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YOLOv8-based Photovoltaic Panel Cleaning Device

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Abstract

In order to improve the efficiency of solar panels and solve the problems of high labour intensity, low efficiency and high safety risk in the cleaning process of photovoltaic panels, this paper designs a photovoltaic panel cleaning device based on YOLOv8 algorithm. Firstly, the YOLOv8 algorithm is used to collect image data of a large number of PV panel surface stains, identify and locate the stained areas in the image for data preprocessing. Then, the microcontroller with the main control chip model STM32F407IGH6 is selected to control the motion of the cleaning device so that it can complete the complete automatic cleaning function. Finally, the complete cleaning process of the photovoltaic panels is achieved by means of a roller brush on the cleaning device. The experimental results show that based on the YOLOv8 data processing results and PID control algorithm, the cleaning strategy can be dynamically adjusted according to the size and location of the target area, and the photovoltaic cleaning device can be accurately controlled to accurately and efficiently clean the dust and stains on the surface of the solar panels, which greatly improves the efficiency of solar energy cleaning.

Keywords

YOLOv8; PID; Photovoltaic Panel Cleaning; Solar energy.

1. INTRODUCTION

In recent years, with the increasing global demand for renewable energy, photovoltaic (PV) power generation[1]has been widely used as an important form of clean energy. However, PV panels are susceptible to dust, bird droppings, pollutants, etc. during long-term use, and these substances can greatly reduce the power generation efficiency of PV panels. Therefore, regular cleaning of PV panels has become a critical part of ensuring their efficient operation.

Most traditional PV panel cleaning methods rely on manual or mechanical cleaning. Although manual cleaning is precise, it is intensive and inefficient, especially in high-temperature and high humidity environments, where there is a greater risk. However, manual cleaning is not only inefficient, but also suffers from high labor intensity and high safety risks. The design and realization of mechanical cleaning devices also face many challenges, and need to take into account the adaptability and cleaning effect of different types of PV panels, especially under the premise of waterless cleaning and not damaging the surface of PV panels, the design and realization is challenging. In recent years, with the development of deep learning[2], computer vision[3]and artificial intelligence technologies[4], vision-based automatic cleaning methods have emerged. These methods use target detection or semantic segmentation algorithms by capturing images of PV panels to localize contaminants or stained areas, thus providing accurate operational guidance for cleaning robots. Existing target detection algorithms, such as Faster R-CNN[5], YOLO series[6], and SSD[7], have achieved initial applications in the field of PV panel cleaning, but there is still room for improvement of these methods in terms of the accuracy and efficiency of detecting pollutants in PV panels.

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YOLOv8[8] is the latest version of YOLO series, which inherits the advantages of YOLO series algorithms and significantly improves the detection accuracy and real-time performance by improving the network structure and loss function. It can not only effectively detect the stains on the surface of PV panels, but also maintain high detection accuracy in complex environments, which provides a strong technical support for the realization of intelligent cleaning devices. Therefore, this paper designs a PV cleaning device based on YOLOv8, which carries out data processing through YOLOv8 and combines with PID control algorithm[9]to accurately recognize and clean the stains on the surface of PV panels, which greatly improves the cleaning efficiency of PV panels.

2. MODEL DESIGN

The photovoltaic panel cleaning device is shown in Fig. 1, which is composed of a power supply, a motor, an industrial camera and an appropriate power cord. In order to ensure the cleaning performance of the device, an industrial camera is installed above the device to recognize the stains on the surface of the solar panel. Below the industrial camera is the main part of the cleaning device, which has two housings surrounding the roller brush, which on the one hand can be fixed and installed on the roller brush, and on the other hand can play a certain protective role for the roller brush. Four M3508 motors are installed on the left and right sides of the main body of the cleaning device to control the movement of the cleaning device. The power supply module is housed inside the unit and is separated from the brushes by a waterproof material to provide power to the entire unit.

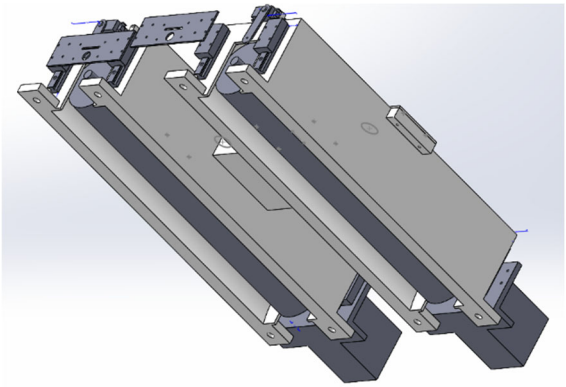


Figure 1. Overall structure of PV panel cleaning device

3. 3. HARDWARE SYSTEM DESIGN

The flowchart and program flowchart of the control system of the designed PV panel cleaning device are shown in Fig. 2 and Fig. 3, which is composed of the main control chip STM32F407IGH6, power supply module, M3508 DC brushless motors (left and right), industrial camera MV-CS016-10GM, and NUC.

