Application of UAV Remote Sensing Technology in Forest Fire Monitoring Based on Retinex Theory Algorithm

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Abstract: This paper discusses the application of UAV remote sensing technology based on Retinex theory algorithm in forest fire monitoring. Firstly, the importance of forest fire detection and the limitation of traditional monitoring methods are introduced. Secondly, the advantages of UAV remote sensing technology are explained, including flexibility, efficiency and accuracy. Retinex theory algorithm is analyzed in detail in enhancing image quality, solving complex illumination processing, color vector and other core problems. The effectiveness and accuracy of this technology combination in forest fire monitoring are demonstrated through practical cases and experimental data. Finally, the future development direction and prospect of this technology are prospected.

Keywords: Retinex Theory Algorithm; UAV Remote Sensing Technology; Forest Fire Monitoring

1. Introduction

1.1 Research Background and Significancein

Today's society, with the global climate change and human activities, the frequency and damage of forest fires are increasing. UAV remote sensing technology plays an increasingly important role in forest fire monitoring, early warning, fire fighting and post-disaster by virtue of its advantages of high efficiency, flexibility and accuracy. However, with the continuous popularization and application of UAV remote sensing technology, it plays an important role in various fields and also has important significance in forest fires. Therefore, more strict requirements are put forward for its technical level, especially the influence of uneven illumination (insufficient) on remote sensing images in forest fire monitoring. For example, at night, when the lighting conditions are insufficient, the quality and clarity of UAV remote sensing images may be greatly reduced, affecting the monitoring effect of fires. A large amount of smoke generated by forest fires may block the line of sight, making it difficult for drones to obtain clear images of the core area of the fire, thus affecting the judgment of the size and spread direction of the fire. Dense trees block sunlight, resulting in underlit areas under trees, which may appear darker in contrast to lighter areas on remote sensing images. This research devotes to divide Retinex theory into three types: path method, partial differential equation method and central peripheral model through algorithm based on Retinex theory. Remote sensing images play an important role in the application of drones in monitoring forest fires, and algorithms based on Retinex theory are the key to completing the task. However, that algorithm based on Retinex theory are still face with many problems, such as limited processing effect for complex illumination, color vector truth or inaccuracy in some case, simplified assumptions based on Retinex theory, which may not be completely true in actual complex illumination conditions, etc. Special, complex lighting environment requires higher requirements for this algorithm. Therefore, this study not only focuses on improving the application of Retinex theory algorithm in forest fire monitoring, but also devotes itself to adapting to the high standard requirements of illumination in different fields. By solving the core problems such as complex illumination processing and color vector truth, the UAV can complete the task stably and efficiently in various lighting conditions.

1.2 Research Status at Home and Abroad

(1) Foreign research teams are constantly exploring the improvement of Retinex theoretical algorithms to better adapt to the

needs of forest fire monitoring. Some developed countries have established a relatively complete unmanned aerial vehicle forest fire monitoring system. These systems use devices such as visual images carried by drones to patrol forests in real time, and enhance the acquired images through Retinex theoretical algorithms to improve the speed of fire recognition by drones. In the Retinex theory algorithm, enhancement methods for weak light intensity problems have been developed. By proposing dark channel prior algorithm and improving algorithm based on Retinex theory, this method can ensure the image definition of UAV under weak illumination intensity. In addition, foreign countries are constantly exploring ways to combine advanced technologies such as deep learning with Retinex theoretical algorithms to improve the timeliness of forest fire monitoring.(2) The application of UAV remote sensing technology based on Retinex algorithm in forest fire monitoring in China is still in its infancy, but it has made a great breakthrough. For example, the scientific research department enhances the remote sensing images acquired by drones by using Retinex theoretical algorithms to improve the identification of fire areas more accurately and efficiently[1]. The scientific research department proposed the dark channel prior algorithm and improved the algorithm based on Retinex theory to ensure the clarity of remote sensing images under weak illumination conditions, which is of great significance for UAV processing forest fire monitoring. In addition, relevant departments have begun to try to equip drones with high-resolution cameras to improve the clarity of remote sensing images, but there are still problems such as system incompatibility. It is currently in the experimental phase.

2. Basic Principles of UAV Remote Sensing Technology

2.1 Overview of UAV Remote Sensing Technology

UAV remote sensing technology is a technology that obtains ground information and processes and analyzes it through unmanned aerial vehicles carrying sensors. The system consists of UAV platform, sensors, ground control system and data processing software. UAV remote sensing technology has the advantages of wide monitoring range, fast response speed, strong flexibility and high resolution, and is widely used in environmental monitoring, urban planning, disaster emergency and other fields.

