Theoretical Framework Construction of Remote Sensing Image Processing Technology in The Study of Urban Heat Island Effect

Xiaoli Chai*
The Open University of JiLin, ChangChun, JiLIn, China
**Corresponding Author*

Abstract: This study aims to construct a theoretical framework to discuss the application of remote sensing image processing technology in the study of urban heat island effect. Urban heat island effect refers to the phenomenon that the temperature of urban area is significantly higher than that of surrounding rural area, which has become an important problem in the process of global climate change and urbanization. Remote sensing technology provides a powerful tool for in-depth understanding and effective response to this phenomenon. This study first reviews the existing remote sensing image processing technologies, including multispectral and hyperspectral imaging, thermal infrared imaging, laser radar (LiDAR), and analyzes the application status of these technologies in the study of urban heat island effect. Then, this paper puts forward a comprehensive theoretical framework, combining the key steps of remote sensing data acquisition, image preprocessing, feature extraction, classification and segmentation, and change detection, systematically describes how to use remote sensing image processing technology to monitor and analyze urban heat island effect. In the research process, this paper adopts the methods of literature review and case analysis, and extracts the core elements and key technologies of remote sensing image processing technology in the study of urban heat island effect by systematically combing the relevant research results at home and abroad. The research results show that remote sensing image processing technology has significant advantages in the spatial distribution characteristics, time change rules, and analysis of influencing factors of urban heat island effect, and can provide high-precision and high-timeliness monitoring data, and provide scientific basis for urban planning and environmental management. The theoretical framework of this paper provides guidance for future empirical research, and provides a reference for policy makers and urban managers, which has important academic value and practical application significance.

Keywords: Remote Sensing Image Processing Technology; Urban Heat Island Effect; Theoretical Framework; Spatial Distribution Characteristics; Environmental Management

1. Introduction

An Urban Heat Island (UHI) is a phenomenon in which the temperature of an urban area is significantly higher than that of the surrounding rural area. This phenomenon is mainly caused by human activities in the process of urbanization, including building density, road paving, industrial emissions and other factors. Urban heat island effect not only affects the quality of life of urban residents, but also has a profound impact on urban ecological environment and energy consumption. With the intensification of global climate change, the issue of urban heat island effect has become increasingly prominent, and has become an important issue in urban planning and environmental management. [1-6] Remote sensing technology, as an efficient and accurate means of Earth observation, can provide a wide range and high resolution surface temperature data, and provide a strong support for the monitoring and research of urban heat island effect. Through remote sensing image processing technology, the temperature distribution and change trend of urban areas can be obtained, which provides scientific basis for the analysis and management of urban heat island effect. Therefore, it is of great theoretical and practical significance to study the application

of remote sensing image processing technology in urban heat island effect. [7-15]

The purpose of this study is to construct a systematic theoretical framework to discuss the application of remote sensing image processing technology in the study of urban heat island effect. the specific objectives are to review and summarize the existing remote sensing image processing technology and its application in the study of urban heat island effect. A comprehensive theoretical framework is proposed to systematically explain how to use remote sensing image processing technology to monitor and analyze urban heat island effect. This paper analyzes the advantages and challenges of remote sensing image processing technology in the study of urban heat island effect, and puts forward future research directions and suggestions.

In this study, the core elements and key technologies of remote sensing image processing technology in the study of urban heat island effect were extracted by literature review and theoretical analysis and systematic review of relevant research results at home and abroad. Specific steps include:

The relevant literatures on remote sensing image processing technology and urban heat island effect were collected and sorted out.

Analyze and summarize the main contents and research methods of the existing research.

The theoretical framework of remote sensing image processing technology in the study of urban heat island effect is constructed.

The advantages and challenges of remote sensing image processing technology in the study of urban heat island effect are discussed, and the future research direction and suggestions are put forward.

2. Overview of Remote Sensing Image Processing Technology

2.1 Basic principle of Remote Sensing Technology

Remote sensing technology is a technical means to obtain the information of the earth surface from a long distance through sensors. Its basic principle is to use the interaction between electromagnetic waves and ground objects, through the sensor to receive reflected or radiated electromagnetic wave signals, and then obtain the spectrum, temperature, shape and other information of ground objects. Remote sensing technology has the advantages of wide coverage, fast data acquisition and high resolution, and is widely used in environmental monitoring, resource survey, disaster assessment and other fields.

