

A Review of UAV Applications in the Design, Construction, and Operation & Maintenance of Overhead Transmission Lines

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Abstract

With the expansion of power systems and the increasing complexity of transmission lines, traditional manual inspection and construction methods-characterized by low efficiency, high costs, and elevated risks-are becoming insufficient to meet the modern power grid's demands for safety and intelligence. This limitation is especially pronounced in challenging environments such as mountainous regions, dense forests, and bodies of water. In recent years, Unmanned Aerial Vehicles (UAVs), owing to their high flexibility, low operational costs, and strong environmental adaptability, have been widely applied throughout the entire lifecycle of overhead transmission lines, including design, construction, and operation & maintenance. UAVs significantly enhance operational efficiency and the intelligence level of grid management through applications in route surveying, 3D modeling, conductor stringing monitoring, safety inspections, and defect detection. This paper provides a comprehensive review of typical UAV applications and key technical approaches in overhead transmission lines. It further analyzes current challenges in environmental adaptability, intelligent operation, data fusion, and standardization systems, and explores future development directions to offer insights for related research and engineering practice.

Keywords

Unmanned Aerial Vehicle; Overhead Transmission Lines; Design; Smart Grid.

1. Introduction

With the continuous expansion of power grids and the increasing complexity of transmission lines, traditional manual approaches in the design, construction, and operation & maintenance stages are facing significant challenges, including high risks, low efficiency, and elevated costs. UAV technology, with its advantages of efficiency, flexibility, and reduced operational risk, has gradually permeated various stages of transmission line projects. It plays an irreplaceable role, especially in aerial operations and power-related tasks conducted in complex terrains. Currently, UAVs are being integrated with intelligent technologies such as image recognition, LiDAR, and AI algorithms, becoming a key driving force in the digital transformation of the power industry.

A typical UAV system consists of a flight platform, mission payload, ground control system, and communication link. In the power sector, multi-rotor UAVs are commonly used for short-range, high-precision tasks such as tower inspections and infrared temperature measurements, whereas fixed-wing UAVs are suitable for long-distance patrols and wide-area surveys. In recent years, new UAV platforms such as vertical take-off and landing (VTOL) fixed-wing and hybrid-wing drones have been increasingly applied to transmission line scenarios. Equipped with high-resolution cameras, infrared thermal imagers, and LiDAR sensors, these UAVs are capable of performing all-weather, multi-angle, and multi-dimensional data acquisition, significantly enhancing operational efficiency and inspection coverage.

2. Use of Unmanned Aerial Vehicles in the Planning and Surveying of Overhead Power Lines

2.1 Transmission Line Surveying and Route Planning

In the preliminary design phase of transmission lines, UAVs can replace traditional surveying equipment to perform tasks such as topographic surveying and corridor environment analysis. By combining aerial imagery with GPS positioning and inertial navigation systems, UAVs generate high-precision digital elevation models (DEMs) and orthophotos, providing accurate foundational data for route planning and construction design. Additionally, UAVs equipped with LiDAR systems can rapidly acquire ground point clouds in complex terrains such as forests and mountainous areas, enabling precise modeling of the ground surface and vegetation conditions.



Fig. 1 UAV-Based Survey

2.2 3D Modeling and Terrain Analysis

Based on a large volume of high-resolution images acquired by UAVs, combined with photogrammetry techniques and 3D modeling software, realistic three-dimensional (3D) models that accurately reproduce terrain and landform features can be rapidly constructed. These models not only provide excellent spatial representation but also serve multiple functions, including visual analysis of transmission line corridors, simulation and evaluation of construction schemes, and refined optimization of tower site selection.

During the engineering design phase, the 3D model comprehensively presents environmental information such as terrain undulation, vegetation coverage, and water bodies surrounding the line. This is particularly valuable for sections crossing complex terrains like rivers and valleys, where it clearly illustrates elevation differences and landform characteristics. Such visualization offers intuitive support for route planning, foundation site selection, and construction method decisions, thereby enhancing the scientific basis and rationality of the design.

Moreover, the model provides a reliable auxiliary tool for subsequent construction organization and safety risk assessment. While improving design efficiency, it also strengthens the feasibility and controllability of project implementation.

