Research on Unmanned Aircraft Power Inspection Path Planning Based on Particle Swarm Algorithm

Weihao Zhang
State Grid Fujian Electric Power Research Institute
Fuzhou, China

Bojian Chen
State Grid Fujian Electric Power Research Institute
Fuzhou, China

Wenbin Wu
State Grid Fujian Electric Power Research Institute
Fuzhou, China

Fang Wang*
Beihang University
Beijing, China
*e-mail: buaaairforce@buaa.edu.cn

Anan Xu
Beihang University
Beijing, China

Cheng Gao
Beihang University
Beijing, China

***Abstract*—With the rapid development of UAV science and technology, its application fields are wide, and the direction of electric power inspection as an emerging field, its application is also essential. This paper researches and designs a power inspection UAV system. The power inspection UAV system uses particle swarm algorithm to plan the optimal route and avoid roadblocks, inputs the optimal route into the UAV navigation system, and inspects according to the regulations, the on- board thermal imaging camera, uploads the images and videos to the cloud in real time and analyzes them, and utilizes the 5G communication system RTK differential equipment to accurately locate the place where the fault occurs; and carries out a lightweight design of the inspection prototype UAV, to enhance the power inspection UAV range time. Thus, it promotes the rapid development of intelligentization of UAV power inspection system and provides design basis for the in-depth research of UAV power system.**

Keywords-power inspection UAV; particle swarm algorithm; lightweight design; 5G communication technology

I. INTRODUCTION

Along with the rapid advancement and development of China's economy, science and technology, and the modernization of culture, the application of drones has been all over the country in various fields, such as military reconnaissance, geographic surveying and mapping, courier transportation, electric power inspection and other aspects. Due to our country's vast territory, transmission lines span a large, and there is no lack of extreme environment, resulting in the traditional manual inspection needs to consume more energy and time, security cannot be guaranteed, so in this case, the drone application in power inspection is to ensure that our country's power grid transmission lines an important means of not only greatly save the cost of time, but also improve the accuracy of the power inspection check.

Although the science and technology of small drones has been developed more maturely, there are still more shortcomings for its application in the direction of electric power inspection. Electric power inspection needs to check the known transmission lines, but its lines are intricate and complex, there may be UAV inter-machine collision, interference, bumping into poles and other emergencies, so in order to improve the accuracy of its electric power inspection, the need for UAV inspection trajectory planning, domestic and foreign scholars on the UAV electric power inspection line has carried out a lot of research and reasonable research [1~6], combined with the background of electric power inspection applications, to the pole as the inspection target, based on the application of computer intelligent algorithm, under the premise of ensuring the flight safety of UAV, to find the optimized trajectory in line with the electric power inspection.

At present, electric power inspection is mostly dominated by small multi-rotor UAVs, and its endurance time is short, most of which is kept within 1 hour, so it needs to be designed in advance to complete the electric power inspection of the fixed line, that is, it needs to return to the ground.station to replace the batteries or charging, which leads to a great decline in its work efficiency, so Zhang Shik-hun [7] et al. analyze the influence of a variety of influences that affects the endurance of UAVs, and starting from its influencing factors, they propose the optimization of its power system and flight control and other methods to improve its endurance. Therefore, Zhang Zhixun [8] et al. analyzed the factors affecting the range of UAVs and proposed the optimization of the power system and flight control to improve its range; Jin Jiayi et al. took the power system as the object of research, studied the paddle efficiency of UAVs, and replaced the motors and propellers to improve the range time. However, the above methods to improve the endurance are relatively small, and still cannot meet the requirements of timely charging and greatly improving the endurance of power inspection UAVs.

China's electric power inspection based on high-tech equipment compared to the developed countries started late, our country for a long time rely on artificial detection, and mainly shoot high- voltage transmission circuit equipment safety, cable damage, natural disasters destroyed ground and other issues, artificial need to spend a great deal of time cost and energy, accuracy is low, so our country in the application of small drones for electric power inspection at the same time, but also

979-8-3315-3508-7/25/$31.00 ©2025 IEEE

through the drones themselves carry the Shooting equipment on the high-voltage transmission lines to take pictures and analyze, and quickly pass the power related staff, the high-voltage transmission lines and other operational status observation, to facilitate the timely discovery of problems in a timely manner to deal with. Dai Yongdong [9] et al. based on convolutional neural network, improve the traditional DCNN algorithm, adaptive selection of photographed images, and verify its accuracy through experiments; Su Kaidi [10] et al. based on the YOLOv5 algorithm, to improve the recognition accuracy in the electric power inspection, and to improve the efficiency of its detection; Domestic engineers [11~13], have also done similar research, aiming to improve the photographic accuracy of the electric power inspection UAVs and the rapid processing method.