2.2 Application of UAV Remote Sensing Technology in Forest Fire Monitoring

2.2.1 Application background

Forest fire poses a serious threat to ecological environment and human safety. It has the characteristics of strong suddenness and great destructiveness, which brings certain difficulty to fire fighting and extinguishing work. Especially after the forest fire occurs, it is necessary to grasp the basic data such as forest fire area and fire assessment at the first time, while traditional monitoring methods such as satellite remote sensing and ground patrol have problems such as poor timeliness and limited coverage. UAV remote sensing technology has become an important tool for forest fire monitoring because of its high resolution, flexibility and real-time.

2.2.2 Technological superiority

(1) High-resolution images: UAVs can acquire centimeter-level high-resolution images to accurately identify fire sources and fires. (2) Wide monitoring range: UAVs can achieve comprehensive monitoring of the entire forest area by adjusting flight altitude and route. (3) Flexible mobility: adapt to complex terrain and bad weather, quickly reach the fire scene. (4) High safety: UAV does not need personnel to enter the scene, greatly reducing the risk of casualties, especially in the case of strong fire and complex terrain, UAV has higher safety.

2.2.3 Specific application

(1) Fire warning: through regular inspections, potential fire sources are found in time to prevent fires.

(2) Fire monitoring: Real-time monitoring of fire spread, providing accurate fire information.

(3) Rescue command: provide real-time disaster information and optimal rescue route for rescue team.

(4) Post-disaster assessment: After the fire is put out, assess the fire area and loss, and provide data support for later forest restoration.

3. Retinex Theory Algorithm

3.1 Overview of Retinex Theoretical Algorithms

Retinex theory was developed by Edwin H.Land in the 1960s to explain how the human visual system perceives color and brightness. The theory holds that the color and brightness perceived by the human eye depend not only on the reflective properties of the surface of the material, but also on the lighting conditions of the surrounding environment. The goal of Retinex theory algorithm is to remove the influence of illumination from the image and retain the inherent reflection properties of the object, thus enhancing the detail and color constancy of the image[2].

3.2 Fundamentals of Retinex Theory Algorithm

The basic principle of Retinex theory decomposes the image into two parts: reflection component and illumination component. The reflection component represents the reflective properties of a material surface, which are usually stable and unaffected by changes in illumination, while the illumination component represents the influence of ambient illumination, which is usually variable. Therefore, by separating these two variables, Retinex algorithm can eliminate the influence of uneven lighting and enhance the detail and color of the image [3].

Retinex theory has evolved from single-scale Retinex (SSR) to multi-scale Retinex (MSR) to multi-scale Retinex with color recovery (MSRCR). SSR algorithm estimates illumination components by using a single-scale Gaussian filter, which is simple but may not be able to handle global and local illumination variations simultaneously. The MSR algorithm estimates illumination components by using a multi-scale Gaussian filter and weights the results. Compared with SSR algorithm, it can deal with global and local illumination variation in image better. MSRCR introduces a color recovery step on the basis of MSR to avoid color vector truth[4]. It is suitable for scenes where image color consistency needs to be maintained.

3.3 Basic Principles of Path Method

The path method is based on Retinex theory, which considers that the perceived image brightness is the result of illumination and object reflection. The path method estimates the reflection component by defining a series of paths in the image along which the relative luminance changes between pixels are calculated.

The core steps of path method include path generation, path weighting calculation, reflection component estimation and image reconstruction.

Path generation is the generation of multiple paths from each pixel in the image. The path can be randomly generated, or it can be generated according to some rules (such as straight path, spiral path, etc.), and the length and direction of the path can be adjusted and improved according to the specific application.

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The reflection component estimation is to estimate the reflection component of the center pixel by weighted averaging the pixel brightness on the path. The formula for calculating the reflection component is usually:

$$R(x,y)=\frac{\sum_{p\in Paths}\omega(p)\cdot I(p)}{\sum_{p\in Paths}\omega(p)} \quad (1)$$

Where $R(x,y)$ is the reflection component of the central pixel;

$I(p)$ is the luminance of the pixel on the path;

$\omega(p)$ is the weight of pixels on the path.

Image reconstruction combines the estimated reflection component with illumination component to reconstruct the enhanced image.

