An Autonomous and Complete System based on UAV for Power Line Detection and Insulator Cleaning

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Abstract. The scale of the global power system is constantly expanding. In order to ensure the safe operation of transmission lines, power line inspection and insulator cleaning are essential. The traditional power line inspection and insulator cleaning methods are low efficiency, high cost and low safety. With the development of unmanned aerial vehicle (UAV), the application scope of UAV is constantly expanding. This paper envisages the design of an autonomous and perfect UAV system to detect power lines and clean insulators. Firstly, this paper reviews the algorithm of visual tracking control UAV, and then seeks the best design scheme of the cleaning tool composed of water pump, nozzle and cleaning liquid. Finally, combined with the ground base station of automatic wireless charging and adding cleaning agent, a perfect UAV system of independent detection of power lines and cleaning insulator is built. Readers of this review can get familiar with the vision algorithm of controlling UAV, have a deeper understanding of the application of a perfect autonomous UAV system in power line, and also put forward solutions to the problems that may be encountered in future power line maintenance, and propose future research directions.

Keywords: UAV, autonomous, system, power line, cleaning, inspection

1 Introduction

It is well known that electricity is not only related to national economic security but also closely related to human social progress. With the expansion of the global power system and the continuous innovation of science and technology, the area of transmission pipeline is increasing. According to the latest figures, transmission lines could continue to grow rapidly at a rate of 25,000 km per year, reaching 1.2 million km by 2050. Distribution line length will accelerate after 2030, reaching 19 million km by 2050. The failure of transmission lines on such a large scale can lead to inconvenience and economic losses at the most, to massive power outages and possibly life safety.

In order to protect the demand of users and the development of economy, the safe operation of power lines is particularly important. The cleaning and maintenance of

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high voltage transmission lines are essential. Most of the transmission lines are installed in the vast and sparsely populated areas, which are prone to aging, corrosion and other problems due to complex geographical environment and harsh climate, and even lead to large-scale power outages. From another point of view, the power line has the problems of high erection height, large weight and difficult to fix, too much mechanical traction, excessive bending of the cable and so on. With the passage of time these problems can lead to cable strain or damage cable, easy to appear friction damage, structural fracture, component fall off and other failures. Insulator is also an important component of power line laying. The main function of insulators is to achieve electrical insulation and mechanical fixation, used for wire and cable connection. Under normal conditions should not be caused by changes in the environment and electrical load conditions caused by various mechanical stress failure. However, in reality, industrial waste gas emissions, salt spray, dust in the air and other pollutants gradually accumulate and adhere to the surface of the insulator, forming a dirty layer. These contaminants have a high conductivity when exposed to moisture. Especially in bad weather, such as rain, snow melting and fog, the insulation strength of dirty insulators is greatly reduced, resulting in insulator flashover under normal operating voltage, resulting in a large area of power failure and pollution flashover events. Therefore, a natural question is how to provide a stable and efficient way to maintain the high-voltage transmission lines and provide an efficient way to clean the insulators. To clarify this problem is of great significance to global economic construction and the development of power industry.

At present, the most common way is manual inspection and maintenance. Inspectors observe and judge the running status of the line through naked eyes and telescopes, and then manually climb the tower to clean it. This approach is heavily influenced by the external environment and is not comprehensive. In the place of complex terrain and harsh environment, the safety of detection personnel is difficult to be guaranteed, and it is inevitable that human negligence will cause omission and false detection, so the reliability is difficult to be guaranteed. With the rapid development of optical imaging technology and flight control technology in recent years, ground photography equipment and helicopter inspection have gradually become the mainstream, but both of them have problems such as high cost, high operating threshold, high use cost and limited detection Angle.

