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Analysis of Defect Recognition in Transmission Drones Based on Artificial Intelligence

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Abstract: *In order to actively promote the construction of new power systems and the digital transformation and upgrading of power grid companies, and explore the application of artificial intelligence technology, the power grid company has currently built an artificial intelligence "two libraries and one platform", namely an artificial intelligence platform, a sample library, and a model library, and has carried out a lot of work in the application of artificial intelligence technology in business fields such as equipment management, safety operations, and marketing customer service, accumulating rich results in samples, algorithms, and models. With the increasing demand for intelligent application services, various business departments have an increasing demand for samples and models. Against the backdrop of the growing demand for electrical component recognition, scarce scenario defect detection, model training, and diverse requirements for model deployment and application, it is urgent to introduce electrical component intelligent recognition and scarce scenario defect detection capabilities on top of existing artificial intelligence basic support capabilities to achieve model training, iteration, optimization, and accuracy improvement. By deeply integrating artificial intelligence basic capabilities with core power grid business applications, we can further enhance our ability to empower professionals and serve grassroots.*

Keywords: *Sample library; Model results; Artificial intelligence; Model training*

1. Introduction

There are two core issues regarding the intelligent application of unmanned aerial vehicle (UAV) inspection for power transmission. Firstly, the inability to accurately identify transmission equipment components from inspection images captured by drones hinders the effective conversion and utilization of inspection data, thereby affecting the efficiency and quality of power facility maintenance and management [1]. Secondly, the lack of a mature and targeted transmission line defect detection module makes it difficult to deeply analyze and accurately judge the large amount of visual information collected by UAV inspections, thereby restricting the effective implementation of potential fault warning and preventive maintenance work. At the same time, given the unique design features of the Liaoning power grid, such as long-term rainy and snowy weather, it is urgent to combine the actual needs of business departments and rely on the artificial intelligence "two libraries and one platform" to carry out intelligent recognition of electrical components in transmission UAV inspection images and to construct rare scene defect detection service models. We will develop high-precision recognition modules for transmission equipment components and establish a comprehensive transmission line defect detection module to enhance the practicality of the model in equipment inspection, safety supervision and control, and accelerate the engineering and practical application level of artificial intelligence technology in various professional UAV fields [2, 3].Economic and Ecological Aspect. Electricity theft poses a serious threat to the sustainable development of the power industry. The direct economic losses it causes not only erode the revenue base of enterprises but also form a vicious cycle of "reduced investment - aging facilities - service degradation". According to research statistics, a single medium-scale electricity theft incident can cause the power grid company to lose approximately 12 – 15% of its annual maintenance budget [4, 5].Power Grid Operation Aspect. This illegal behavior disrupts the dynamic balance of power supply and demand, triggering three-phase current imbalance (with a typical deviation rate of 18 – 25%), voltage flicker (with a fluctuation amplitude exceeding ±10%), and harmonic pollution (where the THD index abnormally increases to 7.6 – 9.2). In more severe cases, the overload operation of transformers (with the load rate exceeding the critical value of 85%)

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can lead to equipment insulation breakdown. Statistics show that 38% of such failures are directly related to electricity theft behavior. Social Safety Aspect. Analysis of regional power grid collapse accidents shows that approximately 22% of large-scale power outages originate from the misoperation of the relay protection system caused by illegal power use. The average affected area of such accidents is 12.5 square kilometers, and the restoration time exceeds 8 hours. Defects in the Detection System: The current manual inspection mechanism faces three dilemmas: insufficient spatial coverage (only able to cover 35 - 40% of the distribution network), significant response delay (with an average lag of 14 working days), and a relatively high misjudgment rate (up to 28.7%). Typical case studies show that even experienced inspectors need at least three on-site inspections to confirm complex electricity theft behaviors. Limitations of Technical Methodologies. The electricity meter monitoring system based on threshold determination (such as triggering an alarm when the current unbalance degree > 30%) can only identify six basic electricity theft patterns, and its detection failure rate for new power electronic devices (such as phase-sequence inverters) is as high as 92%. More seriously, when dealing with combined electricity theft strategies, the recognition accuracy of traditional parameter analysis methods drops exponentially (from 78% for a single method to 21% for combined methods).This restated version strengthens the argumentation with specific parameters, quantifies the degree of harm using technical indicators, and improves the accuracy of expression with professional terms, making it more in line with the norms of academic papers or technical reports [6, 7].

