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FOREST FIRE MONITORING AND INTELLIGENT EARLY WARNING BASED ON MULTI-SOURCE PERCEPTION USING FIXED-WING UAVS

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Abstract: Forest fires are characterized by sudden occurrence, rapid spread, and wide-ranging destruction, posing serious threats to forest resource protection and ecological security management. To address the limitations of conventional monitoring methods, such as manual patrols, fixed video surveillance, and satellite remote sensing, in terms of insufficient coverage, limited real-time capability, and low early-warning efficiency in long-distance and large-area forest fire monitoring, this study proposes a forest fire monitoring and intelligent early warning framework based on multi-source perception using fixed-wing UAVs. In the proposed framework, a fixed-wing UAV serves as the airborne patrol platform and is equipped with sensing devices such as RGB cameras, thermal infrared cameras, and multispectral sensors. The UAV conducts large-area patrols over the target forest region along predefined flight routes and collects fire-related information from multiple dimensions, including smoke, flames, thermal anomalies, and vegetation conditions. Through integrated analysis of multi-source information, the system can preliminarily identify suspected fire points, potential fire-risk areas, and fire warning levels, and transmit the monitoring results to the ground control platform to support early fire detection and emergency response. The study indicates that the combination of the long-endurance and large-coverage capability of fixed-wing UAVs with multi-source perception technology can improve the efficiency, reliability, and intelligence of forest fire monitoring, showing practical value for forest fire prevention and ecological resource protection.
Keywords: Fixed-wing UAVs; Multi-source perception; Forest fire monitoring; Intelligent early warning

1 INTRODUCTION

Forest fires are among the most serious threats to forest ecosystem security and regional ecological stability [1, 2]. They are often characterized by sudden occurrence, rapid spread, wide impact, and great difficulty in emergency response [3, 4]. Once a fire is not detected at an early stage, it may lead to large-scale losses of forest resources and cause severe impacts on biodiversity, air quality, soil conditions, and the safety of nearby communities. Conventional forest fire monitoring methods mainly rely on manual patrols, watchtowers, ground-based video surveillance, and satellite remote sensing. However, in remote, large-scale, and topographically complex forest areas, these methods still suffer from limited coverage, delayed response, low warning efficiency, and high labor costs. Therefore, developing an efficient, flexible, and accurate forest fire monitoring and early warning system is of great significance for improving forest fire prevention and ecological resource protection.
In recent years, the rapid development of unmanned aerial vehicle technology has provided a promising approach for forest fire monitoring. Compared with multi-rotor UAVs, fixed-wing UAVs offer longer flight endurance, greater cruising range, higher flight speed, and larger coverage in a single mission, making them particularly suitable for long-distance and large-area forest patrol tasks. Meanwhile, with the continuous advancement of visible-light imaging, thermal infrared imaging, multispectral remote sensing, and wireless communication technologies, UAV-based monitoring has gradually evolved from simple image acquisition toward multi-source perception, intelligent recognition, and real-time early warning. RGB cameras can be used to identify smoke, flames, and scene features; thermal infrared cameras can detect temperature anomalies and hidden fire sources; and multispectral sensors can assist in evaluating vegetation dryness and potential fire risk. The integration of multi-source perception can compensate for the limitations of a single sensor under complex environmental conditions, such as illumination variation, smoke interference, occlusion, and surface heat disturbance, thereby improving the reliability of fire detection and the accuracy of early warning [5, 6].
Based on this background, this study proposes a forest fire monitoring and intelligent early warning framework using fixed-wing UAV-based multi-source perception. In the proposed framework, a fixed-wing UAV serves as the airborne monitoring platform and is equipped with sensing devices such as RGB cameras, thermal infrared cameras, and multispectral sensors. The UAV conducts large-area forest patrols along predefined flight routes and collects visual, thermal, and vegetation-related information for integrated analysis. On this basis, the system can preliminarily identify smoke, flames, thermal anomalies, and potential fire risks, and transmit the monitoring results to the ground control platform. This provides technical support for early fire detection, fire risk assessment, and emergency decision-making.

The purpose of this study is to improve the coverage capability, response speed, and warning reliability of forest fire monitoring, offering a feasible technical approach for forest resource protection and ecological security management.