3. UAV Applications in Overhead Transmission Line Construction

3.1 Tower Placement and Positioning

UAVs can be used for high-precision positioning of transmission tower foundation sites. Through autonomous flight and image recognition technologies, UAVs rapidly inspect and mark locations, which are then uploaded to the power grid GIS system. Additionally, by integrating RTK-GPS with panoramic imaging technology, UAVs assist construction personnel in on-site staking and structural positioning, thereby improving the efficiency and accuracy of tower installation.

3.2 Conductor Stringing and Traction Assistance

In recent years, the application of UAVs in transmission line construction has been continuously expanding, particularly demonstrating significant advantages in guiding and pulling ropes across natural or artificial obstacles. Traditional methods of rope pulling often face challenges such as high operational difficulty, extended construction periods, and elevated safety risks when dealing with complex terrains or sensitive areas like rivers, valleys, highways, and high-voltage lines. UAVs, with their controllable flight altitude, precise route planning, and strong anti-interference capabilities, can fly stably in complex environments and accurately deploy guide ropes. This significantly improves pulling efficiency while reducing manual labor intensity and the risks associated with high-altitude operations.

In certain mountainous projects with complex terrain, replacing traditional rope-throwing methods with UAV-assisted deployment has not only effectively shortened construction periods but also increased efficiency by over 60%. Meanwhile, it has greatly reduced safety hazards during construction, demonstrating excellent technical adaptability and promising application prospects.