In recent years, UAV technology has attracted more and more attention. It has the advantages of simple operation and flexible flight, and has been widely used in photography, geological monitoring, agricultural production, entertainment performances, war monitoring and other fields. At the same time, the route inspection mode has been transformed to occupy greater advantages in the environment, economy, efficiency and other aspects of UAV inspection. It can reach the places that helicopters cannot reach, collect the images and videos of insulators more clearly and accurately, and identify all kinds of defects of insulators in time. To a large extent, the traditional inspection mode of transmission lines can solve the problems such as manpower shortage, low efficiency and easy to be restricted by special terrain. But most drones are currently used only for image and video capture. With the continuous development of technology, the application of UAV in line inspection will be more intelligent, and the autonomous inspection and cleaning of insulators will eventually be realized. It is the future development trend

to use UAV vision combined with deep learning target detection to complete the detection and identification of insulator faults. According to literature [1], the accuracy of using drones to inspect power lines in complex backgrounds can reach 85%. Reference [2] proposes a method based on Faster RCNN to identify insulators in drone images, which has high accuracy and speed, and strong robustness and practicality. The detection and identification algorithms for insulators include traditional detection algorithms and the continuously improved deep learning detection algorithms in recent years. For example, grayscale matrix and local attribute calculation are used to calculate the geometric features of the target. It turns out that using 3D modeling can not only enable drones to avoid obstacles but also identify faults in power lines. However, these research results still have defects in the identification and detection of insulator defects. And most of them only target at one section of power line detection, failing to thoroughly combine power line detection of UAV with autonomous insulator cleaning of UAV. This paper studies the UAV detection and cleaning system that combines the two. This perfect autonomous cleaning system can not only conduct regular inspection under complex environment, but also design a perfect power base station system to provide sufficient endurance. Therefore, this technology is particularly important for the inspection of power lines and the cleaning of insulators.

An autonomous detection and cleaning system based on UAV will be studied for power line detection and insulator cleaning in this paper. Firstly, power lines and insulators can be tracked and detected by UAV vision to control UAV movement. Then, the drone nozzle and water pump are designed; Secondly, this paper designs a ground base station to realize automatic wireless recharging, supplement cleaning solution and real-time display of UAV status. Finally, the ground base station and the UAV are connected to form a complete system of autonomous detection and cleaning. The remaining chapters of this paper are arranged as follows: Chapter 2 combines UAV vision and deep learning target detection to improve UAV flight accuracy along power lines and insulator detection ability. The third chapter studies the cleaning parts of UAV end and seeks an efficient cleaning method through the design of water pump and nozzle and the selection of cleaning liquid. In the fourth chapter, the design of the ground base station of UAV is studied. Combined with the changing power station, the cleaning liquid replenishment component is added to realize the automatic recharging and replenishment of cleaning liquid for homing. The fifth chapter combines the ground base station with the UAV terminal and realizes the complete system through the UAV precision landing algorithm and real-time information transmission. The sixth chapter is the summary of the paper and the prospect of the future, further condensed the results of the paper and find out the shortcomings and put forward the hypothesis of the future research and development direction.

2 Related Works

2.1 Extraction of UAV Power Line Insulators

To detect insulators using drones, it is necessary to extract the image characteristics of the insulators. After the drone captures the image of the insulator, it will take a lot of

time to manually analyze the image. Therefore, it will be necessary to use drones for automatic recognition and processing of insulator images.

Recognition-based on Visual Algorithm. Target detection is mainly divided into feature extraction and detection recognition. Detection and recognition include two steps: localization and classification. The positioning and classification of one-step detection are carried out simultaneously. Correspondingly, the positioning and classification of two-step detection are divided into two steps.

The two-step target detection algorithm starts from R-CNN.R-CNN uses selective search to output 2000 candidate frames out of the input original images, and then sends them to CNN to extract the feature map and classify the feature map at last. Figure 1 shows the R-CNN network process. In 2014, RCNN was first proposed by Girshick et al. The R-CNN algorithm has the advantages of high precision but long time[3].

