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Identification and Monitoring of Crop Pests and Diseases Based on Remote Sensing Technology

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Abstract. Identifying and monitoring crop pests and diseases are crucial to agricultural production, and they directly affect crop growth and the quality of agricultural products. This paper reviews crop pest and disease identification and monitoring techniques based on remote sensing imagery, emphasizing their advantages in providing timely and accurate information. The paper mainly summarizes the data sources for crop pest and disease detection, including satellite, UAV, aircraft, ground, and aerial remote sensing data, as well as laboratory monitoring data and seven types of multi-source data fusion. Four remote sensing monitoring techniques were discussed: spectral reflectance analysis, vegetation index analysis, regression model analysis, and spectral differential analysis, and their effects in practical applications were demonstrated through case studies. These methods significantly improve the accuracy and efficiency of pest and disease monitoring. The spectral reflectance analysis method directly reflects the changes in spectral characteristics of crops, and the vegetation index analysis method improves the indicative nature of monitoring by integrating the spectral characteristics of vegetation. The regression model analysis method, on the other hand, provides quantitative estimation of the extent of pests and diseases through mathematical modelling. Spectral differential analysis reveals subtle changes in the spectral profile of the crop and helps in the early identification of pests and diseases.

Keywords: Crop Pests and Diseases; Remote Sensing; Identification; Monitoring.

1. Introduction

The identification and monitoring of pests and diseases is an important measure in the growth process of crops. Pests and diseases may harm different parts of crops in different growth periods, while crop pests and diseases are potentially harmful, improper prevention and control is easy to cause widespread dissemination, resulting in large-scale damage [1], which seriously affects the growth of crops, thus leading to a large number of crop yields and reduce the quality of agricultural products. Therefore, identifying and monitoring pests and diseases is important to agricultural production.

Traditional pest and disease identification and detection methods include visual inspection, trap monitoring, and chemical analysis, but their drawbacks are obvious. Visual inspection is inefficient, relies on personal experience, and is difficult to detect early or hidden pests; manual inspection is time-consuming and labor-intensive for large-scale cultivation. Trap monitoring can only monitor specific species of pests and may require regular replacement of traps. Chemical analyses are complex, require specialized personnel, are relatively costly and slow to respond.

Remote sensing technology is gradually applied to the identification and detection of crop pests and diseases, and its advantage is that it can provide timely information, and intuitively and accurately respond to the type of crop pests and diseases, the area and scope of damage, the degree of damage, and the development trend, etc. [2]. By extracting, simulating, and analyzing the information, people can plan and predict better agricultural production (especially for some potential threats) and have a better understanding of agricultural production [3].

This study first summarises the types of remote sensing image data involved in crop pest monitoring and analysis, introduces four important remote sensing technical methods in monitoring crop pests and diseases, and demonstrates their effects in practical applications through case studies. The results provide a scientific basis for early warning and precise prevention and control of crop pests and diseases and help the sustainable development of agricultural production.

2. Types of Remote Sensing Data

Remote sensing image data sources for crop pest identification and monitoring currently include seven main types: satellite, UAV, aircraft data, ground, and aerial remote sensing data, laboratory monitoring data, and multi-source data fusion (Table 1).

Table 1. Source of data

Source of data	Application Analysis
Satellite remote sensing data	Data was acquired using high-resolution, medium-resolution and low-resolution remote sensing satellites, such as the Landsat series of satellites of the United States, the Sentinel series of the European Space Agency (ESA), and the Gaofen (GF) series of China.
Remote sensing data from drones	As a remote sensing platform, drones carry sensors for monitoring crop pests and diseases. UAV remote sensing technology has the advantages of relatively low cost, simple operation and high spatial resolution.
Aircraft Remote Sensing Data	Data on crop pests and diseases are obtained through remote sensing equipment carried by the aircraft, and this method can cover a large monitoring range.
Ground Remote Sensing Data	Data acquired using equipment such as ground-based imaging spectrometers, indoor spectrometers, are useful for extracting information on crop pests and diseases on a small spatial scale.
Aerial Remote Sensing Data	Pest and disease monitoring of ground crops in the air through aerial vehicles as delivery vehicles has the advantages of high spatial and temporal resolution, low cost, flexibility and mobility.
Laboratory monitoring data	The laboratory uses automated delivery equipment and integrated sensors to acquire relevant dynamic growth and developmental phenotypic data of crops infested with pests and diseases.
Multi-source data fusion	Combining these various data sources, the accuracy and reliability of pest and disease monitoring are improved through data fusion techniques.

