ISSN: 2472-3703 DOI: 10.6911/WSRJ.202502_11(2).0005

A Drone System for PV Panel Cleaning Based on YOLOv8 and Automated Flight Path Planning

Tianyu Xie, Yutong Jiang, Chenglin Wang, Hongtao Ni*

Suzhou City University, Suzhou 215000, China

*Corresponding Author

Abstract

As photovoltaic (PV) power generation becomes increasingly important, the cleaning and maintenance of PV modules are critical for improving efficiency and extending lifespan. This paper proposes an automated PV panel cleaning system based on drones, utilizing intelligent cleaning technology to restore the efficiency of PV modules. The system consists of three main components: drones, a ground station, and a hive module. The drones are equipped with cleaning devices, water pumps, and obstacle avoidance radars, enabling autonomous task execution. The ground station uses DJI drone images, GeoServer, and the YOLOv8 algorithm to accurately identify and locate PV panels, generating flight paths automatically. The hive module provides water replenishment and charging for the drones. Experimental results demonstrate that the system effectively removes dust, dirt, and corrosive substances, such as bird droppings and acid rain residues, enhancing power generation efficiency and prolonging the lifespan of PV modules. This system offers an efficient solution for intelligent operation and maintenance of photovoltaic power plants.

Keywords

Drone, Automated Cleaning, Power Generation Efficiency, YOLOv8.

1. INTRODUCTION

Photovoltaic power generation has become an essential part of global energy production. However, dust, dirt, and pollutants accumulating on the surface of photovoltaic modules significantly affect their power generation efficiency, especially in regions prone to environmental factors like desert areas or dust storms. Traditional manual and mechanical cleaning methods are inefficient, risky, and costly, highlighting the need for more efficient, safe, and intelligent cleaning approaches. Drone technology, with its rapid development, offers a promising solution for photovoltaic module cleaning due to its flexibility and automation capabilities [1].

This paper proposes an innovative automated photovoltaic module cleaning system based on drones, combining the YOLOv8 algorithm with image recognition technology for precise identification and location of photovoltaic modules. The cleaning system is designed to autonomously plan cleaning routes and perform the cleaning tasks. The system architecture includes drones, a ground station for image collection and flight route planning, and a hive module providing services like water and battery replacement. Experimental results demonstrate that this system effectively cleans photovoltaic module surfaces, enhances power generation efficiency, and prolongs the lifespan of photovoltaic components [2].

The key contributions of this work are as follows:

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202502_11(2).0005

1. Novel Cleaning Approach: By integrating drone technology, intelligent flight path planning, obstacle avoidance radar, and cleaning devices, the proposed system offers an efficient and automated solution to PV panel cleaning, addressing the inefficiencies and high costs associated with traditional manual cleaning methods.

2. Intelligent Flight Path Planning: The system utilizes DJI drone images, GeoServer, and the YOLOv8 algorithm to accurately identify and locate PV panels, automatically generating optimized flight paths. This intelligent path planning significantly enhances cleaning efficiency, ensuring precise and reliable cleaning operations.

3. Autonomous Operation and Replenishment System: The design of a "hive module" enables autonomous operation of the drones by providing water replenishment and charging capabilities. This feature reduces the need for human intervention, ensuring continuous operation and high system efficiency over extended periods.

4. Experimental Validation and Performance Evaluation: Experimental results demonstrate that the system effectively removes dust, bird droppings, acid rain residues, and other contaminants from PV panels, thereby enhancing power generation efficiency and prolonging the lifespan of the modules. The results validate the feasibility and effectiveness of the system in real-world applications.

5. Scalability and Adaptability: The proposed system is highly scalable and adaptable to various PV plant sizes and configurations. Its intelligent and automated nature allows it to operate efficiently across different environmental conditions, making it a versatile solution with broad potential for application in the photovoltaic industry.

2. METHODOLOGY

A. Core Technologies of Drone Cleaning System

Flight control technology is one of the most critical technologies in the drone cleaning system. It determines the stability of the drone's flight, the precision of task execution, and the autonomous planning of the flight route. During the photovoltaic panel cleaning process, the drone needs to fly freely in a complex power station environment, avoid obstacles, and complete the cleaning tasks accurately. To achieve this, the drone employs a high-precision flight control system (FCS). The FCS integrates various sensors, including an Inertial Measurement Unit (IMU), barometer, GPS, and visual sensors, to ensure stability and high-precision navigation during flight. The drone's flight control system must not only maintain flight stability but also dynamically adjust the flight posture based on terrain variations. Through precise flight control, the drone can complete tasks in complex terrains, ensuring the efficiency of the cleaning process [3] [4].