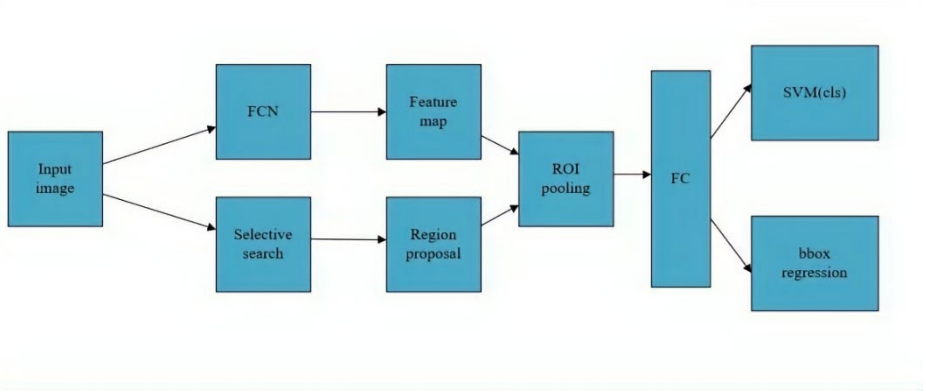

Fig. 1. R-CNN flowchart (Picture credit: Original)

YOLO series algorithm is a one-step detection algorithm, which divides a graph into many equal grids. If there are detection objects in the grid, the grid will extract the information of the target, and finally output the higher-order matrix.The design of YOLOv1 is simple, with many shortcomings, and poor detection effect for small targets. Later, YOLOv2 effectively solved the problem of network degradation and introduced the anchor mechanism of Faster R-CNN, which improved the detection capability in various aspects to varying degrees. To improve the detection performance, YOLOv3 is proposed, which reduces the number of networks layers and improves the precision of target detection.

In recent years, YOLOv4 and YOLOv5 have integrated a large number of relevant model optimization techniques, which has raised the accuracy and speed of target detection to a new height.

Insulator image features. The insulators on the insulator string are all perpendicular to the main axis, and the insulators on the same string have the same spatial characteristics. When using binary images to represent insulator strings, the connecting part of

the insulator string has obvious characteristics. The pixel changes of the insulator in this connecting part are not significant, the horizontal distance between adjacent insulators is roughly the same, and the vertical length of each connected area is close.

When the insulator is damaged, the spatial features undergo significant changes. In the binary image, the vertical length of the damaged connecting area can be seen,and the adjacent horizontal distance undergo sudden changes to determine the defect of the insulator[4].

2.2 Design of UAV cleaning parts

This chapter summarizes and compares the existing UAV cleaning components. After a lot of research shows that the insulator surface fouling composition and structure change with different pollution environments, the main components are CaSO4 and SiO2. the soluble components in coastal area fouling are mainly NaCl, while the main components of inland area fouling are mainly CaSO4 [5]. Considering the UAV conditions required in this paper, the main problems currently exist: 1) Insufficient water injection pressure. 2) Limited UAV load capacity. 3) Cleaning fluid and water flow channel design and selection. To solve these three problems, the currently available solutions.

High-pressure Water Jet Device. The insulators are cleaned using a high-pressure water jet device, a resolution that considers both the insufficient hydraulic force and the burden of the UAV cargo.The device uses high-pressure air as the power to make a high-pressure jet of water, because the part that provides the origin of compression is on the ground, so the volume and weight does not affect the UAV, so you can get 30MPa or even higher pressure. Finally, it will be filled into the high-pressure container of the water jet device can be, the size of the container and the pump is comparable, but its maximum pressure can reach 30 times the pump, the effect is more considerable. Use the pressure through the solenoid valve to control the high-pressure container into the water tank, you can make the water jet at high speed [6].

Different Nozzle Design. By different design nozzle to meet the needs of water injection. In the selection of nozzles mainly consider their performance aspects, the performance of the jet nozzle to measure the three main criteria, respectively, laminar flow, turbulence and internal flow separation. These parameters have a large impact on the performance of the nozzle. Several mainstream nozzles can be classified as: flat nozzles, conical nozzles, conical nozzles and atomization nozzles with transitional rounded nozzles five types of nozzle structure as shown in Figure 2 [7]. Materials can be selected for easy processing and molding, such as copper, stainless steel and other materials [8].