2 RESEARCH BACKGROUND AND RELATED TECHNOLOGIES

2.1 Forest Fire Monitoring Technologies

Forest fire monitoring is a key component of forest fire prevention, aiming to detect abnormal fire sources at an early stage and provide accurate information for emergency response [7]. Conventional forest fire monitoring methods mainly include manual patrols, watchtower observation, ground-based video surveillance, and satellite remote sensing. Manual patrols are flexible and can make use of human experience in field judgment, but they are limited in coverage, labor-intensive, and potentially dangerous in mountainous, dense, or high-risk forest environments. Watchtowers and fixed video monitoring systems can provide continuous observation of selected areas, but their effectiveness is often restricted by terrain variation, vegetation occlusion, weather conditions, and the location of monitoring facilities, which may lead to blind spots. Satellite remote sensing provides large-scale coverage and is useful for regional fire detection and post-disaster assessment; however, its spatial resolution, revisit period, and real-time capability may limit its effectiveness in detecting small fires at an early stage.

With the development of remote sensing, communication, and intelligent recognition technologies, UAVs have become an important supplementary tool for forest fire monitoring. UAVs are characterized by strong mobility, flexible deployment, high-resolution imaging, and relatively low operational cost. They can conduct patrol missions in forest areas that are difficult for personnel to access or hard for ground-based monitoring systems to cover. Compared with fixed monitoring facilities, UAVs can adjust their flight routes according to fire risk levels, terrain conditions, and key protection areas, enabling dynamic patrols and targeted observation. Therefore, UAV-based monitoring has significant application value in early fire detection, fire scene awareness, and post-fire assessment.

2.2 Fixed-Wing UAVs for Large-Area Forest Monitoring

In UAV-based forest monitoring, multi-rotor UAVs and fixed-wing UAVs are two commonly used platforms. Multi-rotor UAVs have advantages such as vertical takeoff and landing, stable hovering, and good low-altitude observation capability, making them suitable for small-area, short-distance, and point-based monitoring tasks. However, their flight endurance and cruising speed are relatively limited, which may reduce their operational efficiency in large forest areas, long-distance patrols, and long-duration monitoring missions [7, 8].

Fixed-wing UAVs are more suitable for large-area and long-distance forest patrol missions. They generally have higher cruising speed, longer flight range, and better endurance, allowing them to cover a much larger forest area in a single mission. This makes fixed-wing UAVs particularly advantageous for forest fire patrols in mountainous forest farms, nature reserves, remote forest regions, and large ecological protection areas. Through predefined flight routes and autonomous flight control, fixed-wing UAVs can conduct rapid inspections of target areas along grid-based or strip-shaped routes, collecting information related to fire events, smoke, vegetation conditions, and surface anomalies.

In addition, fixed-wing UAVs can carry various sensing devices and cooperate with ground control systems to realize data acquisition, location recording, and information transmission. Although fixed-wing UAVs lack hovering capability and are less flexible than multi-rotor UAVs for detailed local observation, their long endurance and large-area coverage better meet the needs of early forest fire patrol and regional early warning. Therefore, in long-distance forest environmental monitoring scenarios, fixed-wing UAVs can serve as efficient airborne monitoring platforms and provide continuous, rapid, and large-scale data support for forest fire warning.

2.3 Multi-Source Perception in Fire Detection

Forest fire detection is challenging because fire phenomena are complex, environmental interference is common, and early-stage fire features are often weak. A single sensor is usually insufficient to meet the requirements of highly reliable monitoring. For example, fire detection based only on visible-light images may be affected by illumination changes, shadows, smoke diffusion, fog, clouds, and complex ground backgrounds. Detection based only on thermal infrared images may also suffer from interference caused by non-fire high-temperature objects, such as exposed rocks, buildings, or surfaces heated by solar radiation. Therefore, the integrated use of multiple types of sensor information has become an important approach to improving the accuracy and stability of forest fire monitoring.

