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Quality inspection technology of solar-powered drones based on artificial intelligence

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ABSTRACT
Solar-powered drones have great environmental monitoring and communication relay potential due to their long endurance and low energy consumption. However, material fatigue, structural damage and battery aging caused by long-term exposure to complex environments seriously threaten flight safety and service life. Therefore, this paper discusses the key technologies and specific applications of artificial intelligence in the quality inspection of solar-powered drones to provide technical solutions for the reliability improvement and intelligent operation and maintenance of solar-powered drones and promote the development of green aviation technology.

KEYWORDS
Artificial Intelligence; solar-powered drones; quality inspection; battery aging assessment

Solar-powered drones can convert solar energy into electricity through efficient photovoltaic systems and fly continuously in the stratosphere for several months. They are widely used in meteorological observation, disaster medicine, and Border Patrol. The traditional quality inspection method visually inspects the appearance of cracks. It uses portable instruments to measure local parameters, which is not only time-consuming and labor-intensive but also difficult to capture, as well as microscopic damage inside the material. Moreover, the existing inspection technology lacks real-time and predictability and can not dynamically evaluate the state of the drones during flight. The potential safety hazards are difficult to eliminate in time. The introduction of Artificial Intelligence Technology provides a breakthrough direction for solving the above problems. Artificial intelligence can collect multi-dimensional data in real-time through sensor networks and extract deep features related to the device's health status, which provides a scientific basis for maintenance decision-making, greatly reduces the cost of operation and maintenance, and improves flight safety. Based on this, this paper will focus on exploring the key technology path of artificial intelligence in the quality inspection of solar-powered drones, focusing on solving the core problems of structural health monitoring and battery aging assessment. It helps the development of green aviation technology and provides a reference paradigm for the health management of other high altitude long endurance equipment.

1 Overview of solar-powered solar-powered drones

1.1 Definition and characteristics of solar-powered drones

Solar-powered drones have the advantages of ultra-high altitude, long endurance, and easy support. The design indexes are deeply coupled with the energy parameters, especially the solar-powered drones in near space, which have the characteristics of high flight altitude. During the day, the solar panels convert sunlight into electricity, some of which are used to drive the propellers, and some are stored in the batteries for use at night, without frequent landings to recharge or refuel. Compared with conventional drones, solar-powered drones have three distinct features: first, they"Fly high," usually operating at an altitude of 20-30 km, an area known as near space. At this altitude, the air is thin and steady, and the drones are less likely to be disturbed by the weather. Second, they"Stay" long. Solar-powered drones can absorb sunlight 24 hours a day and convert it into power for weeks. The third is"Affordable". Although the initial research and development costs are high, solar-powered drones need only a small amount of maintenance and do not require fuel consumption. A common flight mode for solar-powered drones is to climb higher during the day to accumulate potential energy and glide lower at night to reduce energy consumption [1].

1.2 The application fields of solar-powered drones

The application scenarios of solar-powered drones are mainly divided into two categories: disaster emergency communication and the other is remote area coverage. When an earthquake, flood or other disaster knocks out a ground station, solar-powered drones can fly over the disaster area in less than two hours, each providing 4G/5G coverage with a radius of 50 km. In the 2023 Turkish earthquake, three solar-powered drones worked continuously for 12 days to provide emergency communications services to the victims. In uninhabited areas such as oceans and deserts, solar-powered drones could provide internet access for research ships, mining camps, etc. In the study of climate change, drones equipped with multi-spectral cameras can take high-definition images of polar ice caps and tropical rainforests every week and compare and analyze the rate of glacier melting and the degree of forest degradation; it provides scientists with visual data that can guide decision-making. Regarding disaster warning, solar-powered drones equipped with lidar can monitor crater deformation in real-time, and thermal imagers can detect hidden fire spots in the early stage of wildfires. In the Mount Fuji Monitoring Project in Japan, solar-powered drones have detected abnormal changes in the composition of volcanic gas in advance, which has bought valuable time for evacuating surrounding residents and greatly reduced the losses caused by the disaster.