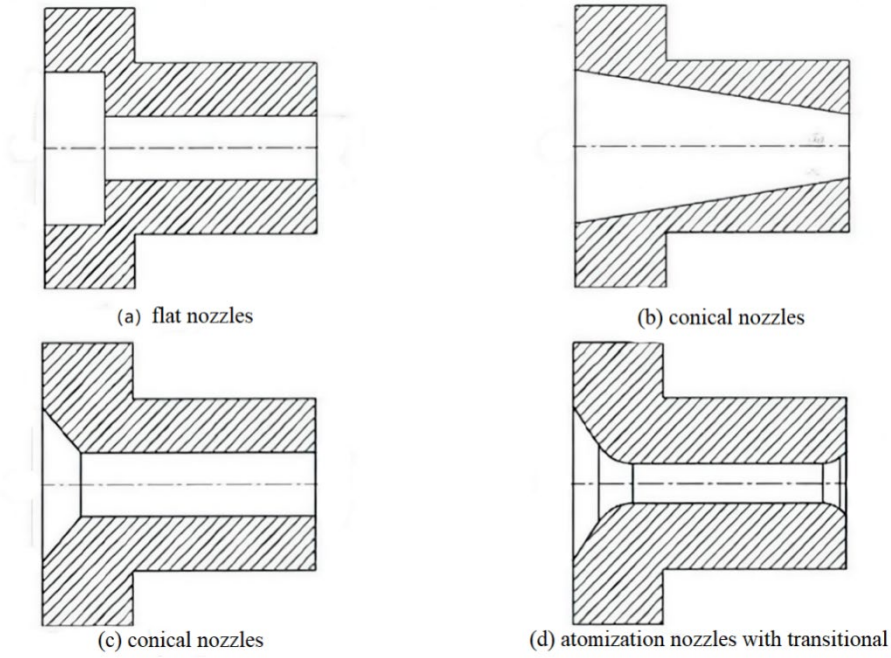

Fig. 2. Different nozzle[7]

Water Jet Clean. The Liquid cleaning insulators currently use the most effective is the best water jet. A drone cleaning water jet cleaning system works as follows: the pump is driven by a motor, and the cleaning fluid is extracted from the water reservoir through a filter, and the cleaning system is controlled by controlling the opening and closing of the solenoid valve. In the working state, when the pressure of the system is higher than the set working pressure, the safety valve will open automatically, and the cleaning fluid will flow back to the water reservoir. Among them, the insulator cleaning system is combined with a right-angle coordinate robot, and the cleaning nozzles are installed on the cleaning bracket, and the pump works by piping the cleaning fluid to the nozzles, through which the insulator surface is cleaned at the same time [7]. And the water jet cleaning mechanism is. Jet water flow through sufficient impact force to crush the scale layer or deposits, the internal layer of scale is penetrated, and the fluid is inserted in a wedge between the scale layer and the metal surface, so that the scale layer falls off and reveals the cleaned surface.

Dry Ice Clean. Dry ice cleaning of insulator fouling is another direction of current research. The air pressure, cleaning angle, and mass flow rate of dry ice can be altered through experimental tests, dry ice cleaning was performed on artificially simulated contaminated ceramic insulators and composite insulators, respectively. It was found that the dry ice cleaning could significantly clean off the sample surface fouling and

change the surface fouling residual degree and contact angle. No significant changes were observed in the surface morphology of ceramic insulators after cleaning [9].

2.3 Selection of Charging Mode of UAV

Above, the main design of power line detection and insulator cleaning by UAV is completed through visual algorithm and design of cleaning parts. With the increase of functions on UAV and the long flight distance required for power line inspection, the endurance of UAV battery and how to reasonably arrange battery charging become very important [10]. Three mainstream methods to improve flight time and their problems: (i) Drones can be equipped with high battery capacity, but it will increase the weight of the drone; (ii) The UAV can realize battery exchange after landing. However, this can also lead to complexity and high costs when switching systems; (iii) It can be charged in the base station of the UAV. Charging can be achieved through wired or wireless charging (WPT) systems [11]. In this paper, several different charging methods are compared to find the most suitable for the power line test insulator clean charging design.

Charging based on PV Cells. The PV cells are charged by sunlight, which requires a certain payload capacity and wing length of the UAV due to the need to lay a large area of PV panels. In addition, there is a well-established [12] photovoltaic cell-based laser power transfer (LPT) charging, which has become a feasible solution for wireless endurance, through a specific wavelength and frequency of the laser beam to power the photovoltaic cells installed on the UAV.