(1) Flight Control Technology

Flight control technology is one of the most critical technologies in the drone cleaning system. It determines the stability of the drone's flight, the precision of task execution, and the autonomous planning of the flight route. During the photovoltaic panel cleaning process, the drone needs to fly freely in a complex power station environment, avoid obstacles, and complete the cleaning tasks accurately. To achieve this, the drone employs a high-precision flight control system (FCS). The FCS integrates various sensors, including an Inertial Measurement Unit (IMU), barometer, GPS, and visual sensors, to ensure stability and high-precision navigation during flight. The drone's flight control system must not only maintain flight stability but also dynamically adjust the flight posture based on terrain variations. Through precise flight control, the drone can complete tasks in complex terrains, ensuring the efficiency of the cleaning process[4].

(2) Navigation and Positioning Technology

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202502_11(2).0005

Navigation and positioning technology is crucial for the success of drone cleaning tasks. The drone must know its precise location to ensure it operates along the predetermined path within the power station. Modern drones are typically equipped with high-precision GPS and RTK (Real-Time Kinematic) systems, which can achieve centimeter-level positioning accuracy. This allows the drone to fly precisely above the photovoltaic panels, without deviating from the planned path or making positioning errors.

(3) Image Recognition and Sensing Technology

Image recognition and sensing technology enable drones to autonomously assess the level of contamination on photovoltaic panels and the distribution of photovoltaic arrays. Drones are equipped with high-resolution cameras or multispectral sensors that capture images of the photovoltaic panels, which are then analyzed using image processing algorithms. These algorithms are often based on deep learning and computer vision technologies, such as the YOLOv8 algorithm, which allows for rapid and accurate identification of panel locations and contaminated areas.

During the cleaning process, the drone uses real-time image recognition to determine which panels require cleaning and which have already been cleaned, enabling targeted cleaning efforts. The core technologies of this process are image segmentation and object detection. By leveraging these technologies, drones can identify each individual photovoltaic panel and assess its contamination level, allowing for dynamic adjustment of the cleaning strategy. The Photovoltaic Panel Recognition Effect Diagram is displayed in Figure 1.

Figure 1. Photovoltaic panel recognition effect diagram.

(4) Automatic Cleaning Device

The automatic cleaning device is the execution component of the drone cleaning system, and it directly affects the cleaning efficiency. Generally, the drone cleaning device includes a water tank, a spraying system, and a brushing system. The water tank of the drone needs to be large enough to ensure that the cleaning task can be completed while minimizing the number of return trips.

B. Automated System Architecture and Workflow

The automated architecture of the drone cleaning system typically consists of three main modules: the cleaning drone, the ground station, and the hive module. Each module works in coordination to complete the cleaning tasks of the photovoltaic power station. The System architecture is displayed in Figure 2.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202502_11(2).0005

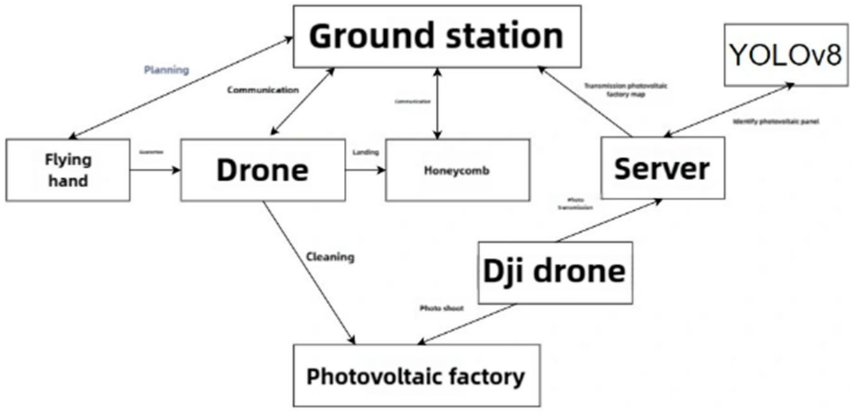

Figure 2. System Architecture.

(1) Cleaning Drone Module

The cleaning drone module is the core component of the entire system, responsible for the actual cleaning of photovoltaic panels. This module is equipped with an efficient cleaning system (including a water tank, spraying system, and sensors) that enables autonomous flight and cleaning operations.

