Transactions on Environment, Energy and Earth Sciences
ISSN: 2960-1924, eISSN: 2960-2300 | Volume 3
GRET 2024

Forest Fire Monitoring Based on Multi-Source Remote Sensing Data

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Abstract. Forest fires refer to forest fires that are beyond human control, freely spreading and expanding within forests, causing certain harm and losses to forests, forest ecosystems, and humans. Despite the rapid development of science in the world today, humanity has yet to make significant progress in combating forest fires. In response to the current problem of single, real-time, and comprehensive fire monitoring methods in forest fire emergency rescue work. This article explores emergency monitoring methods for forest fires based on multi-source remote sensing data. Based on comprehensive geographic data and previous scholars' specific research on remote sensing data such as drones and satellites in fire emergency monitoring, analyze the applicability, advantages, and disadvantages of various remote sensing data. The conclusion drawn is that unmanned aerial vehicle remote sensing has high spatial and temporal resolution and can implement precise fire extinguishing in small areas, while satellite remote sensing has a large spatial span and can provide information throughout the entire time period. Based on this, this article proposes a framework for emergency fire monitoring, visualizing important areas and facilities with fire development and providing information for cities and counties to extinguish forest fires.

Keywords: Forest Fires; Emergency Monitoring; Aerial Remote Sensing; Unmanned Aerial Vehicle; Remote Sensing.

1. Introduction

1.1. Research Background and Significance

Fire refers to uncontrolled combustion in time or space. Among various disasters, fire is one of the most frequent and widespread threats to public safety and social development. Forest fires refer to forest fires that are beyond human control, freely spreading and expanding within forests, causing certain harm and losses to forests, forest ecosystems, and humans. Forest fires not only burn down vast forests and harm the animals inside but also reduce the forest's ability to regenerate, causing soil impoverishment, damaging the forest's role in conserving water sources, and even leading to an imbalance in the ecological environment. Despite the rapid development of science in the world today, humanity has yet to make significant progress in combating forest fires [1].

The monitoring methods for forest fires mainly include manual monitoring and remote sensing monitoring, including: (1) ground patrol, whose main task is to promote public awareness, control man-made fire sources, and patrol in blind spots observed by observation towers. Inspect and supervise the use of fire for personnel and vehicles, as well as for outdoor production and daily life. The shortcomings are that the patrol area is small, the field of view is narrow, and significant errors often occur when determining the location of a fire due to rugged terrain and dense forests. In remote mountainous areas with inconvenient transportation and sparse populations, ground patrols cannot be carried out, and various transportation and personnel salary costs are required. Only video monitoring methods can be used to make up for it. (2) Observatory monitoring. (3) Aviation patrol uses patrol aircraft to detect forest fires. Its advantages are a wide patrol field of view, high mobility, fast speed, and the ability to comprehensively observe the surroundings and development of the fire, and take effective measures in a timely manner. However, there are shortcomings: it is difficult to take off at night, in windy weather, and on cloudy days when visibility is low. At the same time, inspections are

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limited by flight routes and time, and the observation range is small, only one forest area can be observed once a day. If the observation opportunity is missed, forest fires on the same day cannot be observed, which can easily lead to major disasters. The fixed flight cost is 2000 yuan/hour, which is high, and the cost of renting airplanes is expensive. The flight cost is seriously insufficient, which requires the use of fixed-point video monitoring to make up for its shortcomings. (4) Satellite remote sensing uses polar-orbiting meteorological satellites, land resource satellites, geostationary satellites, and low Earth orbit satellites to detect forest fires. Being able to detect hotspots, monitor the spread of fires, provide timely fire information, use remote sensing methods to make forest fire risk forecasts, and estimate the burned area using satellite digital data. It has a wide detection range, fast data collection, and can obtain continuous data, reflecting the dynamic changes of fire. Moreover, the collected data is not affected by terrain conditions, and the images are clear.

1.2. Current Research Status

At present, many experts and scholars have conducted extensive research on early satellite monitoring of fire points, interpretation of burned areas, and assessment of disaster damage using remote sensing technology. Ononye et al. used the Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) and gradient method to extract the fire lines of forest fires [2]. Yu et al. used Mahalanobis distance multivariate truncation method and Mahala Nobis distance multi-class discrimination method to recognize high-temperature targets in ETM+remote sensing images [3]. Wang et al. proposed a method for detecting fire points based on dual temporal images using brightness temperature difference correction to reduce the impact of spatial heterogeneity on background brightness temperature estimation, thereby obtaining more accurate background brightness temperature [4], Utilizing the spectral characteristics of thermal infrared images from domestically produced Gaofen-4 satellite to perceive brightness temperature anomalies, detect hotspots (fire points), monitor changes in fire situation and evolution trends; Utilizing the texture features of visible light and shadow images during the daytime of Gaofen-4 satellite to quickly obtain information on factors such as smoke points, topography, and vegetation distribution in the fire scene; Tang et al. utilized the visible light spectrum characteristics of the Gaofen-6 satellite and selected the Differential Normalized Burn Rate (dNBR) index to extract information on the burned area and conduct preliminary disaster damage assessment [5]. Airborne remote sensing technology, mainly consisting of small and medium-sized unmanned aerial vehicles, is also widely used for forest fire detection. Equipped with optical and thermal infrared sensors, it can transmit real-time small-scale fire information [6].