In terms of its safety, although laser technology has entered daily life, improper use will cause many potential dangers such as retinal damage. In addition, the transmission of laser is also susceptible to weather, soot and other effects, so there are certain limitations in this wayIn terms of its safety, improper use of laser can cause many potential dangers such as retinal damage. In addition, the transmission of laser is also susceptible to weather, soot and other effects [13], so there are certain limitations in this way.

Common Charging Methods. Wired charging and battery exchange are two common ways to charge drones [14]. For example, Skysense's wired automatic charging station is a ready-made solution [15]. Meanwhile, some studies have also proposed a battery exchange method to charge the exhausted batteries of drones [16]. Based on the consideration of economy and charging and changing speed [17], and the power line is a system with high coverage, battery exchange is a better choice.

Design of Power Changing base Station. This section focuses on an automated battery switching base station. Battery switching stations include contact mechanisms, landing infrastructure, on-board circuitry, and ground electronics. The working idea of the ground station is described in [16], as shown in the Figure 3.

At present, the biggest problem facing the ground base station is that the UAV landing accuracy is not high [18]. A basic algorithm for finding landing pad and adapting UAV flight control system to autonomous landing is proposed. Moreover, an ADRC (active disturbance rejection controller) is designed in [19], which has higher accuracy, robustness, adaptability and anti-interference ability compared with the traditional PID, and basically solves the landing problem.

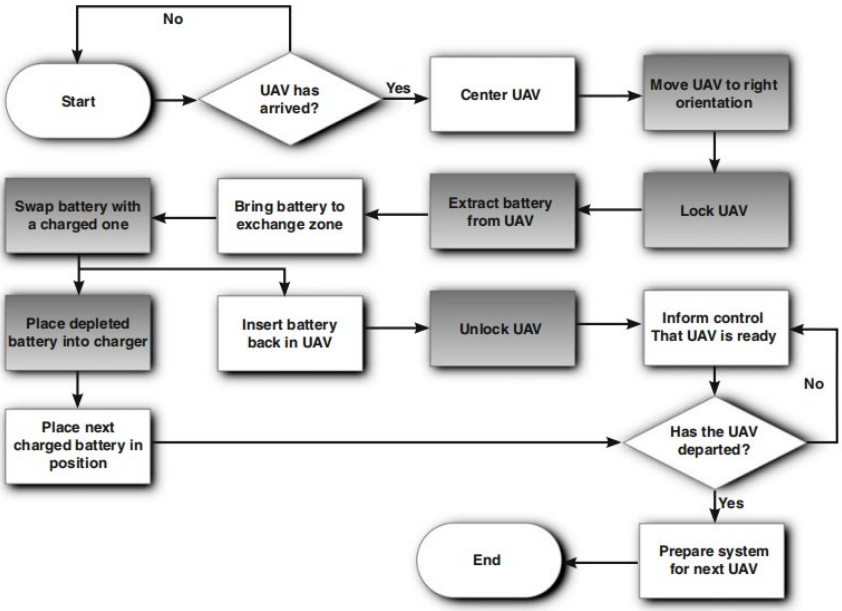

Fig. 3. Flow chart of changing station [16]

3 Discussion

3.1 Selection of the insulator identification algorithm

At present, many scholars have studied the detection method of insulators. Literature uses K-means to optimize Faster R-CNN algorithm to improve the detection rate of insulators [20]. Literature improved a detection network for insulators based on YOLOv3 [21], which can locate the location of insulators and specific damage. However, the above methods cannot take into account the accuracy and real-time performance and cannot accurately locate and identify the defects of insulators.

In view of the current complicated situation of insulator inspection by UAV, the method proposed [20] on the basis of the YOLOv5 has a higher precision and a faster speed. YOLOv5 is based on YOLOv4 and optimized for its backbone network. The YOLOv5 code is small, the detection speed is quick, and the precision is high. It can solve the problems of long detection time of many image recognition algorithms and

high requirements of computer configuration.The input image needs to be cut into a 640x640 scale, but then the image is sent into the main trunk characteristic extraction network, three scale characteristic layers will be exported. Then, the three feature layers are transferred to the feature mixing layer, and the multiscale feature blending is performed. Finally, First, the original image is divided into the output characteristic layer size and size, so as to locate the target region as shown in Figure 4.