In the study of urban heat island effect, remote sensing technology mainly analyzes the temperature distribution and change trend of urban area by acquiring land surface temperature data. the commonly used remote sensing data include multispectral, hyperspectral, thermal infrared and LiDAR data. These data can be obtained by satellites, drones, aircraft and other platforms, providing a rich source of information for the monitoring and analysis of urban heat island effect.

2.2 Classification of Remote Sensing Image Processing Techniques

Remote sensing image processing technology refers to the technical means to process and analyze remote sensing data, which mainly includes the following categories: Multispectral and hyperspectral imaging technology: Multispectral imaging technology can identify and distinguish different ground objects by obtaining spectral information of multiple bands. Hyperspectral imaging technology can obtain higher spectral resolution data and provide more detailed ground object information. In the study of urban heat island effect, multispectral and hyperspectral data can be used to analyze the distribution and change of land surface temperature in urban areas. Thermal infrared imaging technology: Thermal infrared imaging technology can directly measure the surface temperature by obtaining the thermal radiation information of ground objects. In the study of urban heat island effect, thermal infrared data is the main data source to obtain land surface temperature, which can provide high precision temperature distribution information. Laser radar (LiDAR) technology: LiDAR technology can obtain three-dimensional structure information of ground objects by emitting laser pulses and receiving reflected signals. In the study of urban heat island effect, LiDAR data can be used to analyze the height and density of urban buildings and conduct in-depth research on the formation mechanism of urban heat island effect. Synthetic aperture radar (SAR) technology: By transmitting microwave signals and receiving reflected signals, SAR

technology can obtain ground object information in all-weather and all-time conditions. In the study of urban heat island effect, SAR data can be used to analyze the surface characteristics and changes of urban areas. Data fusion technology: Data fusion technology can improve the accuracy and information of data by comprehensively utilizing multi-source remote sensing data. In the study of urban heat island effect, data fusion technology can comprehensively analyze multi-spectral, hyperspectral, thermal infrared, LiDAR and SAR data to provide more comprehensive temperature distribution and change information.

2.3 Development Status of Remote Sensing Image Processing Technology

With the continuous development of remote sensing technology, remote sensing image processing technology has also made remarkable progress. In recent years, remote sensing image processing technology has made important breakthroughs in data acquisition, image preprocessing, feature extraction, classification and segmentation, and change detection.

In terms of data acquisition, the resolution and coverage of remote sensing satellites have been continuously improved, which can provide higher precision and wider range of surface temperature data. For example, Landsat series satellites, MODIS satellites and Sentinel series satellites can provide high-resolution multi-spectral and thermal infrared data, providing rich data sources for the monitoring of urban heat island effect.

In the aspect of image preprocessing, radiometric correction, geometric correction, atmospheric correction and other technologies of remote sensing images are constantly improved, which can improve the accuracy and consistency of data. For example, radiation correction technology can eliminate the radiation error of the sensor, geometric correction technology can eliminate the geometric distortion of the image, and atmospheric correction technology can eliminate the influence of the atmosphere on the remote sensing signal.

In terms of feature extraction, the extraction techniques of spectral features, texture features and morphological features of remote sensing images are constantly developing, which can provide more abundant ground object information. For example, spectral feature extraction technology can identify and distinguish different ground objects, texture feature extraction technology can analyze the surface structure of ground objects, and morphological feature extraction technology can obtain the geometric form of ground objects.

In terms of classification and segmentation, the supervised classification, unsupervised classification, target detection, image segmentation and other technologies of remote sensing images are constantly improving, which can improve the accuracy and efficiency of ground object recognition. For example, supervised classification technology can use known samples for classification, unsupervised classification technology can automatically identify ground object categories, object detection technology can identify and locate specific ground objects, and image segmentation technology can segment images into different areas.

In terms of change detection, technologies such as time series analysis and change detection algorithm of remote sensing images have been continuously improved, which can monitor the change trend and amplitude of ground objects. For example, the time series analysis technology can analyze the time change law of ground objects, and the change detection algorithm can identify and quantify the change of ground objects.