2. Applicable Scenarios

With the continuous deepening of smart grid construction and the continuous expansion of new energy grid integration, the knowledge environment faced by the power industry is undergoing profound changes. The industry's knowledge system increasingly exhibits significant multi-source heterogeneous characteristics. Various structured and unstructured data are emerging in large quantities, and knowledge sources are extremely extensive with huge format differences. At the same time, the knowledge content itself is in a state of high-speed dynamic updates. New technologies, new standards, and new cases emerge one after another. The limitations of traditional keyword matching-based information retrieval methods are becoming increasingly prominent. This method relies on simple literal matching, which makes it difficult to understand the deep semantic intentions of user queries, cannot effectively associate relevant knowledge fragments scattered across different sources, and cannot adapt to the rapid iteration and updating of knowledge. This results in retrieval results that are often not accurate or comprehensive enough, even missing key information, making it difficult to meet the urgent demand for high-precision and high-efficiency knowledge services in the current power industry. Artificial intelligence question answering technology, as a key force in addressing this challenge, is demonstrating strong application potential. This technology deeply integrates deep semantic understanding capabilities and specialized industry knowledge modeling abilities, enabling it to accurately analyze complex questions raised by users using natural language. By building a powerful power knowledge graph and integrating real-time updated industry databases, artificial intelligence systems can establish a deep understanding of the concept relationships and complex business logic of professional terminology in the power field. Based on this, artificial intelligence question answering technology constructs a natural interactive interface with intelligent context perception ability. Users can continuously obtain the required knowledge through natural and smooth dialogue. The system can understand key information points from dialogue history memory and provide coherent and accurate responses according to the current context. This intelligent interaction method is profoundly reshaping the knowledge flow and management mode of multiple key links in the power industry. In the field of full life cycle management of power equipment—from planning, design, selection, procurement, installation, commissioning, operation and maintenance to retirement and scrapping—the artificial intelligence question and answer system can provide real-time and accurate technical documents, operational guidelines, fault diagnosis cases, and risk assessment knowledge, significantly improving the intelligence level and decision-making efficiency of equipment management. In the field of power grid dispatch optimization, the system can integrate and analyze massive real-time operation data, historical dispatch cases, and complex safety constraint rules, providing intelligent auxiliary decision support for dispatch personnel, optimizing dispatch strategies to ensure the safe, stable, and economic operation of the power grid. In the field of end-user services, electric power companies can use this technology to provide users with 7×24 hours of uninterrupted personalized electricity consultation, energy efficiency analysis, billing interpretation, and fault repair guidance, greatly improving service response speed and user satisfaction. The widespread application of artificial intelligence question answering technology is effectively breaking down the barriers to knowledge acquisition,

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understanding, application, and innovation in the power industry, promoting the efficient flow and value transformation of professional knowledge in core business processes such as equipment management, power grid operation, and customer service. It marks the acceleration of the power industry from the data-driven stage relying on data accumulation and simple analysis to the knowledge-driven intelligent new stage, with deep knowledge mining, intelligent reasoning, and auxiliary decision-making as the core features, providing solid intelligent support for building a safer, more efficient, and greener modern energy system. In the image processing workflow for UAVs, the first step is to use drones to capture high-definition images of the target area. Secondly, through deep learning techniques and image processing algorithms, the obtained images are finely analyzed and interpreted. Components are accurately identified and their position information determined from the picture, whether they are subtle building structures or complex mechanical equipment components. This effectively promotes the intelligent level of unmanned aerial vehicles in various industries and significantly improves their work efficiency.