In fixed-wing UAV-based forest fire monitoring, RGB cameras, thermal infrared cameras, and multispectral sensors are typical multi-source sensing devices. RGB cameras can acquire high-resolution scene images and are used to identify smoke, flames, surface changes, and fire scene characteristics. Thermal infrared cameras can capture the temperature distribution of the target area, enabling the detection of thermal anomalies, hidden fire sources, and potential reignition areas. Multispectral sensors can reflect vegetation growth, water content, and dryness through vegetation indices, providing auxiliary information for fire risk assessment.

The advantage of multi-source perception lies in its ability to describe fire-related features from different dimensions. Visible-light data provide intuitive morphological and texture information, thermal infrared data provide temperature anomaly information, and multispectral data provide vegetation condition and environmental risk information. By jointly analyzing these data, the risk of false alarms and missed detections caused by a single data source can be reduced.

For instance, when suspected smoke appears in visible-light images and a local thermal anomaly is detected in thermal infrared images, the system can increase the warning level. Similarly, an area showing persistent vegetation dryness and abnormal surface temperature can be regarded as a potential high-risk fire zone. Therefore, multi-source perception provides a more comprehensive, reliable, and intelligent data basis for fixed-wing UAV-based forest fire monitoring.

3 FRAMEWORK OF FOREST FIRE MONITORING BASED ON FIXED-WING UAVS

3.1 Overall System Framework

The forest fire monitoring framework based on fixed-wing UAVs mainly consists of four components: an airborne monitoring platform, a multi-source perception module, a data transmission module, and a ground-based early warning platform. The fixed-wing UAV serves as the airborne carrier and conducts long-distance, large-area patrols over the target forest region along predefined flight routes. The multi-source perception module is responsible for collecting visible-light images, thermal infrared data, and vegetation-related information. The data transmission module sends monitoring data and flight status information back to the ground platform in real time or near real time. The ground-based early warning platform displays, analyzes, and outputs warning information based on the received data.

The basic workflow of this framework can be described as follows. First, UAV patrol routes are planned according to forest boundaries, key fire prevention areas, terrain conditions, and historical fire-risk distribution. Then, the fixed-wing UAV flies along the planned routes and continuously collects forest environmental information using onboard multi-source sensors. When suspected smoke, flames, thermal anomalies, or vegetation dryness are detected, the related data are transmitted to the ground control platform. Finally, the ground platform integrates image information, temperature information, location information, and risk levels to generate monitoring results and early warning messages. The overall process can be summarized as: Fixed-wing UAV platform → Multi-source sensing → Data transmission → Fire information analysis → Early warning output.

Through this framework, the fixed-wing UAV can not only perform large-area patrol missions but also integrate fire detection, location positioning, and warning output into a relatively complete monitoring loop. Compared with traditional single-source monitoring methods, this framework offers stronger mobility, wider coverage, and better information integration capability, making it suitable for remote, large-scale, and topographically complex forest areas.

3.2 Multi-Source Data Acquisition

Multi-source data acquisition is the fundamental part of the proposed monitoring framework. Before a mission, the flight altitude, cruising speed, route spacing, and data acquisition frequency should be configured according to the size of the target forest area, terrain variation, fire risk level, and weather conditions. During the flight, the UAV follows predefined routes and continuously collects visible-light, thermal infrared, and multispectral data to obtain comprehensive information on forest fire conditions and environmental status.

RGB cameras are mainly used to capture high-resolution images of forest areas. These images can visually reflect surface conditions, smoke, flames, roads, buildings, and other environmental features. In fire monitoring, visible-light images can be used to identify smoke plumes, flame color, abnormal surface changes, and traces of human activity, making them an important data source for fire confirmation and scene awareness. Thermal infrared cameras detect thermal radiation from the target area and provide surface temperature distribution information. Since fire sources and high-temperature regions usually show clear thermal anomalies in infrared images, thermal infrared imaging is suitable for detecting early fire spots, hidden fire sources, and potential reignition areas, especially at night or under smoke-obscured conditions.

Multispectral sensors are used to acquire vegetation reflectance information across different spectral bands, which can help analyze vegetation coverage, growth condition, and dryness. For forest fire monitoring, multispectral data can support not only post-fire damage assessment but also pre-fire risk identification. For example, reduced vegetation water content, increased drought stress, and abnormal surface temperature can all serve as important indicators for fire risk assessment. By combining visible-light, thermal infrared, and multispectral data, fire-related information can be obtained from three dimensions: morphology, temperature, and vegetation condition. This provides a data basis for subsequent fire identification and warning decision-making.