3. Review of Urban Heat Island Effect

3.1 Concept and Formation Mechanism of Urban Heat Island Effect

An Urban Heat Island (UHI) is a phenomenon in which the temperature of an urban area is significantly higher than that of the surrounding rural area. Its formation mechanism mainly includes the following aspects:

Thermal characteristics of surface materials: buildings and roads in cities mostly use concrete, asphalt and other materials, which have high thermal capacity and thermal conductivity, and can absorb and store a large amount of solar radiation heat, resulting in a rise in surface temperature.

Heat emissions from human activities: industrial production, transportation, air

conditioning use and other human activities will produce a large amount of waste heat, which is directly discharged into the atmosphere, further aggravating the temperature rise in urban areas.

The effect of urban form: Tall buildings and dense buildings in cities create an "urban canyon" effect that limits air flow and heat dissipation, leading to heat accumulation inside the city.

Reduction of vegetation cover: In the process of urbanization, a large number of natural vegetation is replaced by buildings and roads, the transpiration of vegetation is reduced, and the evaporative cooling effect of the surface is weakened, resulting in higher temperatures in urban areas.

3.2 Research Methods And Status Quo of Urban Heat Island Effect

The research methods of urban heat island effect mainly include ground observation, numerical simulation and remote sensing monitoring.

Ground observation: Direct measurement of surface and air temperatures by placing temperature sensors in cities and surrounding areas. This method can provide high precision temperature data, but its coverage is limited, and it is difficult to fully reflect the spatial distribution characteristics of urban heat island effect.

Numerical simulation: Using meteorological models and urban climate models to simulate the formation and change process of urban heat island effect. This method can analyze the influence of different factors on urban heat island effect, but the accuracy and reliability of the model depend on the quality of input data and the setting of model parameters.

Remote sensing monitoring: remote sensing data obtained by satellites, drones and other platforms are used to analyze the distribution and change trend of surface temperature in urban areas. This method can provide a large range of high resolution temperature data, and is an important means to study the urban heat island effect.

At present, the research on urban heat island effect at home and abroad has made a lot of achievements. For example, Oke (1982) proposed the basic concept and formation mechanism of urban heat island effect [1]. Voogt and Oke (2003) reviewed the research methods and progress of urban heat island effect [2]. In China, Wang Shaoqiang et al. (2004) analyzed the spatio-temporal variation characteristics of urban heat island effect in Beijing by using remote sensing data [3].

3.3 Environmental and Social Impacts Of Urban Heat Island Effect

The urban heat island effect has multiple impacts on the environment and society: Environmental impact: the urban heat island effect causes the temperature of urban areas to rise, affecting the stability of urban ecosystems. For example, high temperature environment will intensify the transpiration of urban vegetation and increase the consumption of water resources; High temperatures also speed up the chemical reactions of air pollutants, leading to a decline in air quality. Social impact: the urban heat island effect has a negative impact on the quality of life and health of urban residents. For example, high temperatures increase the risk of heat stress and heat stroke for residents, especially for vulnerable groups such as the elderly and children; High temperatures also increase the use of refrigeration equipment such as air conditioners, resulting in increased energy consumption and power loads.

4. Application of Remote Sensing Image Processing Technology in Urban Heat Island Effect Research

4.1 Multispectral and Hyperspectral Imaging Techniques

Multispectral imaging technology can identify and distinguish different ground objects by acquiring spectral information of multiple bands. In the study of urban heat island effect, multispectral data can be used to analyze the distribution and change of land surface temperature in urban areas. For example, the multispectral data provided by the Landsat series satellites can be used to monitor the spatiotemporal characteristics of the urban heat island effect.

Hyperspectral imaging technology can obtain higher spectral resolution data and provide more detailed ground object information. In the study of urban heat island effect, hyperspectral data can be used to analyze the surface materials and vegetation cover of urban areas, and further reveal the formation

mechanism of urban heat island effect.

4.2 Thermal Infrared Imaging Technology

Thermal infrared imaging technology can directly measure the surface temperature by obtaining the thermal radiation information of ground objects. In the study of urban heat island effect, thermal infrared data is the main data source to obtain land surface temperature. For example, thermal infrared data from MODIS satellites can be used to monitor changes in surface temperatures on a global scale. By analyzing the thermal infrared data, the surface temperature distribution map of urban area can be obtained, the high temperature and low temperature areas of urban heat island can be identified, and the spatial distribution characteristics and change trend of urban heat island effect can be analyzed.

