Selection of unmanned aerial vehicles equipped with electric field sensors for detecting deteriorated insulators

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Abstract. With the rapid development of UHV, the demand for power line inspections continues to increase. The optical electric field method is the current cutting-edge insulator detection method, which is accurate. Mounting it on an unmanned aerial vehicle (UAV) can expand detection advantages, improve detection efficiency, and ensure safe electricity use. UAVs are currently developing rapidly, and there are many types of UAVs on the market. Due to the principle of the electric field method for detecting insulators and the real environment of power inspection site, there are certain requirements for UAVs. Therefore, we are striving to compare and analyze the UAVs on the market, and conclude that the optimal UAV choice for power line inspection is the quad-rotor UAV. Finally, the application will be promoted to provide reference and ideas for the inspection of oil pipelines. Introduction.

Key words: unmanned aerial vehicle (UAV), optical electric field method, quad-rotor UAV.

1. Introduction
In 2020, China proposes to develop new infrastructure, which clearly includes UHV [1]. UHV is currently the most advanced power transmission technology in the world, with comprehensive advantages of long distance, large capacity, low loss, and less land occupation. A new round of UHV construction is coming. At present, the State Grid Corporation of China has a clear investment scale of 112.8 billion yuan in UHV construction projects, which can drive social investment of 223.5 billion yuan, and the overall scale is nearly 500 billion yuan [1]. The safety of transmission lines is related to the reliability of power supply of the power grid, and it is also an important foundation for the construction of smart grids.

Insulators are the most used devices in power systems and are important parts of mechanical support and electrical connections in power transmission lines. However, due to long-term exposure to the outdoors, wind and sun, the insulators are prone to contamination and deterioration year by year. In this way, failures can easily occur, causing the power supply system to collapse and endangering the development of the national economy. Therefore, it is necessary to conduct regular inspections of insulators and timely replacement of degraded insulators to prevent accidents and ensure the safety of power transmission lines.
2. Insulator detection

Traditional insulator inspections mostly use manual methods. Line inspection has a large workload and long cycle. For some complex mountainous areas, Gobi and even dangerous areas, it is difficult to manually inspect power lines.

2.1. Existing insulator detection methods

At present, the detection methods of insulators in engineering commonly used infrared detection method, ultraviolet detection method, sonic method [2], and other methods, which are subject to the problem of equipment use distance limitation and transmission signal interference.

| Number | Method          | Detection operation and distance                                      |
|--------|-----------------|-----------------------------------------------------------------------|
| 1      | Observation detection | Manually climb the tower and the detection distance is very close     |
| 2      | Infrared detection        | Collect data remotely using professional equipment                  |
| 3      | UV detection                | Collect data remotely using professional equipment                  |
| 4      | Acoustic detection            | Collect data remotely using professional equipment                  |

2.2. UAV application

With the development of drone technology, its safe and stable operation has improved, making it possible to become a mobile platform to carry sensors for detection. UAV inspection of power lines has many advantages, such as not being restricted by the terrain environment, expanding the detection area, increasing detection scenarios, and more accurate detection results. At the same time, it avoids accidental fall or other casualties of power inspectors that may be caused by manual tower climbing, so it is very popular in the power industry [3].

At present, the cutting-edge technology of insulator deterioration detection is optical electric field detection, which uses the Pockels principle of lithium niobate crystal to manufacture electric field sensors to collect the electric field around the insulator [4]. Compare and analyze the data with the electric field distribution under normal operation and the electric field distribution of typical defects, and get the type and degree of deterioration. The combination of the optical electric field sensor and the UAV will further improve its detection mode, expand the scope and use of the detection device, realize further application innovation, and improve detection efficiency and accuracy. The maneuverability, stability, and endurance of the UAVs are very important for the detection effect. Therefore, it is necessary to select a suitable UAV to carry the electric field sensor.

3. Unmanned aerial vehicle(UAV)

In order to select a suitable UAV, the following will introduce different types of UAVs, compare them, and finally analyze and draw conclusions.

3.1. The development of UAVs

UAVs were originally used in the military field for military activities such as reconnaissance. UAVs began to develop in China in the 1950s for use in national defense construction and scientific research. With the development of embedded processors, micro-sensor technology, and control theory, MEMS technology is widely used in military weapons, civilian products, etc. [5].

UAVs are currently developing rapidly and are widely used in civil applications such as photogrammetry, field surveying and mapping, disaster relief aerial photography, police security, resource detection, express delivery, news media, and so on. As an important means of space data acquisition, the low-altitude data acquisition technology of UAV has the advantages of long endurance, low flight cost, high data resolution, flexible scheduling and maneuverability. It is a powerful supplement to satellite remote sensing technology and traditional aerial photogrammetry.
3.2. Types of UAVs
Three commonly used drones are selected below for introduction and comparison.