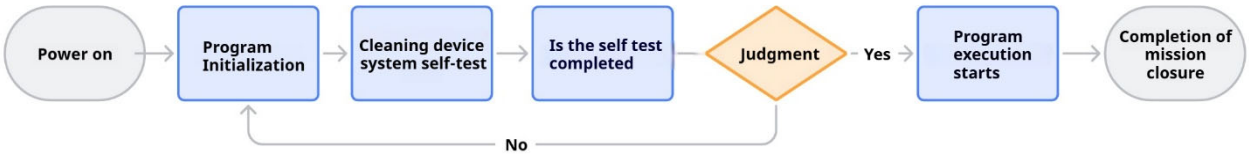


Figure 2. Flow chart of control system of PV panel cleaning device

First, turn on the power supply, the system enters the initialization state, after the self-test is completed, the industrial camera MV-CS016-10GM begins to visually identify the area equipped

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with photovoltaic panels and use the NUC for data acquisition, if pollutants such as dust are detected, the NUC sends the target data to be removed to the main control chip STM32F407IGH6. Then the motor of the ground plate of the cleaning device is Then the motor of the cleaning device's floor is controlled, so that the cleaning device automatically moves in accordance with the specified path. Finally, when the cleaning device moves to the location of the pollutant, the roller brush is turned on for cleaning.

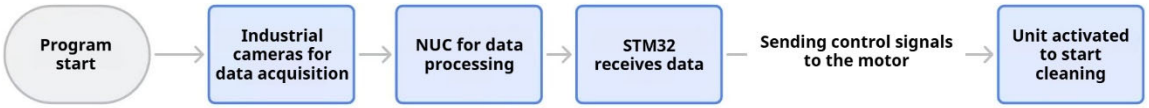


Figure 3. Flow chart of PV panel cleaning device program

3.1. STM32F407IGH6 chip

STM32F407IGH6 chip is a high-performance, low-power, low-cost microcontroller, using Cortex-M4 core, the highest main frequency up to 168MHz, with high-speed computing and data processing capabilities. Including a variety of communication interfaces, a variety of timers, multiple ADCs, etc., support for DMA transfer between a variety of peripherals at the same time with advanced low-power technology, you can minimize the power consumption during operation and extend battery life. In addition, the STM32F407IGH6 chip is also available in various packages such as LQFP, BGA, etc., which is suitable for different application scenarios.

3.2. Motor and Drive Modules

The M3508 power system has an industry-leading power density, providing high power while being only 20% of the size and weight of the same device, saving a lot of space and outputting more power, allowing the cleaning device to operate efficiently. Built-in multiple sensors automatically sense abnormal conditions such as high temperature and broken wires and provide timely alarms to quickly locate faults for safer use. When multiple motors are mounted on the CAN bus of the robot platform, there is no need to set the motor ID individually, and in the quick ID setting mode, the motor ID can be set by manually rotating the motors in sequence, which makes it more convenient to use.GM6020 is a high-performance DC brushless motor with an integrated internal driver. With hollow shaft design, high torque density, high control accuracy, flexible interaction and strong protection function, GM6020 is suitable for low-speed and high-torque direct-drive application scenarios, which is ideal for industrial robots, scientific research and education, automation equipment and other fields. Adopting hollow shaft structure, slip ring and other accessories can be installed according to requirements. Integrated design of motor and driver, compact structure and high integration.

3.3. Industrial Camera MV-CS016-10GM

Industrial Camera MV-CS016-10GM is a high performance industrial camera, which is usually used in machine vision, automated inspection, quality control, etc. MV-CS016-10GM is usually equipped with a high-resolution sensor, which is able to capture clear and detailed images, and it is suitable for industrial applications requiring high-precision images, such as printing inspection, surface defect inspection, etc. MV-CS016-10GM usually adopts Gigabit Ethernet (Gigabit Ethernet) and Gigabit Ethernet (Gigabit Ethernet). The MV-CS016 -10GM usually adopts the GigE interface, which means it can realize high-speed data transmission through the standard Ethernet interface, providing a more stable connection and longer transmission distance (up to 100 meters or more). This is advantageous for industrial applications that require long transmission distances. Industrial cameras are usually characterized by high light

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sensitivity, and the MV-CS016-10GM may also have good low-light performance, capable of capturing clear images even in darker environments, for scenes with unstable or poor lighting. As an industrial camera, the MV-CS016-10GM is likely to support a wide range of image processing software and industrial vision platforms, with strong compatibility, enabling seamless integration with existing automation systems and machine vision systems, reducing the difficulty of system integration.