4.3 Laser Radar (LiDAR) Technology

By sending laser pulses and receiving the reflected signals, LiDAR technology can obtain the three-dimensional structure information of ground objects. In the study of urban heat island effect, LiDAR data can be used to analyze the height and density of urban buildings and conduct in-depth research on the formation mechanism of urban heat island effect. For example, by analyzing LiDAR data, the distribution map of building height in urban area can be obtained, and the influence of building height on urban heat island effect can be analyzed. the vegetation coverage of urban areas can also be obtained to analyze the mitigation effect of vegetation coverage on urban heat island effect.

4.4 Synthetic Aperture Radar (SAR) Technology

By transmitting microwave signals and receiving reflected signals, synthetic aperture radar technology can obtain ground object information under all-weather and all-time conditions. In the study of urban heat island effect, SAR data can be used to analyze the surface characteristics and changes of urban areas. For example, by analyzing SAR data, the information of surface roughness and humidity in urban areas can be obtained, and the influence of surface characteristics on urban heat island effect can be analyzed. It can also monitor the land surface subsidence and building deformation in urban areas, and analyze the influence of urbanization process on urban heat island effect.

4.5 Data Fusion Technology

Data fusion technology can improve the accuracy and information of data through comprehensive utilization of multi-source remote sensing data. In the study of urban heat island effect, data fusion technology can comprehensively analyze multi-spectral, hyperspectral, thermal infrared, LiDAR and SAR data to provide more comprehensive temperature distribution and change information. For example, by fusing multispectral and thermal infrared data, a higher-resolution map of surface temperature distribution can be obtained; By fusing LiDAR and SAR data, more detailed information of urban buildings and surface characteristics can be obtained to further analyze the formation mechanism and change law of urban heat island effect.

5. Construction of Theoretical Framework of Remote Sensing Image Processing Technology

5.1 Data Acquisition and Preprocessing

Data acquisition is the first step of remote sensing image processing, which mainly includes multi-spectral, hyperspectral, thermal infrared, LiDAR and SAR data acquisition. In the process of data acquisition, it is necessary to select a suitable remote sensing platform and sensor to ensure that the spatial resolution, temporal resolution and spectral resolution of the data meet the research needs. Data preprocessing refers to the processing of radiation correction, geometric correction and atmospheric correction on the original remote sensing data to eliminate sensor errors and atmospheric effects and improve the accuracy and consistency of the data. For example, radiometric correction can eliminate the radiation error of the sensor, geometric correction can eliminate the geometric distortion of the image, and atmospheric correction can eliminate the influence of the atmosphere on the remote sensing signal.

5.2 Feature Extraction and Selection

Feature extraction refers to the extraction of

useful information from remote sensing images, including spectral features, texture features, morphological features, etc. For example, spectral feature extraction can identify and distinguish different ground objects, texture feature extraction can analyze the surface structure of ground objects, and morphological feature extraction can obtain the geometric form of ground objects. Feature selection refers to selecting the most useful features from extracted features, removing redundant and noise features, and improving data processing efficiency and analysis accuracy. For example, feature selection can be performed by principal component analysis (PCA), linear discriminant analysis (LDA) and other methods.

5.3 Image Classification and Segmentation

Image classification refers to the classification of objects in remote sensing images into different categories, including supervised classification and unsupervised classification. Supervised classification is based on known samples, and the commonly used methods include maximum likelihood classification, support vector machine (SVM), etc. Unsupervised classification is an automatic classification of ground objects, and common methods include K-means clustering and ISODATA. Image segmentation refers to the segmentation of remote sensing images into different regions, including edge based segmentation, region based segmentation and model-based segmentation. For example, edge-based segmentation can identify the boundary of a feature, region-based segmentation can cluster similar pixels together, and model-based segmentation can leverage prior knowledge.