2 The application of artificial intelligence technology in solar-powered drones

2.1 The role of deep learning algorithms in solar panel inspection

In the long-term high-altitude operation, the solar panel will be slightly damaged by environmental erosion and mechanical stress, gradually expanding and interrupting the energy supply. Each solar panel generates a specific current and voltage change curve when generating electricity, and these curves reflect the state of health. Based on this, a multi-layer neural network model can be constructed based on deep learning algorithms, automatically parsing the complex data generated by the operation of the solar panel. The model can extract key abnormal signals from massive interference information by analyzing the correlation between multi-dimensional data, achieving precise positioning, and intervening and remedying in time [2]. Deep learning algorithms can also dynamically optimize for different flight phases and environmental conditions. When the light is reduced due to cloud cover, the model prioritizes the allocation of limited power to the core components needed to maintain the flight altitude while reducing the power consumption of non-essential equipment; after the light is restored, the model quickly switches to the maximum power tracking mode. Thus, drones can maintain stable operation in complex climatic conditions.

2.2 Application of image recognition technology in drones quality inspection

Image recognition technology equipped with a high-resolution camera can collect the vision information of the surface and internal structure of the drones and realize automatic defect inspection combined with an artificial intelligence model. In the quality inspection process, the image recognition system can scan each part at 360 degrees and accurately locate the scratches and assembly errors by comparing the pixel differences between the standard template and the real-time image . Also, multi-spectral imaging is used to find the material's internal delamination defects, achieve comprehensive testing, and provide a complete and accurate test report. Combining image recognition technology and augmented reality (AR) in daily maintenance can improve maintenance accuracy. After the maintainer wears the AR glasses, the camera will film the drone parts in real-time, and the image recognition model will immediately mark the aging screws, oxidation joints and other parts. For key components such as battery packs and motors, this technology can predict the degree of wear based on historical maintenance data and overlay virtual markers in the AR interface to highlight areas that require special inspection, transforming complex maintenance processes into intuitive visual guidance, thereby significantly reducing the difficulty of maintenance operations.

2.3 The combination of thermal imaging and RGB imaging technology

Thermal imaging technology is a technique that uses the infrared radiation emitted by objects to detect their temperature and heat distribution. The RGB imaging principle is a key technology that combines the three primary colors —red, green, and blue—in different intensities and proportions to achieve full-color image display and capture. Combining these two technologies provides solar-powered drones with multi-dimensional environmental perception capabilities. When solar-powered drones fly at night, thermal imaging can identify mountain outlines to avoid collisions, and RGB cameras use moonlight to fill in terrain details; when detecting high-voltage transmission lines, thermal imaging can spot overheating insulators, the RGB images help locate specific trouble spots, enabling high-precision navigation and target recognition [3]. In forest fire monitoring, thermal imaging can identify high-temperature areas in real-time by capturing surface infrared radiation. RGB imaging can clearly show smoke morphology and color characteristics based on visible light bands. White smoke indicates vegetation burning, and black smoke indicates the burning of oil-containing substances, thus assisting the development of Fire Response Plans. Relying on long-term endurance, solar-powered drones can achieve all-weather and large-scale cruise. The artificial intelligence system automatically marks the fire point's location and the fire spread trend and generates an early warning report to shorten the emergency response time. The collaborative application of the two technologies effectively reduces the missed detection rate and the risk of misjudgment and greatly improves the accuracy and efficiency of rescue.

