to ensure data quality and reliability of analysis results. Through cleaning and standardization techniques, noise in remote sensing images, such as cloud interference and image offset, is removed, and geospatial data is uniformly processed to ensure consistency in accuracy and format of different data sources. The time series processing normalized multi-period data to ensure the time dimension of data alignment, so that the remote sensing images, boundary changes and statistical data of different years can be accurately corresponded. After these preprocessing steps, a solid data foundation is laid for the subsequent dynamic change analysis and training of deep learning models[2].

3.3 Model construction

Two deep learning models, CNN-LSTM and GAN, were used to model and analyze different research objectives. CNN-LSTM model combines the advantages of convolutional neural network (CNN) and long short-term memory network (LSTM). CNN is responsible for extracting spatial features from remote sensing images, such as building density and green space coverage, while LSTM captures the dynamic change trend of these features by analyzing time series data to provide accurate prediction support for spatial evolution laws. Generative adversarial network (GAN) is used to generate future scenarios, simulate the possible evolution of village spatial pattern under different policy scenarios, quantify the impact of policy intervention on key indicators such as building density and green space coverage, and provide a visual and data-driven basis for scientific decision-making and planning[3].

3.4 Model training and verification

In the process of model training and evaluation, the data is reasonably divided into training set, verification set and test set, the proportion is 70%, 15% and 15%, respectively, to ensure the generalization ability and performance stability of the model. The training set is used to learn the parameters of the model, the validation set is used to adjust the hyperparameters and prevent overfitting, and the test set is used to evaluate the model's performance on unknown data. In addition, the cross-validation method is used to further optimize the model parameters, and the robustness and prediction accuracy of the model are improved through multiple rounds of training and validation. In terms of performance evaluation, the mean square error (MSE) is selected as the main index to quantify the difference between the predicted value and the actual value of the model[4]. At the same time, combined with the prediction accuracy, the performance of the model in the dynamic spatial feature prediction task is comprehensively measured, which provides a reliable basis for the result analysis.

4. Dynamic Evolution Rule and Model Verification

4.1 Dynamic change rule

By analyzing the data from 2000 to 2020, the significant law of spatial dynamic change of traditional villages is revealed:

Building density: From 45% in 2000 to 62% in 2020, a growth rate of 37.8%. The increase of building density in the core area is particularly significant, which is greatly influenced by population return and policy drive.

Green space coverage: From 35% to 20%, a 42.9% reduction. The large reduction of green space resources is mainly due to the expansion of building land and infrastructure construction.

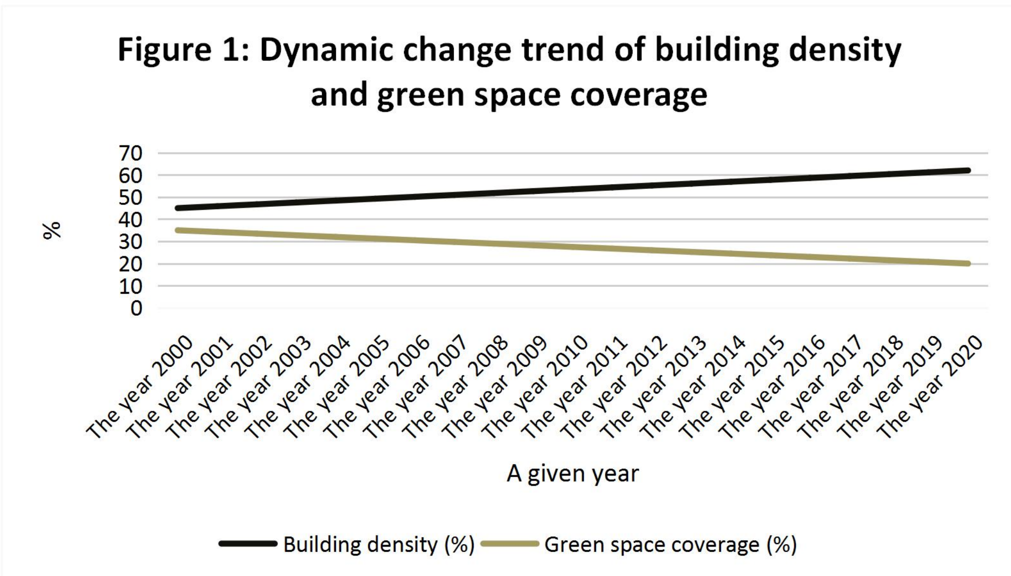

Figure 1. Dynamic change trend of building density and green space coverage. (Data source: self-drawn)

It can be seen from Fig. 1 that building density and green space coverage rate show obvious trends over time: building density increases year by year, while green space coverage rate decreases year by year, showing a significant negative correlation. This change reflects the evolution characteristics of the spatial pattern of traditional villages in the process of modernization, in which the increase of building density is mainly driven by policies and the impact of population return, while the decrease of green space coverage is closely related to land use change and infrastructure expansion[5].

4.2 Model prediction performance

The CNN-LSTM model has excellent performance in forecasting accuracy, with the average prediction error of building density controlled within 1% and the prediction error range of green space coverage rate ranging from 0.5% to

1.5%, which further verifies the high reliability of the model. The following table compares actual and predicted values for some years:

Table 1. Comparison of model predictions with actual values (Data source: self-drawn)

A given year	Actual building density (%)	Predicted building density (%)	Actual green space coverage (%)	Forecast green coverage (%)
2000	45.00	45.50	35.00	34.75
2010	53.50	53.60	27.50	27.85
2020	62.00	62.25	20.00	20.15

Table 1 intuitively reflects that the predicted values of the model are highly consistent with the actual observed values, and verifies the reliability and practicability of the CNN-LSTM model in the prediction of traditional village spatial dynamic characteristics.

5. Conclusion

Deep learning technology is used to reveal the dynamic spatial change law of traditional villages, and scientific basis and practical suggestions are put forward by simulating possible future development scenarios. The research shows that there is a significant negative correlation between building density and green space coverage in traditional villages, while deep learning models show high accuracy and practicability in spatial change law mining and trend prediction. In future studies, data such as drone images and social media can be introduced through multi-source data fusion to further improve the comprehensiveness of the analysis; Combined with reinforcement learning technology, the simulation ability of complex policy scenarios is enhanced. At the same time, the research results will be widely applied to rural revitalization strategy and cultural heritage protection planning to provide strong technical support for the sustainable development of traditional villages.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

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