The workflow of the cleaning drone is as follows:

1. Route Planning: The ground station uses aerial photography to capture images of the photovoltaic power station. The YOLOv8 algorithm is applied to identify the locations of the photovoltaic panels and generate a coordinate map. This map is then sent to the drone by the ground station, serving as the basis for the cleaning route planning.

2. Autonomous Flight and Cleaning: The drone autonomously follows the pre-planned route and, during the flight, utilizes onboard image recognition technology to continuously monitor the pollution level and accurately identify areas of the photovoltaic panels that need cleaning. After completing a cleaning task, the drone automatically determines whether it needs to return to the hive module for water and power replenishment.

3. Return and Task Resumption: If the drone's water supply is insufficient or the battery level falls below the set threshold, the system triggers a return command to guide the drone back to the hive module for replenishment. Once the replenishment is complete, the drone resumes the remaining cleaning tasks[4].

(2) Ground Station Module

The ground station module is responsible for monitoring and controlling the entire cleaning task, playing a role in task scheduling, data processing, and system communication. The main functions of the ground station include:

Map Generation and Route Planning: The ground station generates a map of the photovoltaic power station using aerial photography and image processing technology, and then plans a reasonable flight route based on the distribution of the photovoltaic panels[5].

Task Scheduling and Monitoring: The ground station can monitor the cleaning progress in real-time, checking the drone's operational status and flight trajectory. If any abnormalities occur, the ground station can promptly adjust the task or send new instructions to the drone.

Task Result Feedback and Optimization: After the cleaning task is completed, the ground station receives data feedback from the drone, analyzes the cleaning results, and optimizes and adjusts subsequent tasks accordingly[6]. The route generation and generated image are displayed in Figure 3 and Figure 4.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202502_11(2).0005

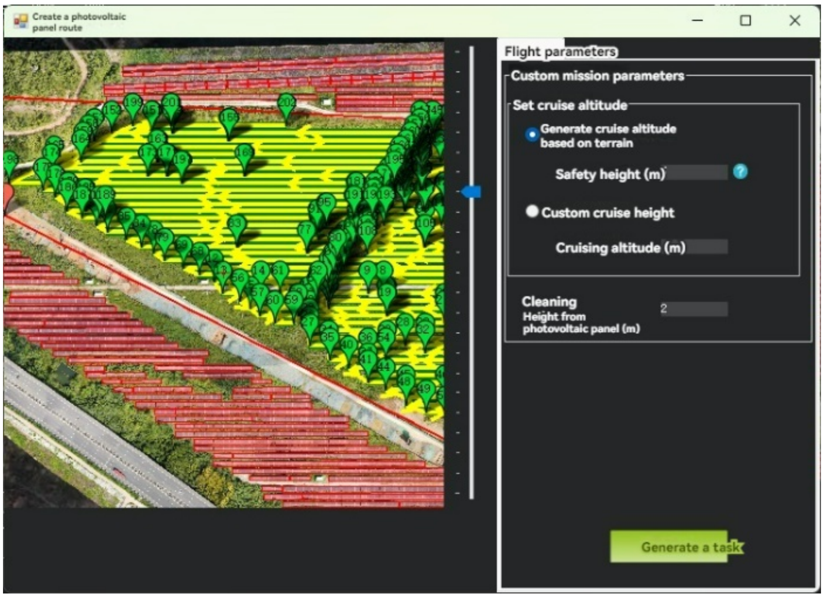

Figure 3. Route generation.

Figure 4. Generated image.

(3) Hive Module

The hive module, as the logistical support unit of the system, is responsible for providing water and battery replacement for the drones. The main functions of the hive module include:

1. Water Supply: When the drone's water tank is depleted, the hive provides a water source to ensure the drone can continue with the cleaning task.

2. Battery Replacement: If the drone's battery charge falls below a set threshold, the hive module will replace the battery to ensure its endurance.

3. Data Communication and Collaborative Operation: The hive is connected to the communication systems of the ground station and the drone via TCP/IP protocol, ensuring smooth information flow and a timely response to the drone's return and task needs.