5.4 Change Detection and Analysis

Change detection refers to the identification and quantification of changes in ground objects by comparing remote sensing images of different periods. the commonly used change detection methods include image difference method, change vector analysis (CVA), principal component analysis (PCA), etc. For example, the image difference method can identify the change area of ground objects by calculating the difference of images in different periods. Change vector analysis can quantify the change amplitude and type of ground objects by calculating the size and direction of the change vector. Change analysis refers to the analysis of the results of change detection to reveal the cause and law of ground object change. For example, it is possible to identify the high temperature region and low temperature region of the urban heat island effect by analyzing the surface temperature change of the urban area, and analyze the spatial distribution characteristics and change trend of the urban heat island effect.

5.5 Result Interpretation and Model Validation

Result interpretation refers to the interpretation and analysis of the results of remote sensing image processing to reveal the features and change laws of ground objects. For example, by analyzing the surface temperature distribution map of urban areas, we can identify the high temperature region and low temperature region of urban heat island effect, and analyze the spatial distribution characteristics and change trend of urban heat island effect. Model validation refers to the verification of remote sensing image processing results to evaluate the accuracy and reliability of the model. For example, the accuracy of surface temperature can be verified by comparing remote sensing data with ground observation data. the accuracy of change detection can be verified by comparing the remote sensing data of different periods.

6. Advantages and Challenges of Remote Sensing Image Processing Technology in The Study of Urban Heat Island Effect

6.1 Advantages of Remote Sensing Technology

Remote sensing technology has the following advantages in the study of urban heat island effect:

Wide coverage: Remote sensing technology can obtain a wide range of surface temperature data and provide comprehensive urban heat island effect monitoring information.

High resolution: Remote sensing technology can provide high-resolution surface temperature data and identify high temperature and low temperature areas of urban heat island effect.

Strong timeliness: Remote sensing technology can provide real-time surface temperature data

and monitor the changing trend of urban heat island effect.

Multi-source data fusion: Remote sensing technology can comprehensively utilize multi-spectral, hyperspectral, thermal infrared, LiDAR and SAR data to provide more comprehensive temperature distribution and change information.

6.2 Challenges Faced By Remote Sensing Technology

Remote sensing technology also faces the following challenges in the study of urban heat island effect: Limitations of data acquisition: the acquisition of remote sensing data is affected by weather, sensor performance and other factors, and there may be data missing and errors. The complexity of data processing: the processing of remote sensing data involves several steps such as radiation correction, geometric correction and atmospheric correction, and the processing process is complicated and easy to introduce errors. Model accuracy and reliability: the results of remote sensing image processing depend on the accuracy and reliability of the model, and the setting of model parameters and the quality of input data have important effects on the results.

6.3 Future research directions and suggestions

Remote sensing image processing technology can be improved and developed in the study of urban heat island effect from the following aspects: Improve the accuracy and timeliness of data acquisition: By improving the remote sensing platform and sensor technology, improve the spatial resolution, time resolution and spectral resolution of data, and provide higher precision and more real-time surface temperature data. Optimize data processing methods and algorithms: By improving radiation correction, geometric correction, atmospheric correction and other data processing methods, reduce the errors in data processing and improve the accuracy and consistency of data. Strengthen the fusion and comprehensive analysis of multi-source data: through the comprehensive use of multi-spectral, hyperspectral, thermal infrared, LiDAR and SAR data, more comprehensive temperature distribution and change information is provided to reveal the formation mechanism and change law of urban heat island effect. Develop intelligent remote sensing image processing technology: Through the introduction of artificial intelligence and machine learning technology, remote sensing image processing is automatically and intelligently carried out to improve the efficiency and accuracy of data processing.

7. Conclusion

This paper discusses the application of remote sensing image processing technology in the study of urban heat island effect by constructing a systematic theoretical framework. the research shows that remote sensing image processing technology has made remarkable progress in data acquisition, image preprocessing, feature extraction, classification and segmentation, and change detection, etc., which provides a strong technical support for the monitoring and analysis of urban heat island effect. the comprehensive use of multispectral, hyperspectral, thermal infrared, LiDAR and SAR data can provide more comprehensive temperature distribution and change information, and reveal the formation mechanism and change law of urban heat island effect. In the future, with the continuous development of remote sensing technology, the application of remote sensing image processing technology in the study of urban heat island effect will be more extensive and in-depth, and provide scientific basis for urban planning and environmental management.

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