In this paper, the proposed drone power inspection system is first based on the determined high-voltage transmission lines, using particle swarm algorithm, stipulating the optimal target line; secondly, the inspection prototype drone lightweight design, and based on the optimal route to set a number of charger nests available to enhance the endurance of time at the same time, minimize the cost of the drone; and then through the on-board camera to shoot images of electric power inspection fault land Then, based on 5G communication technology, the image is transmitted and stored at high speed, and analyzed to generate an analysis report; and using the UAV power inspection differential equipment, based on the BeiDou satellite navigation system, the fault occurs in a precise location, and completes the repair of the fault problem, which greatly enhances the efficiency of the work of electric power inspection, and greatly saves the time and economic costs.

II. Path Planning Based On Particle Swarm Algorithm

When the UAV carries out the electric power inspection task, it needs to find the optimal path solution between many transmission high-voltage power line poles in a certain area, so as to ensure the endurance time of the UAV. Therefore, it is necessary to plan an optimal path that can be accomplished under the condition of known transmission lines to meet the endurance time of the UAV. The UAV designed in this paper is based on the optimization method of genetic algorithm particle swarm (PSO) to obtain the optimal path.

Particle swarm algorithm originates from the behavior of bird flock foraging, bird flock through each other's information transfer, make the bird flock to find the optimal path to the destination, this kind of scenario can be applied to this paper design of power inspection drone path planning, power inspection drone searching for transmission line route poles in a certain area, the drone is not able to know which line is the optimal solution to reach the next transmission line route poles, each drone in accordance with the Different routes to reach the next transmission line pole, and cannot touch the obstacles, in the search process, all the drones will share their own lines and found transmission line poles, in the process of each search, the drone will be based on their own records of the information, the next adjustment of the path of the next inspection transmission line poles, after a period of time after the search, you can know the transmission line in a certain region After a period of searching, the best path for inspecting transmission lines in a certain area can be known.

$$X_i^{k+1} = X_i^k + V_i^{k+1} \qquad (i = 1,2,\cdots i)$$

$$V_i^{k+1} = wV_i^k + c_1 r_1 \left(P_{id}^k - X_i^k\right) + c_2 r_2 \left(P_{gd}^k - X_i^k\right)$$

where X^k is the position of particle i after the kth iteration; V^k is the velocity of particle i after the kth iteration;V_i^{k+1} is the velocity of particle i after the k+1st iteration; X_i^{k+1} is the position of particle i after the k+1st iteration;P^k is the position of the individual optimal particle i after the kth iteration; P^k is the optimal position of the globally optimal particle g$r1$ and$r2$ is a random number of (0, 1), which is used to ensure the diversity of particle swarm optimization paths;$c1$ and$c2$ are the learning factor constants, in this paper's design, 2 is chosen; the inertia weight w is usually used to weigh the ability of the particle local optimization and global optimization, the larger w is, the more conducive to the global search without having to fall into the local optimal results, the smaller w is, the more conducive to finding the optimal solution within the local range, in this paper's design. This process is shown in the following figure 1.

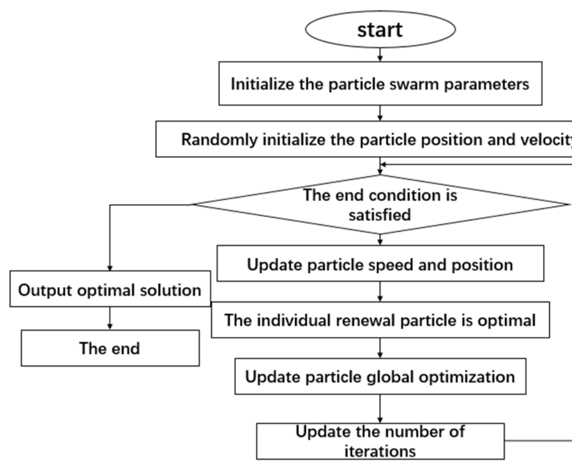

Fig. 1 Flowchart of particle swarm algorithm

First create a two-dimensional environment for modeling, simulate the transmission line route poles, then initialize the parameters, initialize the position and velocity of each particle in the particle swarm, i.e., the position of the UAV designed in this paper; then carry out an iterative loop to update the velocity and position of the particles at each time; update the particle's velocity and range, and process the ones that are out of its range, so as to make them search for the optimal routes within the specified area, and evaluate the Finally output the objective function value of the particle; update the optimal particle of the current particle and the global optimal particle; finally output the global optimal particle. As shown in the figure 2.