These data sources play different roles in monitoring crop pests and diseases by analysing the changes in crop physiological and biochemical information to determine the occurrence of pests and diseases and the degree of damage [4]. In addition to this, there are auxiliary data such as environmental parameters like soil moisture and temperature, crop cultivation types and historical pest and disease occurrence records [5]. Together, these data provide an important basis for identifying and detecting crop pests and diseases. With the development of remote sensing technology, the application of these data sources will become more and more extensive and in-depth, helping to improve monitoring efficiency and reduce costs, which is of great significance for safeguarding agricultural production and food security.

3. Research Methods and Applications

Spectral reflectance analysis, vegetation index analysis, regression model analysis, and spectral differential analysis are important remote sensing technical methods for monitoring crop pests and diseases.

3.1. Spectral Reflectance Analysis

3.1.1. Principle of the Methods.

The spectral reflectance analysis method obtains information on the spectral characteristics of crops by analyzing the spectral data of crop diseases obtained by sensors, transforming them into spectral reflectance characteristics, and comparing the spectral reflectance of healthy plants and disease-sensitive plants. The method has the characteristics of directness, simplicity, rapidity and universality and is the basis of other hyperspectral analysis methods [6].

3.1.2. Cases.

Zhang et al. investigated the relationship between the photosynthetic rate and spectral index of wheat under stripe rust stress by using remote sensing technology for real-time monitoring of wheat stripe rust and identifying the disease in a wide range of crops. During the 2018-2019 winter wheat growing season, the team selected Jiemai 15, susceptible to stripe rust, as a control variety, and Jiemai 22 and Luhuan 502, which have a large planting area, as test varieties. Stripe rust inoculation tests were carried out in large field plots, and the spectral reflectance and disease index of wheat flag leaves were measured regularly.

(1) Spectral reflectance changes: The study pointed out a correlation between the spectral reflectance and the disease index of wheat affected by stripe rust, which could be used for the early diagnosis of stripe rust disease in winter wheat. During the filling period, the spectral reflectance of diseased spots was higher than that of normal spots in the visible light band, and lower than that of normal leaves in the reflection platform area. This indicates that the chlorophyll content is lower in the diseased spot area, reducing light absorption.

(2) Spectral vegetation index and disease index: photochemical reflectance index (PRI), vegetation attenuation index (PSRI) and ratio vegetation index (RVI) were used to monitor changes in disease index. The results showed that PRI and PSRI were higher in diseased spots than in normal spots, and the rate of change of PSRI was larger, while the rate of change of RVI was smaller.

(3) Correlation between photosynthesis rate and spectral reflectance: the correlation between photosynthesis rate and spectral reflectance was different in different reproductive stages of wheat. During the filling stage, the photosynthetic rate of Luyuan 502 was positively correlated with the spectral reflectance, while that of JiMai 22 was negatively correlated.

The study provides a theoretical basis for using remote sensing technologies to monitor wheat growth and disease occurrence over a large area. It lays a foundation for using spectral indicators to predict the occurrence and damage of wheat stripe rust using non-destructive monitoring methods [7].

3.2. Vegetation Index Analysis Method

3.2.1. Principle of the method.

The vegetation index is based on the spectral characteristics of vegetation formed by the combination of visible and near-infrared bands. Common spectral vegetation indices include Ratio Vegetation Index (RVI), Normalized Vegetation Index (NDVI), etc. These indices can visually reflect the growth status of vegetation and potential disease impacts. The vegetation index analysis method evaluates the health status of vegetation and monitors the status of pests and diseases by calculating indicators such as the NDVI. In the research and practice of remote sensing for pest and disease detection, in many cases, the spectral reflectance of plants is not used directly but analyzed by various vegetation indices [8].