3.3 Fire Monitoring and Warning Process

The forest fire monitoring and early warning process mainly includes four steps: patrol mission execution, anomaly detection, risk assessment, and warning output. First, the fixed-wing UAV conducts patrols over the target forest area according to predefined flight routes and continuously collects multi-source perception data during flight. Due to its relatively high cruising speed and large coverage capability, the fixed-wing UAV can complete preliminary scanning of large forest areas within a short time, making it suitable for early fire patrol and regional monitoring.

Second, the system performs preliminary analysis of the collected data, focusing on abnormal features related to fire events. For visible-light images, the system mainly observes smoke, flames, surface color changes, and abnormal human activities. For thermal infrared data, the system focuses on local high-temperature regions, sudden temperature changes, and the spread of thermal anomalies. For multispectral data, the system analyzes vegetation dryness and potential fire-risk areas. When one type of data shows abnormal features, the corresponding location can be marked as a suspected risk point. When multiple types of data show abnormalities at the same location, the confidence of fire detection can be further increased.

Finally, the system generates warning information based on the integrated analysis of multi-source data and sends the fire location, abnormal images, temperature features, and warning level back to the ground control platform. To improve the interpretability of warning results, fire risk can be divided into different levels. For example, when only vegetation dryness or slight temperature abnormality is observed, the area can be classified as low risk. When suspected smoke or a local thermal anomaly is detected, it can be classified as medium risk. When smoke and a significant high-temperature region appear simultaneously, it can be classified as high risk. When flames, spreading thermal anomalies, and intensified smoke are detected, the event can be classified as a severe fire. Through this graded warning mechanism, the system can provide forest fire prevention departments with more intuitive, timely, and actionable information support.

4 APPLICATION ADVANTAGES AND DISCUSSION

4.1 Application Advantages

The proposed forest fire monitoring and intelligent early warning framework based on fixed-wing UAV multi-source perception has clear advantages in large-area forest patrol, early fire detection, and emergency decision support. Compared with conventional monitoring approaches such as manual patrols, ground-based video surveillance, and satellite remote sensing, the proposed framework combines the long-endurance and large-coverage capability of fixed-wing UAVs with multi-source sensing information from RGB cameras, thermal infrared cameras, and multispectral sensors. This improves the mobility, timeliness, and reliability of forest fire monitoring.

Table 1 Comparison of Different Forest Fire Monitoring Methods

Monitoring method	Coverage capability	Real-time performance	Detection accuracy	Main advantages	Main limitations
Manual patrol	Low	Low to medium	Depends on experience	Flexible field judgment	Low efficiency, high labor cost, safety risk
Watchtower monitoring	Medium	Medium	Medium	Continuous observation of fixed areas	Limited by terrain, visibility, and blind spots
Ground video surveillance	Medium	Medium to high	Medium	Suitable for key area monitoring	Requires infrastructure and stable power supply
Satellite remote sensing	High	Low to medium	Medium	Large-scale regional observation	Limited temporal resolution and difficulty in detecting early small fires
Multi-rotor UAV monitoring	Medium	High	High	Flexible, hoverable, suitable for local observation	Limited endurance and coverage
Fixed-wing UAV multi-source monitoring	High	High	High	Long endurance, large coverage, multi-source perception, suitable for early warning	Limited hovering ability and affected by weather conditions

As shown in Table 1, fixed-wing UAV-based multi-source monitoring does not completely replace other monitoring methods in all aspects. Instead, it shows stronger adaptability in large-area, long-distance, and rapid patrol tasks. Manual patrols and ground-based video surveillance are more suitable for long-term observation of local or key areas, while satellite remote sensing is useful for large-scale disaster assessment. Fixed-wing UAVs can effectively bridge the gap between these methods by providing both relatively high spatial resolution and strong mobility. Therefore, they are particularly suitable for early forest fire patrol and regional fire-risk warning.

To further illustrate the comprehensive performance of different monitoring methods, this study compares them from six dimensions: coverage capability, response speed, information richness, safety, cost efficiency, and early-warning potential, as shown in Figure 1.