3.4 Partial Differential Equation

3.4.1 An overview of partial differential equation method

Partial Differential Equation (PDE-based) is a mathematical model-based image processing method, which constructs and solves partial differential equations to achieve image enhancement, denoising, segmentation and other tasks. Partial differential equation method is widely used in image processing. Its core idea is to treat the image as a continuous function, describe the process of image change by mathematical modeling, and solve the equation by numerical method, so as to realize image processing.

3.4.2 Basic principle of partial differential equation method

Partial differential equation method regards image I(x,y) as a two-dimensional function, and describes the process of image change by constructing partial differential equation.

The core methods are as follows:

(1) Diffusion equation method

The diffusion equation smoothes the image by simulating the physical diffusion process.

$$\frac{\partial I}{\partial t}=\nabla\cdot\left(D\nabla I\right) \quad (2)$$

Where D is the diffusion coefficient, controlling the diffusion intensity.

(2) Nonlinear diffusion equation method

It is possible to smooth an image while preserving edges by introducing diffusion coefficients related to image gradients.

$$\frac{\partial I}{\partial t}=\nabla\cdot\left(g\left(\left|\nabla I\right|\right)\nabla I\right) \quad (3)$$

Where the horizontal line represents the gradient dependent diffusion coefficient function.

(3) Poisson equation method

Poisson equation is used for image inpainting and interpolation by solving Laplacian operator.

$$\nabla^2=f(x,y) \quad (4)$$

Where f (x, y) is a known function representing gradient or edge information of an image.

(4) Heat conduction equation method

Heat conduction equation is used for image enhancement and edge detection by simulating heat conduction process.

$$\frac{\partial I}{\partial t}=\alpha\nabla^2 I \quad (5)$$

Where a is the coefficient of thermal conductivity.

3.5 Peripheral Model

3.5.1 Central Perimeter Model Overview

Center-Surround Model (CSM) is a computational model that simulates the visual perception characteristics of neurons in biological visual system. It is widely used in image processing, computer vision and neuroscience. The core idea of this model is to extract salient features from images by simulating the response characteristics of visual neurons to local regions of images.

3.5.2 Fundamentals of the Central Perimeter Model

The central-peripheral model is based on sensory visual field properties of neurons in the biological visual system. In biological visual systems, neuron perception usually consists of a central region and a peripheral region. The central region refers to excitatory responses to specific stimuli, such as brightness, color, etc. Peripheral regions are defined as inhibitory responses to the same stimuli.

This center-periphery antagonism mechanism enables neurons to enhance the local t-ratio and thus better detect features such as edges and textures in images.

4. UAV Remote Sensing Image Processing Based on Retinex Theory Algorithm

UAV remote sensing image processing based on Retinex theory is a technique for enhancing image quality, especially for uneven illumination or low contrast[5]. This method is beneficial to improve the accuracy and timeliness of fire identification. The specific steps are as follows:

4.1 Image Preprocessing

In the process of image acquisition by UAV, due to the image of illumination conditions, atmospheric conditions and other factors, the image may have noise, blur and other problems. Therefore, it is necessary to preprocess the image before the Retinex algorithm processing, including denoising, gray-scale operations, etc. Denoising is the use of Gaussian filtering or median filtering to remove noise. Graying is converting a color image into a grayscale image but processing only luminance information[6].

4.2 Illumination Component Estimation

(1) Gaussian filtering: Gaussian blur the image to estimate the illumination component.

(2) Adaptive histogram equalization: Avoid over-enhancement caused by global histogram equalization by enhancing local details.

(3) Color recovery: For color images, color factors introduced on the basis of MSR avoid color vectors.

4.3 Image reconstruction and post-processing

(1) Exponential transformation: Converting the enhanced reflection component R (x,y) into a luminance component:

$$I(x,y)=\exp R\,(x,y) \quad (6)$$

(2) Multiband fusion: For multispectral images, the enhanced luminance component should be combined with the original chromaticity, such as H and S components in HSV.

(3) Sharpening and Denoising: The process of using Laplacian operators or sharpening masks to enhance edges and suppress noise.

4.4 Fire Identification and Monitoring

After Retinex algorithm processing, the contrast and detail processing ability of UAV remote sensing images are significantly improved, which is beneficial to fire recognition and monitoring. The following is the specific process:

(1) Fire feature extraction: extracting fire

features from enhanced images, including flame color, shape, texture and other information. Feature extraction methods can be used in image processing flame detection, texture analysis, motion trajectory analysis and other methods.