If in the process of updating the position of the particles, a certain section of the particle route collides with an obstacle, i.e., the UAV collides with a transmission line pole, the design algorithm in this paper will apply a penalty factor, or increase the penalty factor, to accelerate the speed of the particles while the particles are approaching the obstacle, so as to make them avoid the obstacle.

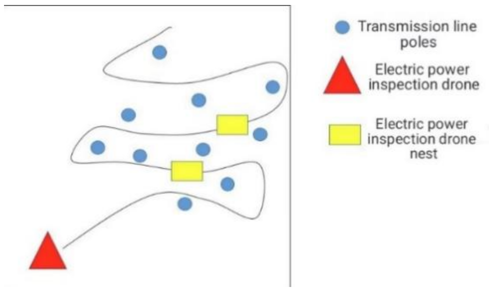

Fig. 2 Schematic diagram of circuit inspection drone

III. Range Enhancement Based On UAV Lightweight Design

The main structural weight of the aircraft includes the structure of the fuselage, wings, landing gear, etc. The ratio of the structural weight of the aircraft to the total weight of the aircraft at takeoff is called the structural weight coefficient of the aircraft, and the structural weight coefficient of the aircraft is an important index reflecting the aircraft endurance time, efficiency, and strength of the aircraft. For the UAV lightweight optimization design of numerous methods, can be based on computer-aided design software, the use of optimization design methods, the UAV lightweight design; or through the production or assembly to reduce unnecessary assembly quality, reduce the installation of glue, filler, etc.; or can be manufactured through the manufacture of a more lightweight materials to complete the structural design, and involves the strength of the design to meet the needs of use. The UAV designed in this paper is designed and produced with carbon fiber composite materials, and the assembly process is strictly quality controlled, so the first method mentioned above is chosen to carry out lightweight design of its structure.

Structural design optimization is mainly divided into size optimization, shape optimization, morphology optimization and topology optimization. The design variable of size optimization is usually the cross-sectional area of the structural member or the interlayer thickness of the composite material; shape optimization usually takes the shape of the structural member as the design variable to optimize the shape of the hole light; morphology optimization is usually used to design the thin- walled structure such as reinforcement bars; topology optimization takes the density of the material as the design variable, which has more degrees of freedom than size optimization and shape optimization, and there exists a larger design space. Therefore, this paper adopts the method of topology optimization to optimize the design of UAV.

For the pure electric UAV designed in this paper, if all the topology optimization of all parts of the aircraft structure is carried out, it undoubtedly greatly increases the energy and time cost, so it is necessary to consider the design optimization variables after the analysis of the working conditions. Therefore, the lightweight design of the UAV in this paper mainly focuses on the aircraft wing structure, in which the mass of the skin of the UAV wing and the edge strip and web structure of the wing beam and rib structure accounts for a relatively small proportion, while the weight of the edge strip and web of the UAV wing accounts for a relatively large proportion, so this paper will carry out the optimization design for it.

In recent years, due to the rapid development of science and technology, computer computing and analysis capabilities significantly enhance the finite element analysis of the front and back processing is increasingly powerful, the emergence of a number of design optimization software, such as ABAQUS, ANSYS, Hyperworks, etc., through the application of finite element optimization and design software, so that the optimization of the design process to shorten the design cycle, the efficiency of the process becomes higher.

In this paper, Hyperworks finite element optimization design software is used and in Hypermesh module, its topology optimization method is mainly SIMP method.

SIMP method, introducing a hypothetical variable material with a relative density in the middle of 0~1, the optimized design of the material elasticity model is nonlinearly related to its density. This is shown in the following equation:

$$E(x_i) = E_{min} + (x_i)^p(E_0 - E_{min})$$

where E(xi) is the optimized material elastic modulus and$E$0 is the initial state material elastic modulus of the structural material and p is the penalty factor.