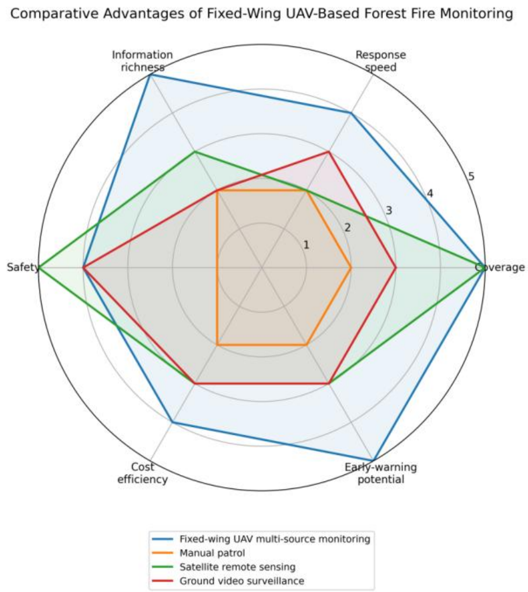

Figure 1 Comparative Advantages of Fixed-wing UAV-based Forest Fire Monitoring

As shown in Figure 2, the fixed-wing UAV-based multi-source monitoring method shows the most balanced and prominent overall performance among the selected monitoring approaches. It performs particularly well in coverage capability, information richness, and early-warning potential. This is mainly because fixed-wing UAVs can patrol large forest areas within a relatively short time, while the integration of RGB cameras, thermal infrared cameras, and multispectral sensors enables the system to obtain fire-related information from multiple dimensions, including visual morphology, temperature anomalies, and vegetation conditions.

Compared with manual patrols, the proposed method can significantly reduce dependence on human labor and improve monitoring safety in remote or high-risk forest regions. Compared with ground video surveillance, it is less restricted by fixed installation locations, terrain occlusion, and blind spots. Compared with satellite remote sensing, it provides better flexibility and stronger real-time response capability for early-stage fire detection. Although satellite remote sensing performs well in coverage and safety, its temporal resolution and difficulty in detecting small early fires limit its early-warning performance. Therefore, the radar chart further demonstrates that fixed-wing UAV-based multi-source monitoring can serve as an effective mobile monitoring and early-warning approach for large-scale forest fire prevention.

In addition, the proposed framework has advantages in information integration and decision support. RGB images can provide intuitive visual evidence of smoke and flames, thermal infrared images can reveal local high-temperature regions and hidden fire sources, and multispectral data can reflect vegetation dryness and potential fire risk. The combination of these data sources can reduce the uncertainty caused by a single sensing method and improve the reliability of warning results. By transmitting fire location, abnormal images, temperature features, and warning levels to the ground control platform, the system can provide more timely and actionable information for forest fire prevention departments.

Overall, the fixed-wing UAV-based multi-source perception framework is suitable for serving as an important component of an integrated forest fire monitoring system. It can cooperate with satellite remote sensing, ground video surveillance, watchtower monitoring, and manual inspection to form a more complete fire prevention network. In such a system, fixed-wing UAVs can be used for routine large-area patrol and rapid risk scanning, while ground-based systems and multi-rotor UAVs can be used for continuous local monitoring and detailed confirmation of suspected fire points.

4.2 Limitations

Although the proposed framework has strong application potential, several limitations remain in practical deployment and long-term operation. First, fixed-wing UAVs generally lack hovering capability. As a result, after a suspected fire point is detected, their ability to conduct detailed local observation is weaker than that of multi-rotor UAVs. For small fire spots, hidden fire sources, or local anomalies in complex terrain that require close-range confirmation, a single fixed-wing UAV platform may not provide continuous and stable point-based observation.

Second, forest environments are highly uncertain. Complex terrain, strong winds, rainfall, smoke occlusion, and low visibility can affect UAV flight safety and sensor imaging quality. In active fire environments, thermal turbulence and strong winds may influence UAV attitude stability, which can further affect image acquisition and fire localization accuracy. In addition, although thermal infrared imaging is effective for detecting high-temperature anomalies, non-fire heat sources such as exposed rocks, buildings, roads, and sun-heated surfaces may also be misclassified as suspected fire points under strong solar radiation.