3.4. NUC

NUC (Next Unit of Computing) is an ultra-small, compact computing platform launched by Intel, NUC's most important feature is its extremely compact size. Compared to a traditional desktop computer, it is typically about one-tenth the size of a standard desktop computer. This compact design is ideal for space-saving environments, and the NUC utilizes a low-power processor that provides sufficient computing power while dramatically reducing power consumption. This makes it particularly suitable for scenarios that require long periods of operation, such as remote monitoring equipment. Despite its compact size, the NUC still delivers powerful computing performance. It supports Intel's latest processors and can be equipped with different memory, storage, and graphics cards as needed.The NUC offers a wide range of configuration options, allowing users to customize its hardware composition according to their needs.As a small but efficient computing device, the NUC is characterized by its ultra-small size, low power consumption, powerful performance, and flexibility, making it suitable for a variety of application scenarios, especially in places where space is limited, or where energy efficiency is required.

NUC is a small but efficient computing device with ultra-small size, low power consumption, powerful performance, flexibility and other characteristics, suitable for a variety of application scenarios, especially in the space is limited, or the need for energy-saving and environmental protection applications.

4. ALGORITHM DESIGN

4.1. YOLOv8 algorithm design

The basic design idea of the YOLO series is to transform the object detection problem into a regression problem, where the network directly predicts the location of the object as well as the category probability, without the need for complex candidate region generation and post-processing as in traditional methods. YOLOv8 follows this idea, while improving the network architecture, training strategy, etc., in a number of ways.

4.1.1. Network Architecture Design

YOLOv8 continues the architecture of YOLOv5, but with several detailed optimizations to make the model more streamlined, efficient, and adaptable to a wider range of application scenarios. The architecture of the network broadly includes the following modules:

Backbone: YOLOv8 uses a more efficient backbone network, such as CSPDarknet (Cross-Stage Partial Darknet) or the more advanced Efficient Net, which can significantly improve performance while keeping computational complexity low through efficient feature extraction by design.

Neck: YOLOv8 employs FPN (Feature Pyramid Networks) or PANet (Path Aggregation Network) in the Neck section, which are structures that facilitate efficient fusion between features at different scales, enhancing the model's multi-scale detection capabilities.

Head (Output Layer): The Head part of YOLOv8 is usually a lightweight detection head, which classifies and regresses the target based on the output of the network (including the class of the object, the coordinates of the bounding box, and the confidence level). By predicting the location

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of the bounding box, the class of the object, and the confidence level of each bounding box, the network directly outputs the results of target detection.

4.1.2. Improved Loss Function

YOLOv8 improves the traditional YOLO loss function by introducing a more flexible loss design with the goal of improving detection accuracy, especially when dealing with small or overlapping objects. Common YOLO loss functions include:

Localization Loss: Used to measure the error of the bounding box coordinates (center point, width, height). More refined IoU variants such as CIoU (Complete Intersection over Union) or DIoU (Distance Intersection over Union) are usually used instead of the traditional IoU in order to more accurately calculate the target position error.

Classification Loss: Used to calculate the difference between the predicted categories and the true categories, usually using Cross-Entropy Loss.

Confidence Loss: Used to measure the network's confidence in the presence or absence of an object. YOLOv8 makes the model more accurate in detecting small objects with an improved confidence loss function.

4.2. PID control algorithm design

PID control algorithms can be adapted to many different types of dynamic systems, including linear systems, nonlinear systems, and inertial systems. In many industrial control applications, PID control algorithm is one of the default control strategies, which can provide good enough performance in many cases.PID control algorithm can flexibly optimize the control performance by adjusting its parameters (proportional, integral, differential) to meet the requirements of different applications on the response speed, steady state accuracy, system stability. Through appropriate parameter adjustment, it can effectively respond to disturbances and changing operating conditions.

$$u(t) = K_p \cdot e(t) + K_i \cdot \int_0^t e(t)dt + T_d \cdot \frac{de(t)}{dt}$$

5. CONCLUSION

In this paper, a photovoltaic cleaning device based on YOLOv8 and PID control algorithm is designed to visually recognize the stains on the photovoltaic panels through YOLOv8 and send the collected data to the microcontroller through NUC, and the cleaning device is automatically controlled through path planning, which solves the problem of relying on manual or mechanical cleaning for a long time, and greatly improves the cleaning efficiency.

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