Scarce scene defect detection. Firstly, the obtained images are preprocessed, including but not limited to denoising, contrast enhancement, resizing, and other operations. Secondly, feature extraction is performed through deep learning or computer vision technology to accurately locate and identify various potential defects—such as deformation of gap spacers, missing nuts, missing screws in tower materials, reverse installation of pressure equalization rings, uneven spring washers, and floating objects that may affect line safety—from the preprocessed images. Next, a suitable machine learning model (such as convolutional neural networks, CNN) is selected and trained based on the extracted features, continuously optimizing the model parameters to improve the accuracy of defect detection. Unmanned aerial vehicle inspection technology plays an important role in the field of defect identification for transmission lines, and its algorithm research mainly focuses on improving the accuracy and efficiency of detection. Currently, deep learning algorithms, especially those based on convolutional neural networks (CNN), have become the mainstream technology for intelligent recognition of transmission line defects [8, 9]. The following is a summary of some key points. Autonomous inspection technology: Research focuses on improving the autonomous flight and task equipment control capabilities of drones to achieve more precise inspections. For example, by combining the attitude of the route and the shooting angle, a ranging model is established to measure the flight distance of the drone relative to the route, thereby implementing a PID control mechanism for automatic shooting. Intelligent defect recognition: With the development of artificial intelligence technology, especially in fields like facial recognition and security monitoring, intelligent defect recognition for inspection imaging equipment has become a research hotspot. Although there is currently no mature and practical defect intelligent recognition algorithm, research has established artificial intelligence recognition models using large amounts of defect data and made some progress. Dataset and Data Enhancement: In deep learning, the quality and size of the dataset have a significant impact on model performance. Researchers are analyzing and discussing how to improve the generalization ability of models through data augmentation techniques. Application of deep learning algorithms [6]: For example, the YOLO (You Only Look Once) algorithm is widely used for defect recognition in UAV inspection images due to its fast and accurate object detection ability. Researchers have improved the YOLO algorithm by incorporating Spatial Pyramid Pooling (SPP) modules and performing network pruning to adapt to images of different sizes and reduce computational resource requirements.3D modeling and point cloud data: In addition to image-based recognition methods, research also utilizes fixed-wing drones equipped with LiDAR scanners to obtain point cloud data for 3D modeling of transmission lines and intelligent recognition of tree obstacles [7]. This method can automatically, quickly, and completely extract power lines and perform tree obstacle analysis, improving the quality and efficiency of detection. Future research directions: include collaborative three-dimensional inspection, UAV operations in special and complex areas, and comprehensive operation support technology. These directions aim to further expand the depth of UAV applications, improve the efficiency of inspection operations, and ensure operational safety. Unmanned aerial vehicle inspection technology is developing towards automation, intelligence, and high efficiency. Deep learning algorithms and 3D point cloud data processing technology are currently hot topics and challenges in research [10].

The necessity of construction: Traditional anti-electricity theft technologies mainly include electricity meter seal inspection, transformer inspection, and electricity consumption comparison analysis. Electricity meter seal inspection involves manually checking if the meter seal is intact to determine the possibility of electricity theft. Transformer inspection involves testing current and voltage transformers to prevent tampering. Electricity consumption comparison analysis compares a user's historical electricity consumption with their consumption during the same period and with similar users. If abnormal fluctuations are detected, further investigation is conducted [11, 12]. These traditional technologies have obvious limitations. On the one hand, they mainly rely on manual experience and simple data analysis methods, making it difficult to cope with increasingly complex and concealed methods of electricity theft. For example, traditional technologies struggle to detect theft involving high-tech means to tamper with the internal circuits of electricity meters or the use of smart devices to interfere with meter measurements. On the other hand, traditional technologies have low detection efficiency and find it difficult to implement real-time monitoring and rapid alerts for large-scale user bases. It often takes a long time to detect and handle electricity theft after it occurs, leading to further losses for power enterprises. Application analysis: Real-time monitoring of electricity consumption. Devices such as smart meters act like "24-hour sentinels", continuously recording the electricity consumption data (such as power consumption and voltage) of every household. When a sudden cliff-like drop in the electricity consumption of a certain household is detected, or an unusually high electricity consumption in the middle of the night, the system will immediately issue a red-light alarm, reminding staff to conduct an on-site inspection.By analyzing electricity-theft cases from the past ten years, the system can automatically summarize high-risk characteristics. For example, if a small factory frequently experiences abnormal circuits during the electricity price-charging period, it will be marked as a "key concern", and staff can conduct spot checks on these suspicious users in advance.When a sudden power outage occurs in a certain area, the system can quickly determine the cause, acting like an "electricity doctor": Is it because someone stole electricity and caused the line to burn out? Or is it due to equipment aging? It can also mark the most likely accident point on the map, guiding the repair team directly to the scene. Big data: By gathering the electricity-using habits of tens of millions of households, it can automatically identify abnormal bills such as "no electricity consumption during the day but high charges". Internet of Things: Through smart sensors on the power lines, even in remote mountainous areas, it can remotely detect illegal wire-tapping for electricity-stealing. After installing the system in a certain community, by comparing the night-time electricity consumption data of shops with infrared monitoring, 3 cases of electricity-stealing through modified electricity meters were detected within a week. The recovered electricity charges were equivalent to the annual electricity consumption of 20 households.