(2) Fire classification and verification: It is divided into two categories: feature fusion and space-time verification. Feature fusion is to reduce the false detection rate by combining visible light, such as flame color, smoke texture and thermal infrared temperature features. Spatio-temporal verification is to verify whether suspected fire spots persist in continuous multi-frame images, and at the same time, combine geographic information system (GPS) data to exclude non-fire heat sources, such as high temperature heat sources and reflective objects.

(3) Fire Monitoring and Warning: Through fire spread analysis and early warning output, accurate fire information can be obtained at the first time. Fire spread analysis is to track the speed and direction of fire boundary expansion by using time series images, and predict the development trend of fire by combining natural factors such as wind speed and air humidity. Early warning output is to transmit early warning information directly to the command center through satellite communication system in real time.

5. Experimental Results and Analysis

In the application experiment of UAV remote sensing technology based on Retinex theory algorithm in forest fire monitoring, the main focus is on the optimization effect of image fogging and enhancement on fire feature extraction. The following is discussed from the aspects of algorithm principle, experimental design and experimental result analysis:

5.1 Principle of Retinex Algorithm and Its Adaptability in UAV Image Processing

The core of Retinex theory is to enhance image detail by separating illumination component from reflection component. In forest fire scenes, remote sensing images taken by unmanned aerial vehicles are affected by natural conditions such as smoke and fog, which makes it more difficult to identify fire spots. The Retinex algorithm optimizes images by:

(1) Single Scale Retinex (SSR): Gaussian filter is used to estimate illumination component and enhance local contrast, which is suitable for scenes with thin smoke.

(2) Multi-scale Retinex (MSR): Gauss kernels of different scales are combined to balance global and local enhancement effects, which can effectively deal with complex lighting scenes.

(3) MSRCR (MSR with Color Recovery): Color restoration factor is introduced to avoid color vector truth and ensure color authenticity of fire spot area.

Experiments show that MSRCR algorithm can significantly improve the definition of fire edge after fog removal, and restore the details of the ground covered by smoke, which provides effective help for later fire situation analysis.

5.2 Experimental Design and Key Indicators

The experiment adopts fire remote sensing images collected by unmanned aerial vehicles. Compared with the effect of Retinex algorithm, the evaluation indicators include:

(1) Image quality indicator: The peak-to-noise ratio and structural similarity are improved by about 20%-30%, making the defogging image closer to the real effect.

(2) Fire spot detection accuracy: After Retinex processing, the accuracy of flame recognition based on maximum segmentation is improved by about 15%, and the false alarm rate is about 10%.

(3) Treatment efficiency: The processing time of a single frame is about 0.5 seconds. Meet the real-time monitoring needs of drones.

5.3 Experimental Analysis

(1) Image quality assessment: After Retinex processing, the contrast of the image is improved by 30%-50%, the smoke penetration is enhanced, and the definition of the fire point edge is significantly improved. In smoke-covered scenes, Retinex can effectively suppress ghosting caused by uneven lighting[7].

(2) Fire monitoring performance: The optimized Retinex algorithm takes about 50ms for a single frame image and meets the real-time monitoring requirements of drones (usually requiring response times of less than 200ms). Furthermore, the adaptability of the algorithm is improved significantly in the case of strong illumination variation and complex background.

6. Conclusion and Prospect

Retinex algorithm effectively solves the problems of smoke and uneven illumination, and improves the recognition ability of smoke and fire point in the early stage of fire[8]. For example, after Retinex treatment, the flame and background noise can be more clearly separated, and the sensitivity of early fire detection is improved. UAV combined with Retinex algorithm realizes fast image processing and real-time transmission, which improves the timeliness of forest fire monitoring, especially in complex terrain and night environment. The multi-spectrum processed by Retinex algorithm can be combined with the data of other remote sensing platforms such as satellites and rockets to construct a more comprehensive fire dynamic model, which provides help for fire spread prediction and fire extinguishing strategies.

In the future, we need to improve the adaptability of Retinex algorithm in extreme environments such as heavy smoke and rainstorm. Combined with UAV remote sensing technology, develop more intelligent and efficient image analysis algorithms to realize the identification and classification of fire characteristic areas, reduce manual input and improve monitoring efficiency. Unmanned aerial vehicle (UAV) remote sensing technology based on Retinex theory algorithm is applied to forest fire monitoring and post-disaster recovery assessment. Through the analysis and assessment of forest vegetation destruction and soil change after disaster, it provides strategies for forest ecological restoration and promotes forest sustainable development.

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