C. System Advantages and Innovations

The automation advantages of the drone cleaning system lie in reducing manual operations, improving efficiency, and lowering costs. The following are its main innovations:

(1) Efficiency

The drone cleaning system can autonomously fly and perform tasks efficiently, saving a significant amount of human resources while improving task execution accuracy. Compared to traditional manual cleaning or mechanical cleaning equipment, drones can quickly cover a large

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202502_11(2).0005

area of photovoltaic panels while working at high altitudes, avoiding operational challenges faced by ground equipment due to terrain or weather conditions[8].

(2) Intelligence and precise control

The drone cleaning system utilizes image recognition, sensor technology, and flight control systems to enable intelligent operations. It can precisely locate the areas of photovoltaic panels that need cleaning and adjust the cleaning strategy based on real-time conditions. The intelligent navigation system ensures that drones can perform tasks efficiently and accurately within the photovoltaic power station[10]. The Flowchart is displayed in Figure 5.

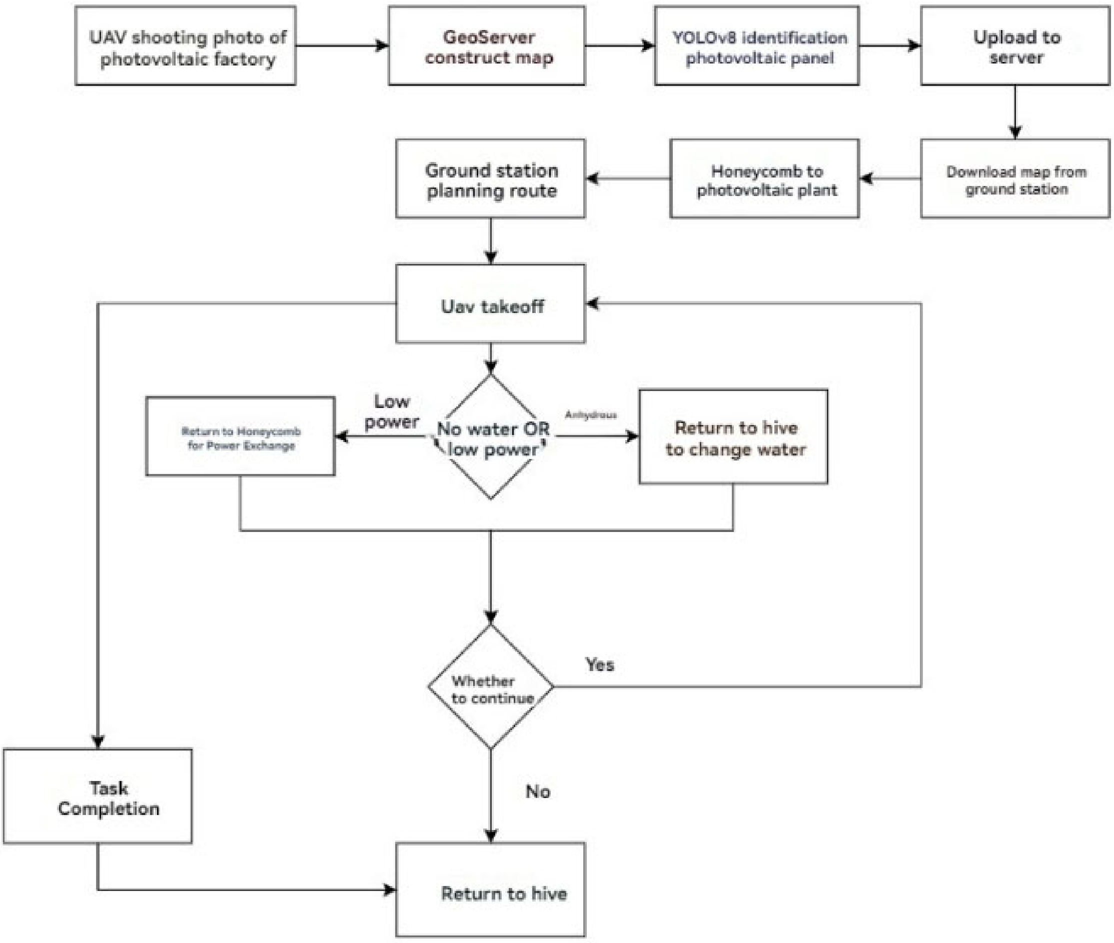

Figure 5. Flowchart.

(3) Cost Savings and Improved Safety

By reducing manual intervention and minimizing equipment maintenance requirements, the drone cleaning system can significantly save costs during long-term operation. The automated system also effectively reduces safety risks associated with high-altitude operations, ensuring the safety of workers.