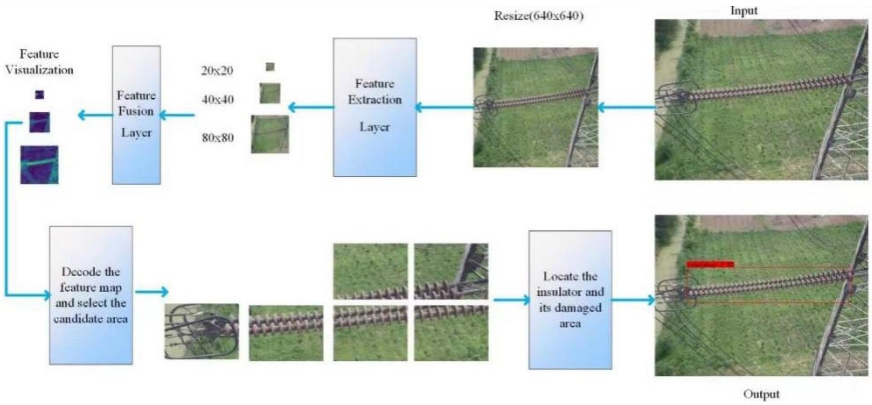

Fig. 4. Calculation flow chart of YOLOv5[22]

3.2 Effective cleaning component design

After consideration, the solution of adjusting the water pressure through high pressure equipment was not applicable because of the need to apply to conditions such as treacherous terrain. Because of the need to manually adjust the position of the ground equipment constantly, plus the terrain reason equipment is not good to set up. Want to apply to clean insulators in remote and rugged terrain, in order to meet the cleaning at the same time, need to be independent and autonomous UAV to complete the task of identification scanning and cleaning, which is our purpose. Dry ice is ideal in terms of cleaning effect, but the overall cleaning system is not convenient to carry and considering the cost issue. So comprehensive consideration by using special nozzle effect is better.

Comparing and analysing the existing water jet nozzle structure and performance characteristics to meet the cleaning requirements. The conical combined with cylindrical exit segment type nozzle and straight conical nozzle were selected. The nozzle designed in is shown in Figure 5 [7]. The nozzle has a long range, high density and is not easily dispersed. Also, the nozzle was chosen to use stainless steel for processing.

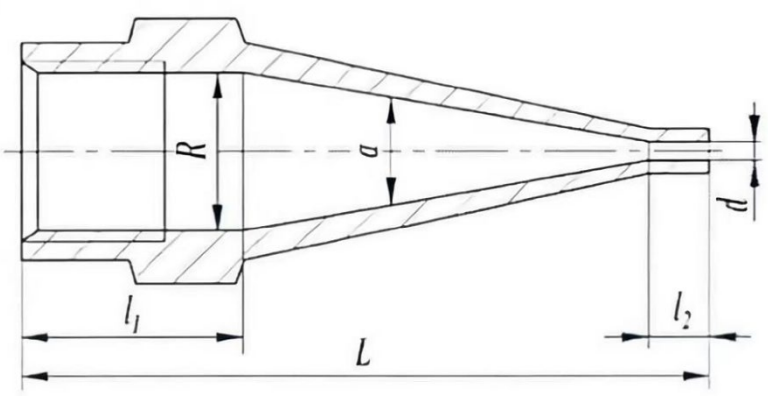

Fig. 5. The outlet section type nozzle of the cone combined with the cylinder [7]

Straight conical nozzle structure as shown in the Figure 6, which has the characteristics of improved water pressure and stability, at the same time, by changing the internal inclination angle, the nozzle can be converted between column spraying and atomization spraying, the effect is shown in the Figure 7. When the presence of thick and hard dirt can choose the direct spray mode, if there is dust and other small dirt, you can choose atomization cleaning.