3.2.2. Cases.

Li Jiazi et al. used remote sensing technology to research the monitor of maize pests and diseases. The team firstly pointed out that pests and diseases are the main reason for the significant reduction of maize yield. It proposed that calculating NDVI by remote sensing images can quickly and intuitively monitor agricultural pests and diseases. The study was conducted to monitor maize pests and diseases in Dongping County, Tai'an City, Shandong Province, China.

The study mentioned that the spectral reflectance of crops could be obtained by remote sensing and positively correlated with the chlorophyll content, thus estimating the extent of crops affected by pests and diseases. In the study, remote sensing images from August to September were selected to observe the NDVI distribution pattern of vegetation in the onset area and to determine whether the target area was infested or not by calculating the NDVI and comparing it with the NDVI curves at the time of the known onset of the disease.

The research methodology included selecting reference samples, processing remote sensing data from other years, validation, and monitoring applications. Firstly, by analyzing the Landsat image data 2009, the NDVI distribution pattern of the disease-affected area was determined. Then, remote sensing images from other years were downloaded and processed using the same method to obtain the NDVI distribution curve and compare it with the comparison standard. During the validation process, the curves with similar characteristics to the comparison standards were determined to be affected by pests and diseases, and relevant information was consulted for validation.

The study results showed that severe pests and diseases occurred in 2010, pests and diseases also occurred in 2005 but to a lesser extent, and no pests and diseases occurred or occurred to a very lesser extent in 2016. In addition, the NDVI distribution characteristics were calculated for 2001 and 2017 to determine whether maize pests and diseases occurred in these two years, respectively. The current remote sensing image data acquisition is flawed and needs to be improved in terms of timeliness, and further research is needed on how to differentiate between types of pests and diseases [9].

3.3. Regression Modelling Analysis

3.3.1. Principle of the method.

The regression model analysis method refers to the inversion of one- and multiple-regression models. The one-dimensional regression model, multiple regression model, and simple linear function are most widely used in the monitoring research of the regression model analysis method to discriminate crop pests and diseases. By studying and analyzing the spectra of crops after disease susceptibility, one- and multiple-regression regression equations for inversion of pests and diseases are established, and the inversion models established by this method have high accuracy. For example, one- and multivariate stripe rust inversion regression equations are established by researching and analyzing the spectra of winter wheat stripe rust rust after susceptibility to the disease. The inversion model established by this method has high accuracy and can effectively predict and monitor crop pests and diseases [6]. The extent of crop pests and diseases can be quantitatively assessed by establishing regression relationships between spectral reflectance and pest and disease monitoring parameters. This method usually requires a large amount of measured data as a basis and may be affected by factors such as changes in surface roughness.

3.3.2. Cases.

Cotton yellow wilt is a disease that seriously affects the efficiency of cotton production, and rapid diagnosis of the disease is of great significance for large-scale remote sensing monitoring and the application of hyperspectral remote sensing technology. Huang Wenjiang et al. studied the relationship between disease severity and hyperspectral reflectance of cotton single-leaf yellow wilt, and constructed a hyperspectral inversion model of disease severity. The team conducted the study in the yellow wilt disease nursery field of Xinjiang Crop High Yield Research Centre, Shihezi University. Cotton leaves with different disease severity were selected as test materials and classified into five grades according to the damaged area. The spectral reflectance of cotton leaves was measured using an ASD Field Spec Pro FR2500 portable spectrometer.

The measurement and analysis of spectral data showed that the spectral reflectance of cotton single leaves increased gradually with the increase of disease severity in the visible light and short-wave infrared wavelengths, especially in the visible light wavelengths. The changes were significant. The change of spectral reflectance in the near-infrared band is small, which may be related to the internal cell structure of the leaf. The experimental team extracted hyperspectral feature parameters, including the original and first-order differential spectra extracted based on hyperspectral position, area, and vegetation index variables. Inversion models of disease severity with remote sensing parameters as independent variables were constructed, including univariate linear and nonlinear models. The logarithmic model at wavelength 694 nm and the first-order differential spectral linear model at wavelength 717 nm were found to have better inversion accuracy.