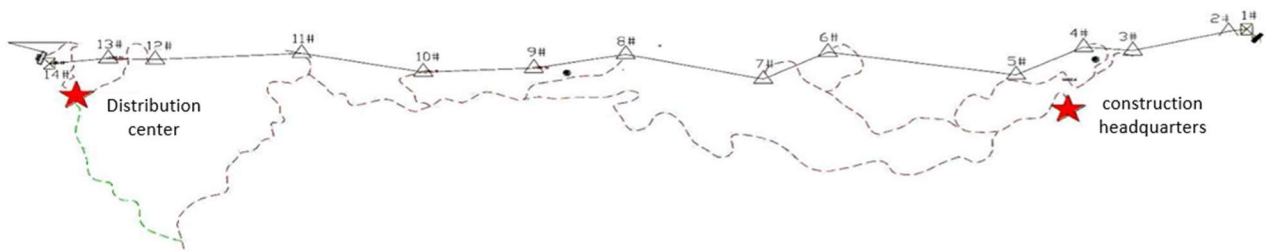


Fig. 2 Transmission Line Layout

4. Applications of UAVs in the Operation and Maintenance Phase of Transmission Lines

4.1 Inspection Operations and Image Recognition

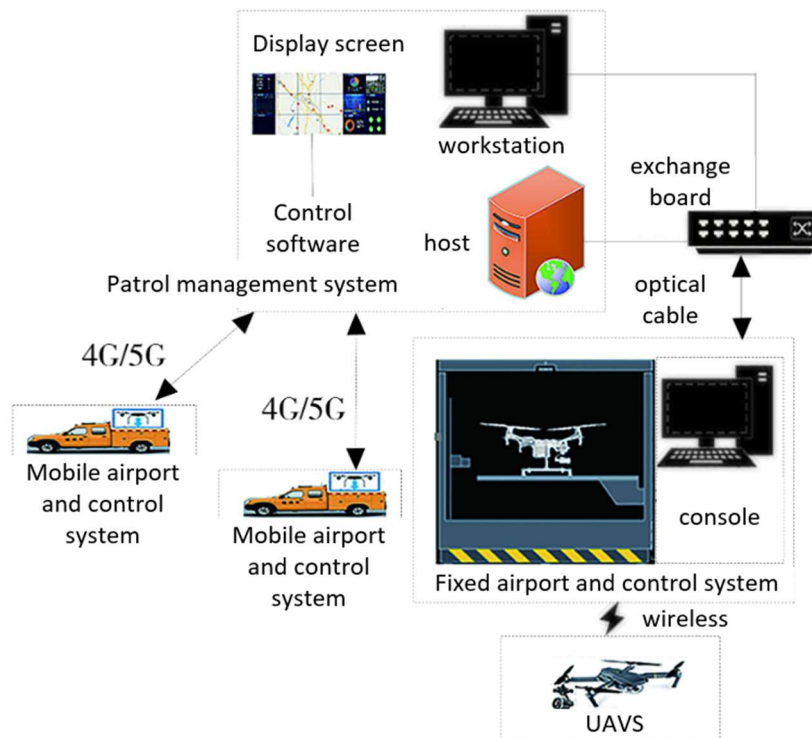


Fig. 3 Layout of Transmission Lines

UAV inspections, equipped with high-definition cameras, thermal imagers, and infrared sensors, enable image capture and defect detection of transmission line components such as conductors, insulators, and fittings. In recent years, the integration of deep learning-based image recognition algorithms in UAV inspection images has greatly improved the automation and accuracy of identifying potential faults, including broken strands, corrosion, and discharge marks.

4.2 Fault Early Warning and Integration with Intelligent Operation and Maintenance Platforms

In recent years, the application of UAV technology in transmission line construction has been continuously deepening, especially demonstrating unique advantages in guiding and pulling ropes across rivers, valleys, highways, forested areas, and other regions where traditional construction methods are difficult to apply or pose high risks. During the conductor stringing process of transmission lines, crossing obstacles with guide ropes is a critical step. Traditional methods such as manual rope throwing, balloon-assisted pulling, or mechanical rope launching are not only highly constrained by terrain but also suffer from low operational efficiency, strong dependence on weather conditions, and elevated safety risks.

In contrast, UAVs possess controllable flight trajectories, strong hovering stability, and high operational flexibility, enabling them to accurately fly over obstacle areas along preset routes and precisely deploy traction ropes at designated locations. This significantly improves work efficiency and construction safety. Practice has shown that in projects involving complex mountainous terrain or frequent obstacle crossings, using UAVs for guide rope deployment increases construction efficiency by more than 60% compared to traditional methods. It not only substantially shortens the deployment cycle but also greatly reduces the frequency of workers operating in hazardous environments such as high altitudes and steep slopes, demonstrating excellent engineering adaptability and promotion value. With the continuous advancement of UAV intelligence, its application prospects in transmission line construction will become even broader.

5. Key Technological Challenges and Future Outlook

Although UAV applications in the transmission line sector have achieved significant progress, numerous challenges remain. On one hand, the anti-interference capability of flight control systems and multi-UAV coordination mechanisms still require improvement. On the other hand, due to the complex electromagnetic environment and high-voltage induction, UAV flight stability and safety assurance remain key research focuses. Meanwhile, image recognition algorithms face limitations in robustness under complex backgrounds, few-shot learning, and model generalization.

In the future, UAVs will continue to develop toward more intelligent flight platforms, diversified mission payloads, and integrated platform systems. By integrating 5G communication, artificial intelligence, edge computing, and high-precision navigation systems, UAVs will play a greater role in power grid equipment inspection, fault emergency response, and post-disaster assessment. Technologies such as long-endurance, wind-resistant UAVs and swarm coordinated flight will also be promoted in long-span and ultra-high-voltage transmission lines.

6. Conclusion

This paper comprehensively reviews the typical application scenarios and key technological pathways of UAVs in the three phases of overhead transmission line design, construction, and operation & maintenance, systematically summarizing their technological evolution and development trends in power grid engineering practice.

In the design phase, UAVs combined with remote sensing, surveying, and 3D modeling technologies have improved the accuracy and efficiency of route planning. During construction, UAVs assist in precise management and risk control through tower site selection, conductor stringing, and construction monitoring. In the operation and maintenance stage, UAVs employ high-resolution

image acquisition, infrared thermography, and AI-based recognition to conduct aerial inspections, fault diagnosis, and hidden hazard detection, significantly enhancing maintenance efficiency and the safety and reliability of grid operation.

Although current challenges remain in UAV adaptability to complex weather conditions, autonomous navigation accuracy, data fusion and processing capabilities, and standardized operational systems, with the integrated development of artificial intelligence, remote sensing, 5G communication, and edge computing technologies, UAVs are expected to further expand their depth and breadth in full lifecycle power grid management, becoming a critical technological force supporting smart grids and digital transformation.

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