In Hypermesh, the flexibility and mass response are first defined, and the volume fraction is set to 30% of the designable area as a constraint; the minimized flexibility is defined as an objective function as shown in the following equation, and the load and boundary conditions are applied to perform topology optimization.

Objective function: F(x)

$$\begin{cases} g_i(x) = 0 & (i = 1,2,\cdots\cdots i) \\ x_i \le x_j \le x_k & (i \le j \le k) \end{cases}$$

where $gi(x)$ is the topology optimization constraint function, which can be stress-strain, displacement and other constraints, andxj is its topology optimization design variable.

Its topology optimization mathematical model is shown below:

$$\min C(x) = \left\{ W^2 \sum_{k=1}^{n} W_k^q \left[\frac{C_k(x) - C_k^{min}}{C_K^{max} - C_k^{min}}\right]^q \right\}^{\frac{1}{q}} + (1 - W^2)\left[\frac{S_{max} - S(X_e)}{S_{max} - S_{min}}\right]$$

where q is the penalty factor, which is usually defaulted to 2 in the software settings, W is the weights for different working conditions, andC(x) is the minimized flexibility of the optimized structure.$Smax$, and$Smin$ are the maximum and minimum values of the average value of flexibility after the last optimization iteration, respectively.

And the final optimization design results are combined with the actual manufacturing process design, applied to the finite element model, and exported to the 3D finite element software model, and finally endowed with the material properties of its units to obtain its final weight.

In this paper, the design UAV range power is Li-ion battery, its weight is reduced after topology optimization, and its airtime will be improved.

IV. Power Inspection Application Based On 5G Communication Technology

The fifth generation mobile communication technology is more and more mature and widely used in our country, which has the functions of fast transmission speed, real-time rapid transmission of high-definition image and video, and high-precision positioning. Therefore, UAV + 5G communication technology has a wide range of scientific and technological application prospects, and the effective combination of the two reduces the cost of manual inspection, and makes great contributions to China's electric power and energy construction.

The power inspection drone designed in this paper carries a 4K high-definition infrared thermal imaging camera to carry out power inspection tasks, and shoots the transmission line poles of high- voltage power lines, fault points and special wire locations. The power inspection drone uploads the collected high-definition images to the cloud platform's intelligent computation server from the on- board end of the drone through 5G communication links, and analyzes and identifies the images intelligently by utilizing the filtering-based detection algorithms provided by the cloud, and generates the power inspection report of the drone, and then uploads the report to the manual end of the cloud platform. Analyze and identify, and generate the drone power inspection report, and then upload the report to the artificial end of the cloud platform, the artificial power inspection drone report for checking and verifying, timely processing of problems encountered and reporting high-voltage power line warning information.

At the same time, power inspection drone equipped with 4K ultra-high definition camera will be on the high-voltage power line poles for video shooting, 4K high-definition camera based on the principle of infrared thermal imaging, such as if you find the temperature of the line poles abnormal area, power inspection drone will be close to the video shooting, real-time uploaded to the cloud drone intelligent control system through the 5G communication system, after the power patrol staff to analyze and judge the existence of abnormal high voltage power line poles for numbering and arranging the power maintenance personnel to repair the faulty points. After the electric power inspection staff analyzes the video to judge and number the abnormal high-voltage power line poles, and accurately locate the faulty points of the poles, and arrange the electric power maintenance personnel to repair the faulty points.

Power inspection drone equipment loaded with flight control, Beidou RTK differential equipment, and with power inspection drone SDK secondary development software, as a drone power inspection navigation system, through the content of the second section of the development of the drone's autonomous routes, and in the ground station control software to simulate the test flight, according to the reality of the high-voltage power line transmission line poles as required to modify the route, after the simulation of the completed route into the drone Navigation system, autonomous route inspection, inspection process, RTK differential system centimeter-level positioning, remote control of the drone, high-definition image video real-time back to fully meet the design requirements for the use of high-voltage power lines transmission lines for real-time detection, timely processing. The processing flow is shown in the figure 3 below.