Third, multi-source data fusion still faces technical challenges. RGB images, thermal infrared images, and multispectral data differ in spatial resolution, imaging mechanism, acquisition frequency, and environmental sensitivity. If these data are not accurately synchronized and spatially registered, the reliability of integrated analysis may be reduced. In addition, the weight assignment of different sensing information under different weather, terrain, and illumination conditions remains a difficult problem. For example, visible-light images may be more useful during daytime and under good visibility, while thermal infrared information may be more reliable at night or under smoke interference. Therefore, adaptive fusion strategies are needed to improve detection robustness in complex forest environments.

Fourth, real-time data transmission and processing may become a bottleneck. Fixed-wing UAVs can collect a large amount of high-resolution image and sensor data during long-distance patrols. However, in remote forest areas, communication infrastructure is often limited, and the stability and bandwidth of wireless transmission may not always meet the requirements of real-time monitoring. If all data need to be transmitted to the ground platform for analysis, delays may occur. Although edge computing can reduce transmission pressure by enabling onboard preliminary recognition, it also increases requirements for UAV payload capacity, power consumption, and onboard computing resources.

Fifth, the proposed framework still requires further validation using real-world monitoring data. At the current stage, the framework mainly focuses on system design, monitoring logic, and application feasibility. To verify its practical effectiveness, field experiments should be carried out under different forest types, seasons, terrain conditions, and weather environments. Quantitative indicators such as detection accuracy, false alarm rate, missed detection rate, response time, patrol coverage, and warning reliability should be further evaluated. Without sufficient real-world data and comparative experiments, the actual performance of the proposed system in complex forest fire scenarios still needs to be carefully confirmed.

Finally, deployment cost and operational management should also be considered. Although UAV-based monitoring can reduce labor intensity and improve monitoring efficiency, fixed-wing UAV platforms, multi-source sensors, ground control systems, data processing software, and maintenance personnel all require financial and technical support. For large-scale application, issues such as flight permission, route planning, battery or fuel supply, equipment maintenance, operator training, and data management need to be addressed. Therefore, the practical promotion of the proposed framework should consider both technical feasibility and operational cost.

4.3 Future Work

Based on the current framework and the above limitations, future research can be further carried out from short-term optimization, medium-term extension, and long-term system integration. The development roadmap of the proposed framework is shown in Figure 2.

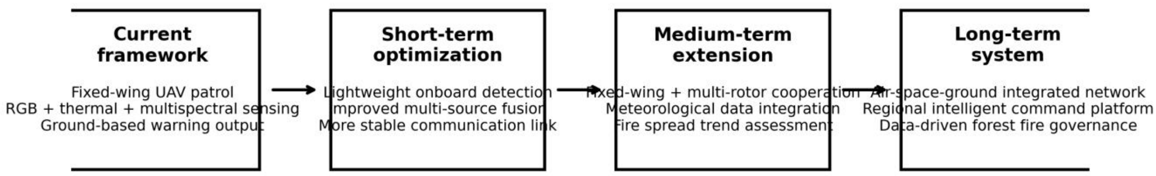

Figure 2 Development Roadmap of the Fixed-wing UAV-based Forest Fire Monitoring Framework

As shown in Figure 2, the current framework mainly focuses on fixed-wing UAV patrol, RGB and thermal-based multi-source sensing, and ground-based warning output. At this stage, the fixed-wing UAV is used as the main airborne monitoring platform to conduct large-area patrols, while RGB cameras and thermal infrared cameras are used to identify smoke, flames, and thermal anomalies. The ground control platform receives monitoring information and outputs early warning results. This framework provides a basic technical path for large-area forest fire monitoring and early warning.

In the short-term optimization stage, future work should focus on lightweight onboard detection, improved multi-source fusion, and more stable communication links. Lightweight fire detection models can be deployed on UAV onboard computing units to conduct preliminary recognition during flight. In this way, the UAV does not need to transmit all raw images to the ground platform, but only sends key information such as suspected fire images, abnormal temperature areas, location coordinates, and warning levels. This can reduce communication pressure and improve early-warning timeliness. At the same time, the fusion method of RGB, thermal infrared, and multispectral data should be further optimized to improve detection accuracy and reduce false alarms caused by complex backgrounds or non-fire heat sources.