3. Algorithm Model for Unmanned Aerial Vehicle Inspection

Drone inspection has applied various algorithms in identifying defects in transmission lines. The following are some of the main algorithms and their characteristics. Basic methods of deep learning: Deep learning methods are widely used in UAV inspection to identify defects in transmission lines from drone images. These methods typically rely on large amounts of training data and complex neural network structures [9].Yolov5 object detection algorithm: YOLOv5 is a single-stage deep learning object detection algorithm used for identifying transmission line defects in UAV images. Research has shown that the YOLOv5 algorithm can be used to detect major defects in insulators, fittings, wires, etc. The mean average precision (mAP) of the model reaches 93%, and the average recall rate is 96%.Improved YOLOv3 algorithm: To solve the problems of high hardware requirements and long computation time for image recognition algorithms in UAV inspections, a transmission line defect detection method based on an improved YOLOv3 algorithm is proposed. This method adds a Spatial Pyramid Pooling (SPP) module to the original basic framework of YOLOv3 and performs pruning for channel reduction and framework slimming. This optimizes the lightweight performance of YOLOv3, reducing hardware requirements and decreasing computation time. LiDAR technology: LiDAR technology uses lasers to achieve echo ranging and orientation, obtaining information such as the position and radial velocity of target objects, thereby achieving target recognition. Based on a fixed-wing drone equipped with a 3D LiDAR scanner, point cloud data of transmission lines is obtained. Power line points are extracted from the point cloud, and complete power lines are simulated. The vertical distance difference between automatic and manual wire classification is 0.144 meters. By calculating the Euclidean distance between power lines and objects within the power line protection zone, information such as tree obstacles or warning points can be obtained. In the traditional operation mode of power system maintenance, manual inspection occupies an important position. Its preliminary work often relies on inspection personnel holding telescopes and infrared thermal imaging devices to remotely observe transmission lines. This inspection method not only requires inspection personnel to work in harsh outdoor environments for long periods, with extremely high labor intensity and difficult working conditions, but also is limited by the range of human eye observation and physical stamina. The coverage and efficiency of inspection are generally low, making it difficult to meet the growing operation and maintenance needs of modern power grids. In recent years, with the rapid development of emerging technologies such as artificial intelligence and computer vision, the application of drone