3 The application of quality inspection technology for solar-powered drones based on artificial intelligence

3.1 Automatic identification of material surface defects

The material surface defects of solar-powered drones directly affect their structural strength and flight safety. Artificial intelligence technology, high-resolution cameras, and edge inspection algorithms can be used when detecting material surface defects. Among them, the high-resolution camera can capture the surface of the drone materials with micron-level accuracy. After obtaining the image, the artificial intelligence model analyzes the texture features of the image, and regular patterns and abnormal patterns are identified. The edge inspection algorithm further strengthens the edge recognition of the pattern contour to determine the defect type and provide the basis for the subsequent processing. Because the defects of drone materials do not easily appear due to light reflection, surface reflection, shadow interference, etc., the artificial intelligence model can automatically switch the light source from different angles or change the focal length of the camera; it can effectively eliminate the interference of reflection and shadow on the inspection. The model can also accumulate the defect evolution law of different materials in different environments through continuous learning and improve detection sensitivity [4].In continuous learning, the model automatically records the morphological changes of material defects under different environmental conditions and compares the newly detected defect data with the historical data; the recognition threshold and feature weights are dynamically adjusted. This process significantly reduces the missed detection rate of traditional manual sampling and meets the inspection requirements of drones under complex working conditions. The inspection results can also be synchronously fed back to the production side to guide the adjustment of process parameters.

3.2 Real-time monitoring and early warning of structural health

During the flight, solar-powered drones are subjected to multiple pressures such as airflow impact, temperature change, and mechanical vibration, and the small damage inside the structure gradually accumulates into a fatal risk. Artificial intelligence technology can continuously capture the subtle changes inside the material through sensor networks distributed on the wing, fuselage and joints. When the internal fracture of the carbon fiber reinforced polymer (CFRP) of the drones occurs, the vibration frequency will deviate from the normal range, and the metal fatigue at the aluminum alloy joint will cause local stress anomaly. After the artificial intelligence model detects the energy mutation of the specific frequency band in the vibration spectrum and the asymmetric distortion signal of the stress distribution curve, it will immediately mark the abnormal area and trace the source of damage through the algorithm. Thus, the maintenance personnel will be alerted to the relevant treatment. The artificial intelligence model can also deeply analyze the data generated during the operation of solar-powered drones and the trend of the data. At the same time, the physical model of damage propagation can be combined to predict the speed of failure development and the risk level after the failure. When the risk index is detected to exceed the safety threshold, the system will directly issue an early warning signal, and the drone's control console will immediately receive this signal to adjust the flight and plan an emergency landing path. This greatly reduces the probability of safety risks caused by structural damage to drones and earns maintenance time for ground personnel.

3.3 Assessment of the aging degree of solar panels

The aging of solar panels is mainly manifested in decreased photoelectric conversion efficiency. Usually, the defects of semiconductor materials caused by aging will gradually shift the maximum output power point to the left, the electrode oxidation will increase the circuit's internal resistance, and the voltage curve collapses in the high-load region. The operation and maintenance personnel can use artificial intelligence technology to analyze the panel's output voltage, current curves, and environmental parameters. They can also continuously monitor the changes in these electrical characteristics to construct a dynamic model of the performance degradation of the panel. The model quantifies the health index of the panel by comparing historical data with real-time waveforms, showing the wear and tear on each cell[5]. In addition to electrical parameters, AI can combine thermal and spectral data to reveal signs of aging that are invisible to the naked eye. The local aging of the panel will cause abnormal heating due to the increase in resistance, and the temperature distribution captured by the thermal imaging camera can locate the hot spot area. The degradation of packaging materials caused by UV irradiation will shift the surface reflection spectrum of drones. Maintenance personnel can use the high-precision spectrometer to analyze the wavelength distribution of reflected light and judge the deterioration degree of polymer coating. This refined assessment not only supports preventive maintenance but also provides a reference for the maintenance plan to extend the service life of the panel.

4 Conclusion

To sum up, the combination of sensor networks and artificial intelligence algorithms enables solar-powered drones to sense internal damage and warn in real time; for the aging problem of solar panels, the construction of multi-dimensional data fusion and performance degradation model can achieve accurate evaluation and provide a scientific basis for optimizing maintenance strategy. In the future, the application of a lightweight artificial intelligence model can be further explored to adapt to the computational power limitation of the drone-embedded system. A collaborative learning network across the drone cluster can be established to improve the model's generalization ability by sharing detection experience to provide more solid technical support for the large-scale application of green aviation technology.

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