The domestically produced high-frequency monitoring satellites in geostationary orbit, represented by Gaofen-4, have shown good performance in forest fire monitoring and identification. The night light remote sensing satellite represented by Jilin-1 Gaofen03C can monitor fire areas and situations in nighttime environments. Airborne remote sensing technology, mainly consisting of small and medium-sized unmanned aerial vehicles, is also widely used in forest fire detection. Equipped with optical and thermal infrared sensors, it can transmit real-time small-scale fire information.

1.3. The Research Content of this Article

Due to the lack of single, real-time, and comprehensive fire monitoring methods in current forest fire emergency rescue work. Based on research results related to emergency monitoring, this article explores forest fire emergency monitoring methods based on multi-source remote sensing data, providing suggestions and references for forest fire emergency work.

2. Unmanned Aerial Vehicle Remote Sensing for Emergency Monitoring of Forest Fires

2.1. The Advantages of Drones in Forest Fire Monitoring and Rescue

Drones have unique advantages over traditional monitoring and satellite data in monitoring forest fires. Drone monitoring has higher spatial resolution, shorter data acquisition and processing time, and finer distinction of fire types, which can effectively distinguish forest fires, underground fires, and surface fires [7]. By monitoring real-time fire situations, analyzing aerial monitoring images, and transmitting data, it is possible to achieve tasks such as fire prediction, fire point monitoring, smoke identification, and firefighting support.

2.2. Identification of Forest Fire Ignition Points by Unmanned Aerial Vehicles

Dai et al. collected forest fire patrol data in the semi-arid regions of northern China, amplified the characteristic values of forest fire burning points, and attempted to improve the monitoring method of unmanned aerial vehicles for fire points, improve monitoring accuracy, and shorten monitoring delays [8].

Chongli District in Zhangjiakou City is located in the temperate semi-arid region of northern China, with low annual precipitation and an average annual temperature of about 10 ℃. It is covered with ice and snow for a long time. This study simulates the early stages of forest fires and collects unmanned aerial vehicle (UAV) forest patrol data on site. The study found that the detection performance of the model reached its highest under three data augmentation modes: image flipping, image rotation, and image affine transformation. The forest fire combustion point detection model based on infrared images is more sensitive to forest fires, reducing the computational load of forest fire detection and alleviating the computational burden on ground station computers.

2.3. Identification of Forest Fire Smoke by Drones

Zu et al. proposed an improved YOLOv3-SPP forest fire smoke recognition method based on the existing problems in current forest fire smoke recognition [9]. This method uses the Focus module based on the YOLOv3-SPP algorithm, decouples the head, anchor-free box detection mechanism, and dynamic label assignment strategy to improve the speed and accuracy of smoke recognition. Using a self-built drone forest fire remote sensing image dataset for training and testing, the proposed model achieved smoke recognition accuracy, mAP, F1 score, and recall rate of 91.07%, 92.02%, 90%, and 89.08%, respectively, with a recognition rate of 51 frames per second. The recognition rate of this model is 1.5 times that of the YOLOv3-SPP model. Through setting up comparative experiments, the effectiveness and accuracy of the model proposed in this study were verified. The experimental results show that the improved YOLOv3-SPP model achieves real-time and accurate positioning of smoke areas in forest fire images, providing an important method for large-scale, high-efficiency, and low-cost forest fire monitoring research.

2.4. Drones Participate in Forest Firefighting

Hou proposed the use of drones carrying fire extinguishers to promptly extinguish small-scale forest fires [10]. Adopting multi-rotor unmanned aerial vehicles with higher endurance and electromagnetic interference resistance, accurately launching fire extinguishing bombs to strike the fire point, and quickly and timely controlling the development of the fire in the early or late stages. This method has greater advantages over traditional forest fire rescue methods, mainly reflected in higher firefighting efficiency, greater precision, stronger safety, and higher economic efficiency. As shown in Figure 1.