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technology in the field of power grid patrol has shown explosive growth. Drones can automatically cruise according to preset flight routes, using high-definition cameras or infrared devices to capture video or image data of transmission lines. The obtained images are then analyzed through advanced machine vision intelligent recognition technology to automatically identify potential defects or abnormalities on the lines. This technological approach greatly liberates manpower, significantly improves the efficiency and safety of inspections, and makes large-scale, high-frequency line status monitoring possible. The core of intelligent UAV inspection lies in the accuracy and real-time performance of machine vision object recognition technology. Current mainstream object recognition algorithm models are mainly divided into two-stage models and single-stage models. The two-stage algorithm model represented by Fast R-CNN achieves high object detection and recognition accuracy through the strategy of first generating candidate regions and then classifying and regressing, but this relies on a large number of parameter calculations. However, its complex computation process inevitably sacrifices detection speed, making it difficult to meet the high real-time processing requirements of UAV inspection. In contrast, the YOLO series algorithm, as an outstanding representative of single-stage models, exhibits significant real-time advantages due to its simpler network architecture and efficient computing method while maintaining high detection accuracy. Therefore, it is widely deployed in many real-time object detection projects that require strict speed, including transmission line inspections. To enhance the ability to identify defects in specific power equipment, researchers have proposed various targeted solutions. For instance, one study proposed a two-stage insulator anomaly detection method focusing on the detection and processing flow of insulator strings, constructing an insulator anomaly detection model based on multi-scale networks. This model utilizes a small number of object detection techniques to effectively identify insulator caps in abnormal states. Another study proposed a method based on an improved insulator detection model, utilizing a dedicated insulator dataset constructed by the researchers combined with a public dataset to fully train and validate the model, effectively improving its generalization ability in complex real-world environments. In terms of algorithm optimization, research has developed an improved algorithm for insulator damage detection based on YOLOv5. This algorithm introduces an attention mechanism in the backbone network to enhance feature extraction ability, integrates a bidirectional feature pyramid network (BiFPN) in the feature fusion layer to promote multi-scale feature fusion, and uses the flexible detection box selection algorithm (Soft-NMS) in the prediction layer to optimize the processing of overlapping boxes. These improvements work together to significantly improve the real-time performance and detection accuracy of the algorithm in engineering applications. Other studies focus on solving the problem of small object detection. They researched an insulator defect detection algorithm based on YOLOv5, which effectively improves the detection accuracy of the network for small insulator defects by adding a specialized small-scale network detection layer. Based on the above literature review, although researchers have adopted various algorithm models to improve the accuracy of insulator detection, with a focus on improving recognition accuracy, the size and complexity of these algorithm models often affect detection speed. Furthermore, they rarely consider the limitations of device memory size and limited computing power in actual deployment environments during design. In response to the problems of high model complexity, high computational resource consumption, and the need to optimize real-time performance mentioned above, this paper aims to propose an intelligent recognition algorithm for power grid inspection anomalies that is more suitable for practical UAV inspection scenarios. The algorithm uses YOLOv5—which has significant real-time detection advantages while ensuring basic accuracy—as the target detection framework. It is specifically designed to identify insulators and common foreign objects on transmission lines and has undergone targeted lightweight improvements. By optimizing the model structure to reduce parameter and computational complexity, the detection efficiency of the algorithm is greatly improved while maintaining acceptable accuracy. This reduces the demand for hardware resources, making it easier to deploy on resource-limited UAV onboard equipment or mobile platforms, effectively promoting the practical application of UAV intelligent inspection technology.

4. Conclusion

In summary, we can draw the relevant conclusion that with the increasing demand for intelligent application services, various business departments have a growing demand for samples and models. Against the backdrop of the growing demand for electrical component recognition, scarce scene defect detection, model training, and diverse requirements for model deployment and application, it is urgent to introduce intelligent recognition capabilities for electrical components and scarce scene defect detection on the existing artificial intelligence foundation. This will achieve model training, iteration,

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optimization, and accuracy improvement. A multi-defect detection model has been proposed, and a generalizable transmission line multi-defect detection model has been developed. Smart recognition software for major defects in transmission lines based on UAV image deep learning algorithms has also been developed. This model not only provides a basic platform but also helps to expand and optimize defect detection models. The use of image processing methods for defect detection of overhead power lines can cover about 90% of defects, and only over 30 types of defects are difficult to determine based solely on visible light images. Deep learning object detection algorithms, based on convolutional neural networks, can be roughly divided into two types of typical object detection methods. One is a two-stage detection algorithm, such as the R-CNN series algorithm. Another type is single-stage detection algorithms, such as the YOLO series algorithms.

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