D. System Application Prospects

With the continuous development of drone technology, artificial intelligence, and sensor technology, the market prospects for automated photovoltaic panel cleaning systems are highly promising. Drone cleaning systems not only improve the operational efficiency of photovoltaic power generation systems but also reduce labor costs and enhance safety, while promoting the intelligent development of the entire photovoltaic industry. As global demand for clean energy

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202502_11(2).0005

continues to rise, automated photovoltaic panel cleaning systems are expected to play a key role in the future operations and maintenance of photovoltaic power stations[10].

3. CONCLUSION AND FUTURE WORK

This paper presents an innovative automated photovoltaic panel cleaning system that leverages drone technology and intelligent algorithms to address the critical challenges of maintaining PV module efficiency and extending their lifespan. By integrating cleaning devices, obstacle avoidance radars, and automated flight path planning, the system significantly enhances PV maintenance. The ground station, utilizing DJI drone images, GeoServer, and the YOLOv8 algorithm, ensures precise identification and localization of PV panels for optimal cleaning. The hive module supports uninterrupted operations through water replenishment and charging functionalities. Experimental results validate the system's ability to effectively remove contaminants such as dust, bird droppings, and acid rain residues, resulting in improved power generation efficiency and extended module lifespan. This system demonstrates significant potential as a practical and scalable solution for intelligent operation and maintenance in photovoltaic power plants.

Future work will focus on improving cleaning efficiency by optimizing water usage and developing advanced cleaning materials. Efforts will be directed towards making the system more scalable and adaptable for diverse PV plant layouts. Integration of advanced AI models can enhance obstacle avoidance, fault detection, and flight path optimization. Sustainability will be prioritized by exploring renewable energy sources, such as solar-powered charging for drones. Extensive field testing under various environmental conditions will help evaluate long-term reliability and economic benefits. Additionally, incorporating Internet of Things (IoT) technologies for real-time monitoring and remote control will further streamline operations, ensuring the system's continued evolution to meet the needs of the photovoltaic industry.

REFERENCES

[1] Libra M, Daneček M, Lešetický J, et al. Monitoring of defects of a photovoltaic power plant using a drone[J]. Energies, 2019, 12(5): 795.

[2] Al-Housani M, Bicer Y, Koç M. Experimental investigations on PV cleaning of large-scale solar power plants in desert climates: Comparison of cleaning techniques for drone retrofitting[J]. Energy Conversion and Management, 2019, 185: 800-815.

[3] Rehman S, Mohandes M A, Hussein A E, et al. Cleaning of photovoltaic panels utilizing the downward thrust of a drone[J]. Energies, 2022, 15(21): 8159.

[4] Mohandes M, Schulze F, Rehman S, et al. Cleaning photovoltaic solar panels by drone aerodynamic[C]//2021 4th International Symposium on Advanced Electrical and Communication Technologies (ISAECT). IEEE, 2021: 1-5.

[5] Zhang Y T, Zhang J T, Liu Y, et al. Spray-on steady-state study of multi-rotor cleaning unmanned aerial vehicle in operation of photovoltaic power station[J]. Energy Reports, 2024, 11: 5638-5653.

[6] Martínez Ambrosio M. Study of an UAV implementation for solar panel cleaning[D]. Universitat Politècnica de Catalunya, 2023.

[7] He Z, Zhang Y, Li H. Self-inspection cleaning device for photovoltaic power plant based on machine vision[C]//IOP Conference Series: Earth and Environmental Science. IOP Publishing, 2019, 242: 032020.

ISSN: 2472-3703 DOI: 10.6911/WSRJ.202502_11(2).0005

[8] Sarkis S S, Khanfar L A, Ghabour B N, et al. Novel design of a hybrid drone system for cleaning solar panels[C]//2022 Advances in Science and Engineering Technology International Conferences (ASET). IEEE, 2022: 1-6.

[9] Tavasci L, Nex F, Gandolfi S. Reliability of Real-Time Kinematic (RTK) Positioning for Low-Cost Drones' Navigation across Global Navigation Satellite System (GNSS) Critical Environments[J]. Sensors (Basel, Switzerland), 2024, 24(18): 6096.

[10] LI Y, DU Y, FANG Z, et al. Review of the operation and fault handling analysis of new energy microgrid systems in military applications[J]. Energy Storage Science and Technology, 2024, 13(8): 274.