Figure 1. Schematic diagram of unmanned aerial vehicle fire extinguishing [10]

3. Emergency Monitoring of Forest Fires Using Remote Sensing Satellite Data

3.1. Emergency Monitoring of Forest Fires Using Optical Satellites

Huang et al. conducted research on the frequent forest fires in the Liangshan area of Sichuan Province, using FY-4A satellite data as the main source and GF-4 satellite data as an auxiliary to monitor forest fire points [11] effectively. By comparing and analyzing fire monitoring algorithms such as the fixed threshold method, brightness temperature vegetation index method, three channel synthesis method, and up-down grammar, it was found that contextual algorithms perform well in the accuracy of fire point detection. It can accurately detect the location of the fire point with a low miss rate, and the overall algorithm index reaches over 0.7, providing a reliable reference for fire monitoring. This method can quickly and accurately locate the time and location of the fire point, achieve real-time monitoring of forest fires and extraction of burned area, and provide technical support and guarantee for forest fire prevention work. Research has shown that GF-4A satellite data has potential application prospects in fire monitoring and identification of burned areas, and has demonstrated certain technological advantages.

3.2. Emergency Monitoring of Forest Fires Using Night Light Satellites

Considering the environmental factors such as difficulty in takeoff and landing and strong wind during unmanned aerial vehicle monitoring of the burning area at night, in order to effectively complete uninterrupted monitoring within 12 hours at night, monitoring work calls for night light remote sensing satellite data such as Jilin-1 night light satellite, as shown in Table 1.

Table 1. Characteristics of Luminous Remote Sensing Satellites [12]

Satellite name	"Jilin-1" Gaofen03A satellite	"Jilin-1" Gaofen03A satellite	"Jilin-1" Gaofen03A satellite	"Jilin-1" Gaofen03A satellite
Single star quality	Below 40 kg	41 kg	42 kg	42 kg
Number of satellites	1	6	3	54
Type of orbit	inclined circular orbit			inclined circular orbit,
Orbital altitude	572 km			535 km
resolution	Better than 1.1 m		Panchromatic: Better than 1m Multispectral: Better than 4m video: Better than 1.2km	Panchromatic: 0.75m Multispectral: 3m
Imaging width	Better than 18.5km	Better than 17km		>18km
Standard Scene Size			14.4km×6km	17.5km×17.5km
Imaging spectral range				Panchromatic P:450-700 nm Blue B1:430-520 nm GreenB2:520-610nm Red B3:610-690 nm Near infraredB4:770-895 nm
Data transmission rate				maximum 900Mbps
Inverted angle range				±45°
Imaging mode		Stacked scanning imaging	Stacked scanning imaging, video imaging	stacked scanning, inertial space imaging
Total mass of satellite	<40kg			43kg

Wu et al. proposed a new spectral index called Enhanced Luminous Fire Disturbance Index (ENFDI) to address the difficulty of fully separating forest fires from industrial combustion, urban heat sources, and other sources solely based on radiance or temperature in low light remote sensing images. Additionally, due to frequent data saturation issues, NPP fire products currently only provide detection location information [12]. This index has sensitivity, stability, and accuracy in identifying forest fires, but at the edge of the fire, the radiance of the low light band and the brightness and temperature of the infrared band are reduced, and the suspected fire pixels at the edge are easily confused with the urban center pixels. The research provides a basis for obtaining more reliable remote sensing identification results of forest fires using low-light satellites and infrared bands.

3.3. Satellite Remote Sensing Data Used to Evaluate Vegetation Restoration on Burned Ground

Normalized Burn Ratio (NBR) is a remote sensing indicator used to evaluate vegetation restoration after wildfires or ground burns. NBR can enhance a larger area of fire, such as over 200 hectares. It is calculated by comparing the reflectance of the far-infrared band (SWIR) and the near-infrared band (NIR). The SWIR band measures the reflectance of burned ground, while the NIR band measures the reflectance of vegetation that has not been affected by burns. The calculation formula for NBR is NBR=(NIR-SWIR)/(NIR+SWIR). NIR is the near-infrared band, and SWIR is the short-wave infrared band. The value range of NBR is usually between -1 and 1, where -1 represents complete burning, O represents vegetation that has not been burned, and 1 represents the area without vegetation coverage before the burn. The lower the NBR, the more severe the impact of burn disasters on the ecosystem. Therefore, NBR is commonly used for monitoring and evaluating burn areas, as well as assessing the recovery of vegetation after burns.

4. Real-Time Fire Monitoring

Based on the different roles and advantages of integrating multi-source remote sensing information in forest fire monitoring, this paper proposes a framework for emergency fire monitoring, as shown in Figure 2.