In the medium-term extension stage, the cooperation between fixed-wing UAVs and multi-rotor UAVs should be further explored. Fixed-wing UAVs are suitable for rapid scanning and large-area patrol, while multi-rotor UAVs are suitable for hovering observation and detailed local inspection. After a fixed-wing UAV identifies a suspected fire point or high-risk area, a multi-rotor UAV can be dispatched to conduct close-range verification, continuous monitoring, and detailed image acquisition. In addition, meteorological data integration should also be strengthened. Wind speed, wind direction, humidity, temperature, precipitation, and terrain data can be combined with UAV monitoring results to support fire spread trend assessment and improve the accuracy of fire risk prediction.

In the long-term development stage, a more comprehensive air-space-ground integrated forest fire monitoring network can be established. Satellite remote sensing, fixed-wing UAV patrols, multi-rotor UAV local inspection, ground video surveillance, watchtower observation, and meteorological monitoring stations can be integrated into a unified regional fire prevention platform. Through data sharing and intelligent analysis, the system can support regional forest fire trend analysis, emergency resource allocation, evacuation planning, and ecological protection decision-making. With the continuous accumulation of monitoring data, data-driven forest fire governance can be gradually realized, enabling the system to evolve from passive fire detection to active risk prediction and intelligent prevention.

Overall, future work should not only improve the detection accuracy of individual sensors or algorithms, but also strengthen system-level integration. By combining intelligent recognition algorithms, adaptive multi-source data fusion, onboard edge computing, UAV cooperative monitoring, meteorological data, and regional fire prevention platforms, the proposed framework can become more intelligent, reliable, and practical for real forest fire prevention applications.

5 CONCLUSION

Forest fire monitoring and early warning are essential for forest resource protection, ecological security management, and emergency disaster response. To address the limitations of conventional monitoring methods, such as insufficient coverage, delayed response, limited real-time capability, and low early-warning efficiency in large-scale and complex forest areas, this study proposed a forest fire monitoring and intelligent early warning framework based on multi-source perception using fixed-wing UAVs.

In the proposed framework, the fixed-wing UAV serves as an airborne patrol platform and conducts large-area monitoring along predefined flight routes. RGB cameras, thermal infrared cameras, and multispectral sensors are used to collect fire-related information from multiple dimensions, including smoke, flames, thermal anomalies, and vegetation conditions. Through integrated analysis of multi-source data, the system can preliminarily identify suspected fire points, potential fire-risk areas, and different warning levels. The monitoring results can then be transmitted to the ground control platform to support early fire detection, fire risk assessment, and emergency decision-making.

Compared with manual patrols, watchtower monitoring, ground video surveillance, satellite remote sensing, and multi-rotor UAV monitoring, the proposed fixed-wing UAV-based multi-source monitoring framework has advantages in coverage capability, response speed, information richness, and early-warning potential. Fixed-wing UAVs can rapidly patrol large forest areas, while multi-source sensors can improve the reliability of fire detection by combining visual, thermal, and vegetation-related information. Therefore, the proposed framework has practical value for large-area forest patrol and regional fire prevention.

However, the framework still has some limitations. Fixed-wing UAVs have limited hovering ability and may be affected by complex weather, terrain, and communication conditions. Multi-source data fusion, real-time processing, and accurate fire-risk assessment also require further improvement. In addition, more real-world experiments are needed to evaluate the system in terms of detection accuracy, false alarm rate, response time, and operational stability.

Future research should follow a progressive development path. In the short term, lightweight onboard detection, improved data fusion, and stable communication links should be strengthened. In the medium term, fixed-wing and multi-rotor UAV cooperation, meteorological data integration, and fire spread trend assessment should be developed. In the long term, an air-space-ground integrated forest fire monitoring network and regional intelligent command platform can be constructed to support data-driven forest fire governance. Overall, the combination of fixed-wing UAVs and multi-source perception provides a feasible and promising technical approach for improving forest fire prevention capability and protecting ecological resources.

COMPETING INTERESTS

The authors have no relevant financial or non-financial interests to disclose.

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