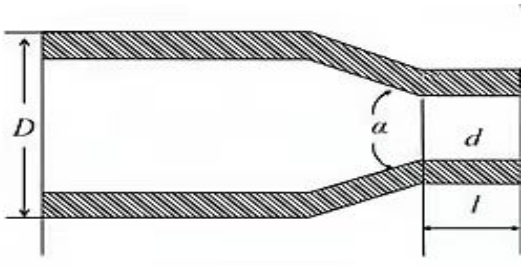

Fig. 6. Straight conical nozzle [23]

Fig. 7. Example of Straight conical nozzle [23]

As for the design of ground station change points, a recent study proposed the use of robotic arms to independently replace UAV batteries [24]. This method has wide applicability and can complete the power change work in a short time, so that the detection and cleaning system can run continuously and completely.

3.3 Power changing base station

Based on the above discussion, the charging method based on photovoltaic electricity is limited by the volume of the UAV and the space occupied by the cleaning parts, and it is impossible to install a large area of photovoltaic panels. Secondly, photovoltaic cells also have strict requirements for weather, and power line inspection may encounter various adverse weather and climate, so this scheme is not selected. For the charging method, whether wired charging or wireless charging, it will waste time to wait for the battery to be fully charged to a certain extent, and the cleaning of the insulator and the power line detection should be a continuous work, because this charging method is not used. We believe that the electric exchange type UAV hangar is the best solution to solve the battery life required for UAV power inspection and insulator cleaning. And, Figure 8 showed the UAV changing station.

Fig. 8. UAV changing station[24]

Regarding the design of the power change of the ground base station, a recent study proposed the use of a robotic arm to replace the UAV battery independently [24]. This method has wide applicability and can complete the electrical change work in a short time, so that the detection and cleaning system can run continuously and completely. At the same time, the UltraHive Mk4 Pro fixed charging and recharging integrated library designed by Skysys company is also designed to change the power of DJI M300 through the mechanical arm.

4 Conclusion

The above described the related work of insulator vision algorithm, UAV nozzle design, UAV charging mode, and the advantages and disadvantages of various schemes are discussed. In conclusion, YOLOv5 series algorithm is used to identify insulators. The special processing nozzles and convertible nozzles are selected,and the charging mode of the ground exchange station are merged in the same UAV system.Combined with the above design, the UAV system not only has fast detection speed in insulator detection, but also can detect longitudinal insulators. In terms of nozzles, it can meet the cost performance and water pressure requirements at the same time, it can change the water outlet way to clean the insulator more comprehensively, and realize uninterrupted continuous operation of the whole work process in terms of battery life.It is because of these features that the entire UAV power line cleaning and insulator monitoring system becomes autonomous and perfect, just like the title of this article. It aims to provide a perfect, convenient, efficient and safe power line autonomous cleaning and insulator monitoring system by using UAV.

Acknowledgment (Authors Contribution)

All the authors contributed equally and their names were listed in alphabetical order.

References

1. Wang, M., Du, Y., Zhang, Z. Research on UAV assisted inspection and insulator defect image recognition [J]. Journal of Electronic Measurement and Instrumentation, 2015,29 (12):1862-1869.
2. Guo, T., Yang, H., Shi, L., et al. Identification of Insulator Self Explosion Defects Based on Faster RCNN [J]. Electric Porcelain Arrester, 2019, 289(03):183-189.
3. Liu, X. Drones power inspection image of insulator detecting research [D]. Shandong university, 2022.
4. Huang, X., Shang, E., Xue, J., et al. A multi-feature fusion-based deep learning for insulator image identification and fault detection[C]//2020 IEEE 4th Information Technology, Networking, Electronic and Automation Control Conference (ITNEC). IEEE, 2020, 1:1957-1960.
5. Li, H., Liu, G., Li, L. Analysis of natural fouling components on insulator surface and its research prospect [J]. Chinese Journal of Electrical Engineering, 2011, 31(16):128-137
6. Huang, H., Wang, C., Zhou, H. Development of a high pressure water jet cleaning insulator device carried by a drone[J]. Science and Technology Information, 2018, 16(31):246-247.
7. Du, H. Design and research of transmission line insulator cleaning device [D]. Tianjin University of Science and Technology: 2017.
8. Lavrence, J. D. C. Combined numerical/analytical solutions of the navier stokes equations for aerodynamic ejector/mixer nozzle flows [D]. Texas A&M University, 1995.