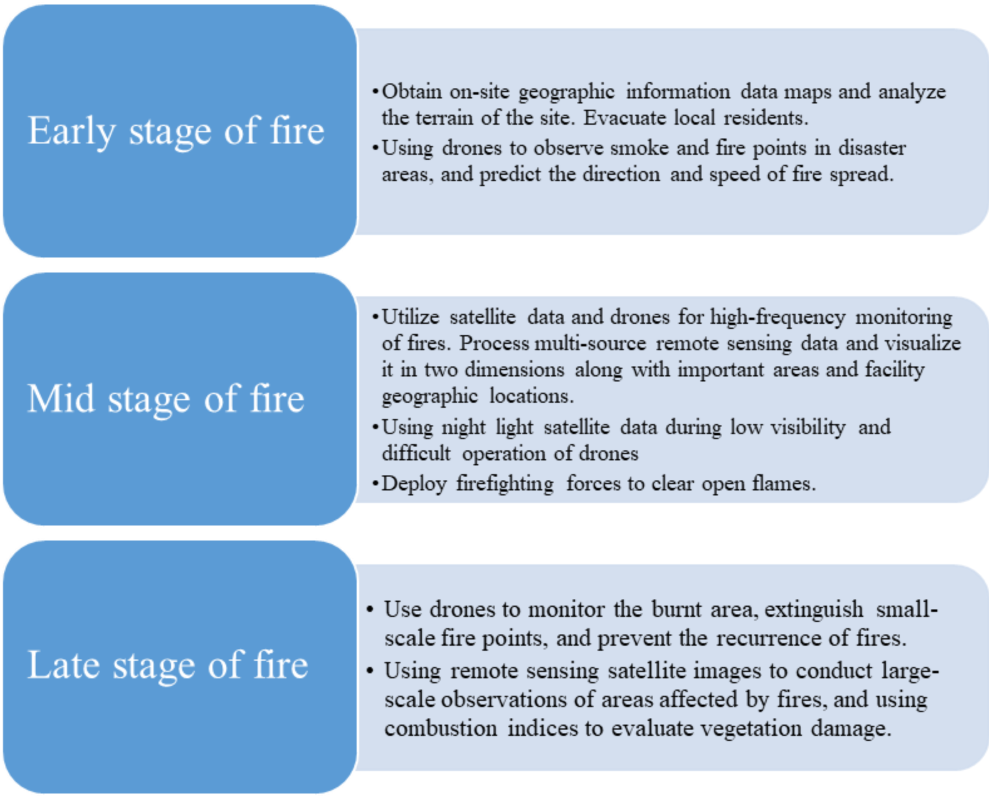

Figure 2. Fire Emergency Monitoring Framework (Original Figure)

4.1. Comprehensive Analysis and Judgment of Initial Fire Scene Information

The initial emergency monitoring work of a fire mainly involves three-dimensional simulation of the terrain and topography of the fire scene and map visualization of all rescue element data required for emergency rescue command work. Visualize key features such as the fire scene command center, road traffic, village gathering places, water sources, and power facilities in 3D modeling, and submit them to the command group for comprehensive analysis and judgment of the fire scene overview to grasp accurate information.

4.2. Real-Time Monitoring of Mid-term Fire Situation

Mid-fire rescue work refers to the process from the development of the fire, rescue deployment, extinguishing of open flames to preventing reignition in high-temperature areas. The entire process includes drone monitoring and satellite monitoring.

4.3. Post-High Temperature Point Detection

In the later stage of the fire, there is no obvious large-scale burning area, but there are still scattered high-temperature points in the burnt area that have not been completely burned. Monitoring work uses M30T unmanned aerial vehicles equipped with laser rangefinders for fire point perception and high-precision positioning. After the fire is completely extinguished, satellite data is called to assess the overall burning of the forest, providing information for subsequent ecological construction.

4.4. Other Data

Visualize the geographical location and related information of important facilities such as residential areas, roads, water sources, aircraft takeoff and landing points, and power plants, in the vicinity of forest fires in a geographic information data map, providing decision-making basis for the disaster relief command center.

5. Conclusion

Faced with forest fires, drone remote sensing has a high temporal and spatial resolution and drones carrying fire extinguishers can safely and quickly achieve small-scale firefighting. It can help rescue personnel control the initial fire and provide monitoring information for key areas. At the same time, it can also monitor the open flames and smoke in the disaster area in the later stage of the fire, extinguish small fire points in a timely manner, and prevent the recurrence of the fire.

Satellite remote sensing has the capability of large-scale and full-time detection. Not only can it provide nighttime monitoring information and large-scale fire evolution information for rescue command work, but it can also calculate and evaluate the damage and recovery of vegetation in the fire area over a long period of time after the disaster by combining remote sensing indices.

This article explores emergency monitoring methods for forest fires based on multi-source remote sensing data. This study analyzes the applicability, advantages, and disadvantages of various remote sensing data based on comprehensive geographic data and previous scholars' specific research on remote sensing data, such as drones and satellites in fire emergency monitoring. A framework for emergency fire monitoring, visualizing important areas and facilities with fire development is proposed, providing information for cities and counties to extinguish forest fires.

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