1) Fixed-wing UAV:
The fixed-wing UAV has strong endurance, fast flight speed and long flight distance, so it is suitable for large-scale surveying and mapping or information collection. However, the fixed-wing aircraft has many restrictions during take-off and landing, and it cannot hover. The crash rate of landing is relatively high. Landing through parachuting or crashing into the net has an irreversible negative impact on the life of the aircraft.

2) Unmanned helicopter:
The unmanned helicopter has relatively slow flight speed, short endurance, and good wind resistance. It can work normally at winds below level 6. It can hover and has strong load capacity.

3) Multi-rotor UAV
Multi-rotor UAVs can generally be divided into four rotors, six rotors, and eight rotors. It is controlled by remote control, so the working distance should not be too far, and the endurance is short. Multi-rotor drones are simple in technology, low in cost, convenient and lightweight.

3.3. Requirements for UAVs equipped with electric field sensors

Table 2. Detection methods of insulators

| Number | Requirements for UAVs |
|--------|-----------------------|
| 1      | It has fixed-point hovering ability to ensure that the distance between the drone and the insulator to be tested remains constant, making the collected data more reasonable. |
| 2      | The size of the UAV should not be too large to avoid inconvenience and accidents when crossing obstacles. |
| 3      | The electric field of its own electrical equipment has a small influence on the distortion of the electric field around the insulator, ensuring that the influence error is within a reasonable range. |
| 4      | It has a certain load capacity and can carry a variety of sensors. |

3.4. Comparison of UAVs
Compare the three types of UAVs in pairs and choose the UAV based on the requirements of the UAV equipped with the optical electric field sensor.

Comparison of fixed-wing UAV and unmanned helicopter:
The biggest advantage of unmanned helicopters over fixed-wing UAV is that helicopters can achieve fixed-point hovering. In terms of load capacity, although fixed-wing UAV are not as good as unmanned helicopters, they can be used to carry common optical instruments. At present, the power system of fixed-wing UAV has two types: oil-powered and electric, and its wind resistance is slightly stronger than that of unmanned helicopters. In summary, the advantages of unmanned helicopters are greater than fixed-wing UAV in power line inspection operations.

Comparison of fixed-wing UAV and multi-rotor UAV:
The endurance of fixed-wing UAVs is better than that of multi-rotor UAV, but the most significant disadvantage is that it cannot achieve fixed-point hovering, and under cruising conditions, the speed is too fast and the flying altitude is too high.

Multi-rotor UAVs are lighter than fixed-wing UAVs and have more versatile flight operations. Both have a certain load capacity and can carry common optical instruments. In summary, the advantages of multi-rotor aircraft are greater than fixed-wing aircraft in power line inspection operations.

Comparison of multi-rotor UAV and unmanned helicopter:
Both can realize fixed-point hovering and precise positioning of inspection points. Unmanned helicopter is larger in size than multi-rotor UAV, and is not as flexible as multi-rotor UAV during inspections, so it cannot detect insulators under some complex terrain. At the same time, the cost of multi-rotor drone is lower, which can reduce inspection costs in actual production. After simulation
verification, the quad-rotor UAV measurement system has extremely low impact on the original electric field of the insulator, which meets engineering requirements. Therefore, the advantages of multi-rotor aircraft are greater than fixed-wing aircraft in power line inspection operations.

In summary, the multi-rotor UAV is the best choice for power inspection operations.

4. Conclusion

According to the research conducted by North China Electric Power University on the multi-rotor DJI Matrice 600 Pro, when the applied electric field is parallel to the UAV, the error is 0.8%~1.9%; when the applied electric field is perpendicular to the UAV, the error is 1.8 %~7.9%, all meet engineering needs, so the multi-rotor UAV equipped with optical electric field sensor will not affect the accuracy of its measurement results. [4]

Among the multi-rotor UAVs, the quad-rotor UAV is a good choice.

Quad-rotor UAV is a kind of aircraft with four rotors, and the four rotors are distributed in a crisscross pattern, which can achieve stable hovering and precise flight by balancing the forces generated by the four rotors[6]

The quad-rotor UAV can land vertically and hover freely. At the same time, it has the following obvious advantages.

1. Small size, light weight, easy to carry, quadrotor UAV has strong maneuverability and can conduct inspections more quickly and efficiently.
2. The structure is simple, the rotor is fixedly connected to the motor, and no complicated mechanical transmission device is required, so the manufacturing process becomes simple.
3. There is no need for a professional airport to take off and land, it can adapt to multiple platforms and can take off and land flexibly on the ground.
4. The flying altitude is a few meters to a few hundred meters, and the speed is a few meters to tens of meters per second, which are suitable for insulator detection.

These advantages enable the quad-rotor UAV to be equipped with an integrated optical electric field sensor to inspect the spatial electric field of line insulators, detect degraded insulators in time, and ensure line safety and grid power supply safety.

5. Result promotion

UAVs used for power inspections can provide references and ideas for oil pipeline inspections. The UAV platform can be equipped with multiple sensors [7], such as: visible light camera, infrared thermal imager [8], ultraviolet detector [9], laser scanner, etc., to collect various information on the inspection line.

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