9. Li, T. Design of dry ice cleaning robot for pillar insulator and its cleaning method[D]. Changsha University of Technology:2021.
10. Jawad, A. M., Jawad, H. M., Nordin, R., Gharghan, S. K., Abdullah, N. F., Abu-Alshaeer, M. J. Wireless Power Transfer with Magnetic Resonator Coupling and Sleep/Active Strategy for a Drone Charging Station in Smart Agriculture. IEEE Access 2019, 7, 139839–139851.
11. Campi, T., Cruciani, S., Feliziani, M. Wireless Power Transfer Technology Applied to an Autonomous Electric UAV with a Small Secondary Coil. Energies 2018, 11, 352.
12. Ouyang, J., Che, Y., Xu, J., Wu, K. Throughput maximization for laser-powered UAV wireless communication systems. In Proceedings of the 2018 IEEE International Conference on Communications Workshops (ICC Workshops), Kansas City, MO, USA, 20–24 May 2018; pp. 1–6.
13. Lahmeri, M. A., Kishk, M. A., Alouini, M. S. Charging Techniques for UAV-Assisted Data Collection: Is Laser Power Beaming the Answer? IEEE Commun. Mag. 2022, 60, 50–56.
14. Bushnaq, O. M., Kishk, M. A., Celik, A., Alouini, M. -S., Al-Naffouri, T. Y. Optimal Deployment of Tethered Drones for Maximum Cellular Coverage in User Clusters. IEEE Trans. Wirel. Commun. 2020, 20, 2092–2108.
15. Contact charging station E-resource] // Skysense - Access Mode:https://www.skysense.co/ (Address date: 01.04.2021).
16. Suzuki, K. A. O., Filho, P. K., Morrison, J. R. Automatic Battery Replacement System for UAVs: Analysis and Design. J. Intell. Robot. Syst. 2011, 65, 563–586. Doi:10.1007/s10846-011-9616-y.
17. Michini, B., Toksoz, T., Redding, J., Michini, M., How, J., Vavrina, M., Vian, J. Automated battery swap and re-charge to enable persistent UAV missions. Infotech@ Aerosp. 2011, 2011, 1405.
18. Dergachov, K., Bahinskii, S. and Piavka, I. "The Algorithm of UAV Automatic Landing System Using Computer Vision," 2020 IEEE 11th International Conference on Dependable Systems, Services and Technologies (DESSERT), Kyiv, Ukraine, 2020, pp. 247-252.
19. Zhang, Z. and Zhang, Y. Research on UAV Precision Landing Technology Based on ADRC, 2022 41st Chinese Control Conference (CCC), Hefei, China, 2022, pp. 2815-2820.
20. Yang, Y., Cao, Y. Drones insulator image target detection based on depth study [J]. Journal of laser, 2020, 9 (10) : 63-66. The DOI: 10.14016 / j.carol carroll nki JGZZ. 2020.10.063.
21. Wu, T., Wang, W., Yu, L., Xie, B., Yin, W., Wang, H. Lightweight YOLOV3 insulator defect detection method [J]. Computer engineering, 2019, (8) : 275-280.
22. Li, Q., Zhao, F., Xu, Z., Wang, J., Liu, K. and Qin, L. "Insulator and Damage Detection and Location Based on YOLOv5," 2022 International Conference on Power Energy Systems and Applications (ICoPESA), Singapore, Singapore, 2022, pp. 17-24. Doi:10.1109/ICoPESA54515.2022.9754476.
23. Wang, Q. Design of UAV-based PV module cleaning system [D]. North Central University:2022. DOI:10.27470/d.cnki.ghbgc.2022.000795.
24. Voznesenskii, E. A. Automated Battery Charging System for Multi-Rotor Aerial Vehicles, 2021 Wave Electronics and its Application in Information and Telecommunication Systems (WECONF), St. Petersburg, Russia, 2021, 1-4. Doi: 10.1109/WECONF51603.2021.9470571.

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