The calibration results showed that the first-order differential spectral linearity model at wavelength 717 nm had the best model for disease severity inversion.

The results provide a theoretical basis and application value for monitoring cotton yellow wilt using hyperspectral remote sensing. The generalizability of the model needs to be further studied, but it is important for early detection of disease information and timely control measures. This study provides new technical means and theoretical support for remote sensing monitoring of cotton yellow wilt, which helps to improve disease management [10].

3.4. Spectral Differential Analysis

3.4.1. Principle of the method.

The differential spectrum represents the slope on the spectral curve, which is obtained by estimating the whole spectrum through differential or mathematical functions. By applying differential transformation to the original spectrum, the characteristic parameters of the crop spectrum, such as the position of the red edge and the area of the red edge, can be extracted. These parameters are important for identifying physiological and biochemical changes in crops after they have been subjected to pest and disease stresses. Changes in the spectral absorption waveforms of internal plant substances are a reflection of the nature of the plant spectral derivative. Spectral differential analysis does not produce redundant data information but rather reduces background noise and improves overlapping spectral resolution.

3.4.2. Cases.

Jiang et al. used hyperspectral remote sensing to identify wheat stripe rust. The red-edge phenomenon indicates vegetation growth and is closely related to plants' physiological and biochemical parameters. The yellow-edge phenomenon is in the 550-670 nm band, and its characteristics are less affected by plant cell structure or water content.

The raw spectral data were smoothed using a 5-point weighted smoothing method, and the first-order differential spectra were calculated to enhance the subtle changes in the spectral curves for extracting the red-edge position (REP) and yellow-edge position (YEP).

The results showed that as the severity of the disease increased, the REP shifted to the short-wave direction, and the YEP shifted to the long-wave direction, while the difference between the two (REP-YEP) decreased rapidly. There was an excellent one-variable quadratic equation relationship between the REP-YEP and the disease index (DI), and the model had a high prediction accuracy. Further conclusions are drawn: (1) The correlation between REP and DI is higher than that of the first-order differential maximum method. (2) The REP-YEP parameter can identify healthy and diseased wheat 12 days in advance and has a good differentiation ability.

This study provides an effective method for early identification and monitoring of wheat stripe rust using hyperspectral remote sensing technology, which helps improve the efficiency and accuracy of agricultural disease management. It also supports the use of hyperspectral remote sensing to monitor wheat diseases over large areas, which is of great significance for implementing precision agriculture [11].

4. Discussion

Each of the four research methodological approaches has its strengths. The spectral reflectance analysis method directly reflects changes in the spectral characteristics of crops, and the vegetation index analysis method improves the indicativeness of monitoring by integrating the spectral characteristics of vegetation. The regression model analysis method quantitatively estimates pest and disease occurrence through mathematical modelling. The spectral differential analysis method can reveal subtle changes in crop spectral curves, which can help in the early identification of pests and diseases. In practical applications, these methods are often used to improve the application of remote sensing monitoring crop pests and diseases. By continuously optimizing algorithms and models and combining multi-source data, they can better serve the early warning and precise management of crop pests and diseases [12-13].

5. Conclusion

This study discusses the feasibility and effectiveness of a crop pest and disease identification and monitoring system based on remote sensing images. Through the integration of multi-source remote sensing methods, early identification and dynamic monitoring of crop pests and diseases can be realized, which provides strong support for sustainable agricultural development. The advantages are its wide coverage area, suitable for large-scale monitoring, and the convenience of remote operation. The disadvantages are that it is greatly affected by the weather; the initial investment cost is high. Remote sensing image-based crop pest and disease monitoring technology has made remarkable progress but still faces many challenges, such as improving the spatial and temporal resolution of monitoring and reducing the interference of environmental and human factors.