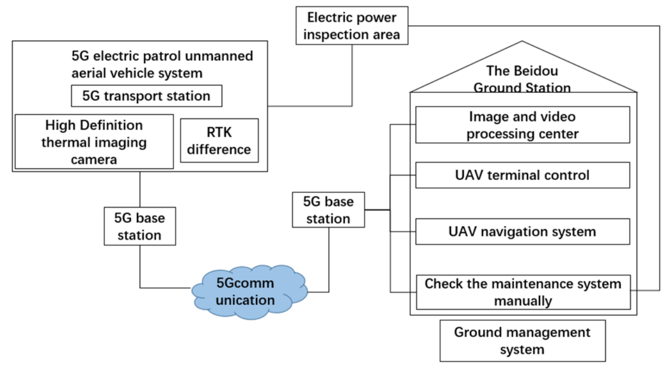

Fig. 3 Power inspection drone 5G communication inspection scene

5G communication technology is vital for intelligent power inspection by drones, based on 5G communication power inspection drone intelligent inspection, real-time judgment on transmission line fault information effect is remarkable, greatly improving the efficiency of power inspection.

V. Conclusion

In this paper, the proposed UAV power inspection is based on particle swarm algorithm, which specifies the optimized target line and inputs it into the UAV system, and then shoots images of the power inspection fault ground through the on-board thermal imaging camera, uploads the images to the cloud in real time and analyzes them, and accurately locates the fault ground based on the RTK difference of 5G communication system; and secondly, conducts a lightweight design of the inspection prototype UAV and vigorously improves the UAV's Endurance time. The power inspection UAV designed in this paper greatly improves the efficiency of power inspection and saves labor energy and time cost.

Funding

Research on large-scae fine patrol inspection and material transportation technology of high plateau complex environment power grid based on medium-load unmanned helicopter platform.

Number: 5500-202321181A-1-1-ZN

References

[1] Qichun Xu, Chenchen Guo, Zhiming Liu, Yayun Ma, Zhuo Pan, Jianhui Li. A dynamic trajectory planning method for autonomous inspection of UAV lines[J]. Journal of Power System and Automation, 2022, 34(10):24-31.

[2] Wang Zhou. Substation UAV inspection based on route autonomy planning [J]. Automation Instrumentation, 2022, 43(06):43-46+53.

[3] LI Xiaohui, ZHANG Lu, LIU Chuanshui, ZHAO Yi, DONG Yuan. Path planning algorithm for unmanned aircraft swarm in power inspection[J]. Computer System Applications,2022,31(03):241-247.

[4] XIE Zhiwen,WU Hui. Design of intelligent inspection system for power line UAV applying robot trajectory tracking technology[J]. Automation and Instrumentation, 2022,37(02):44-49.

[5] Cristian Ramirez-Atencia and Victor Rodriguez-Fernandez and David Camacho. A revision on multi-criteria decision making methods for multi-UAV mission planning support [J]. Expert Systems With Applications, 2020, 160(prepublished)

[6] MIAO Dongdong, LU Pin, WANG Qing, XU Haiming. Trajectory planning for power inspection UAV based on improved artificial potential field method[J]. Computer and Digital Engineering,2021,49(11):2260-2265.

[7] ZHANG Zhixun,XIA Qingfeng,CAO Yang. Range optimization of multi-rotor UAV[J]. Military Automation,2020,39(10):93-96.

[8] JIN GAYI, ZHU YE, ZENG SHUTING, XIA QINGFENG. Research on small multi-rotor UAV range problem[J]. Computer Knowledge and Technology, 2017,13(16):197-199.

[9] Y.D. Dai, J.G. Yao, Y. Li, F. Mao, Z.K. Wen, S.P. Cao. Power defect recognition method based on fixed-pointed adaptive selective convolutional neural network[J]. High Voltage Technology, 2021, 47(11):3827-3836.

[10] Su Kaidi, Zhao Qiao'e. Fast image recognition for UAV power inspection based on YOLOv5 algorithm[J]. Electric Power Science and Engineering, 2022,38(04):43-48.

[11] Ding-Song Wang. Research on the design and image processing of transmission line three- dimensional inspection system based on UAV [D]. Yangzhou University, 2021.

[12] Xie Linfeng. Research on the Recognition of Bare Ground Surface in Aerial Images of UAV Inspection [D]. Guangdong University of Technology, 2021.

[13] Chu Hongning. Design and implementation of intelligent analysis system for UAV inspection image [D]. University of Electronic Science and Technology, 2021.