Spectral reflectance analysis, as the basis of other hyperspectral analysis methods, is used to obtain spectral feature information of crops by analyzing their spectral data and converting them into spectral reflectance features. The difference in spectral reflectance between healthy and disease-sensitive plants is compared to identify and detect pests and diseases. Vegetation index analysis method assesses the health of vegetation and monitors the occurrence and development of pests and diseases by calculating indicators such as the NDVI. This method uses vegetation's spectral characteristics to visually reflect vegetation's growth status and potential disease impacts through the combination of visible and near-infrared wavelengths, providing an effective means for remote sensing pest and disease detection. The regression model analysis method quantifies crop pests and diseases by establishing a mathematical model between spectral reflectance and pest monitoring parameters. Spectral differential analysis method extracts characteristic crop spectral parameters, such as red-edge position and area, through differential transformations to identify physiological and biochemical changes following pest and disease stress. This method helps to improve the early identification capability and resolution of pest and disease monitoring by revealing subtle changes in spectral curves.

In the future, the application of remote sensing images in crop pest and disease identification and monitoring will be more promising. The study will further optimize the model performance and explore the integration and application with other agricultural data to achieve more refined agricultural management. Through technological innovation and algorithm optimization, it is expected to achieve more accurate and efficient pest and disease monitoring and management.

References

[1] Zhang Xia. Integrated control measures of common pests and diseases in forestry and fruit industry. Agricultural Science and Technology and Letter, 2022 (13): 41 - 43.

[2] Bao Hao, Zhang Xiao, Zhang Nannan, et al. Current status of research on the application of crop pests and diseases based on hyperspectral remote sensing technology. Agriculture and Technology, 2023, 43 (13): 1 - 4. DOI: 10.19754/j.nyyjs.20230715001.

[3] Liu Qinghui. Application of Remote Crop Sensing in Pest Control of Pulses. Agricultural Engineering Information. 2022, 42 (21): 26 - 28.

[4] Liao Juan, Tao Wan Yan, Zang Ying, et al. Research Progress and Prospect of Key Technologies for Remote Sensing Monitoring of Crop Pests and Diseases. Journal of Agricultural Machinery, 2023, 54 (11): 1 - 19.

[5] Zheng Q, Huang W, Xia Q, et al. Remote Sensing Monitoring of Rice Diseases and Pests from Different Data Sources: A Review. Agronomy, 2023, 13 (7):

[6] Sz Zhengbang, Qiao Huanhuan, Isma, et al. Application of remote sensing technology in crop pest monitoring. Tibet Agricultural Science and Technology, 2023, 45 (04): 35 - 39.

[7] Zhang Xiaoyan, Hou Xuexue, Wang Meng, et al. Study on the relationship between photosynthetic rate and spectral index under wheat stripe rust stress. Spectroscopy and Spectral Analysis, 2022, 42 (03): 940 - 946.

[8] Woldemariam W G, Awoke G B, Maretto V R. Remote sensing vegetation Indices-Driven models for sugarcane evapotranspiration estimation in the semiarid Ethiopian Rift Valley. ISPRS Journal of Photogrammetry and Remote Sensing, 2024, 215136 - 156.

[9] Li Jiazhi, Liu Zedong, Wang Heng, et al. Corn pest and disease monitoring based on remote sensing. Modern Agricultural Research, 2019, (06): 63 - 64.DOI: 10.19704/j.cnki.xdnyyj.2019.06.027.

[10] Jingxia, Huang Wenjiang, Wang Jihua, et al. Hyperspectral inversion modelling of disease severity of cotton single-leaf yellow wilt. Spectroscopy and Spectral Analysis, 2009, 29 (12): 3348 - 3352.

[11] Jiang Jinbao, Chen Yunhao, Huang Wenjiang. Identification of wheat stripe rust using hyperspectral red-edge and yellow-edge positional distances. Spectroscopy and Spectral Analysis, 2010, 6 (5): 1614 - 1618.

[12] Zhang Chao, Kang Qin. Research progress of UAV remote sensing to monitor crop pests and diseases. Agriculture and Technology, 2022, 42 (03): 47 - 49.DOI: 10.19754/j.nyyjs.20220228014.

[13] Zhang Ning, Yang Guijun, Zhao Chunjiang, et al. Progress and prospects of hyperspectral remote sensing of crop pests and diseases. Journal of Remote Sensing, 2021, 25 (01): 403 - 422.