Design and implementation for integrated UAV multi-spectral inspection system

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Abstract. In order to improve the working efficiency of the transmission line inspection and reduce the labour intensity of the inspectors, this paper presents an Unmanned Aerial Vehicle (UAV) inspection system architecture for the transmission line inspection. In this document, the light-duty design for different inspection equipment and processing terminals is completed. It presents the reference design for the information-processing terminal, supporting the inspection and interactive equipment accessing, and obtains all performance indicators of the inspection information processing through the tests. Practical application shows that the UAV inspection system supports access and management of different types of mainstream fault detection equipment, and can implement the independent diagnosis of the detected information to generate inspection reports in line with industry norms, which can meet the fast, timely, and efficient requirements for the power line inspection work.

1. Introduction
The stable operation of the transmission line is a prerequisite to ensure the complete operation and the social stability of the power system, which is a key point in the power distribution. As most of transmission line equipment is exposed to the complex environment of the outdoors over the long term, oxidization, broken strand, rust, overheating and other defective conditions may occur with the wires, lightning wires, insulators, fittings and other equipment. In order to ensure the normal operation of the transmission line, the inspector shall regularly inspect the fault of the transmission line. In order to avoid missed inspection, the inspector shall carry a variety of testing equipment for comprehensive testing [1]. Such comprehensive inspection work will consume a lot of manpower. Even with all kinds of testing equipment being carried, the instruments do not have the linkage characteristics to each other, and each instrument needs to detect each phenomenon one by one to find contrasts, which has low efficiency and is difficult to find potential problems. With the increase in the number of inspection equipment, the inspection workload is also increasing. Therefore, we urgently need a convenient, comprehensive and efficient inspection method.

UAV has advantages of easy carrying, simple operation, rapid response, abundant load, wide range of tasks, low environment requirements for take-off and landing, autonomous flight, etc. [2] The application of UAV to power inspections can greatly improve the speed and the efficiency of power maintenance and overhaul so that many jobs can be completed in a fully charged environment to
ensure the electrical safety. The use of UAV in the conventional transmission line inspection can reduce the labor intensity, and can improve the safety of inspection operators and reduce the costs as compared with the inspection with a manned helicopter. UAV inspection is fast, has high speed in emergency, is capable of detecting defects, and provides information in a timely manner to avoid the power outages due to line accidents and restores the high losses caused by power outages. Through the joint line inspection with rotor wing and fixed wing UAVs, we can quickly inspect a wide range of transmission line corridor and efficiently have access to high-definition photos of the line equipment. This allows us to clearly distinguish the defects of the common transmission line, which greatly enhances the inspection efficiency of the transmission lines, and provides an advanced technical means with practical values for the maintenance of the modernized transmission line. For the infrared, UV detection and other tasks shot by UAV with visible light, the airborne equipment implements the flight inspection to the transmission line, and transmits the on-site situation back to the ground monitoring system in real time in order to make a correct judgment and promptly exclude line failures. It also shoots 360 degrees around the target and in all directions for zero dead angle.

In recent years, the means of optical detection have become more and more important in electric power detection systems. At present, the optical charged detection means used in the power system includes infrared imaging technology, UV imaging technology and visible light HD monitoring [3]. Because of different natures of the detected faults, these three detection techniques are often independent of each other in the hardware. In the power detection process, different devices are used to separately detect faults of the circuit system in different stages. Therefore, it is not conducive to the safe and efficient operation of the power detection. It is of practical significance to develop UAV-mounted UV/visible/thermal infrared composite system [4].

On the other hand, the UV detection technology has gradually developed into a newly-emerging photoelectric detection technology following the infrared and laser detection technologies. The core technology in UV detection -- solar-blind UV imaging technology is one of the most sophisticated military-purpose photoelectric detection technologies in the world. It uses "solar blind region" to reduce the background interference of ultraviolet radiation from the sun, and only needs to detect the UV radiation of the target, so as to enhance the speed of information processing. Ultraviolet light is the electromagnetic wave with the spectrum wavelength between 100nm and 400nm. Solar radiation background noise is natural noise. All ultraviolet detectors actually work in the context of solar spectral radiation. Figure 1 is a schematic diagram for solar-blind UV detector under the background of solar spectral radiation [5].

![Schematic diagram for solar blind UV detector in the context of solar spectrum radiation](image)
The ideal detector response curve is sharply cut off at 285nm, and for the wavelength part afterwards, the background of solar radiation is negligible. But due to the decreased photon absorption rate near the cut-off wavelength, there is usually a drop tail in the detector response curve. And after wavelength exceeds 285nm, solar spectral radiation increases exponentially, and has reached $10^{13}$ph/cm²/nm¹/s¹ at 300nm, so such a tail produces a large number of photons that cannot be ignored [6]. Even if we take into account the environmental reflection loss, the number of leaked photons is still very large. Therefore, solar radiation background noise is another major source of detector noise that cannot be ignored, in addition to the noise of the detector itself [7].

This article will design a light-duty solar-blind UV camera for the integrated UAV multi-spectral inspection system.

2. System design
As the UAV load has a certain limit, the inspection equipment shall be light-based, and the inspection analysis needs to have the automation capability. The design first considers maximizing the integration of inspection modes of all inspection equipment. It then considers the realization of interoperability of all types of inspection equipment, build a data information processing system, and considers the scalability of the entire system. Finally, it implements a lightweight design for each piece of inspection equipment.

2.1. Integration mode
This paper designs the integration mode applicable for UAV inspection, including UV, infrared and visible inspection equipment, based on the understanding of all types of equipment for power line inspection.

2.2. System architecture design
The whole architecture is divided into three parts, including the information collection equipment, the information-processing platform, and the remote terminal equipment. The information collection equipment, the information processing platform and the terminal are networked in the wired or wireless way, and the wired interface is a common communication interface, such as a network port, RS232/RS485, USB, etc., with strong universality. The information-processing platform contains the wireless network module, of which the function is used to communicate with the remote terminal to facilitate the processing of its equipment information collection, processing, management, storage and forwarding output services.

2.3. Data information processing system
After completing the integration mode of the inspection equipment, all the equipment needs to be interconnected, so that the whole system can play its value [8]. On the other hand, an information-processing platform is needed to collect, process, store, manage and output all the information of the testing equipment, thus reducing the function dependency of the system on the inspection equipment. There are many sets of detection equipment of a variety of data types in the transmission line inspection; the integrated information processing terminal should include multi-channel video, voice and data stream information processing, and has low power consumption, small size, strong performance, easy expansion and other properties.
2.3.1. Hardware platform selection
In all information types, multi-channel voice and data class information processing has relatively lower requirements for the platform, so the solution of the multi-channel video information processing is the key to the system. In the actual inspection, it should meet at least three-channel video information collection, algorithm operation, coding and network output, and need to have enough voice and universal data transmission interfaces for accessing of inspection equipment. The information processing terminal usually uses the X86 or embedded platform. The single-chip embedded processor has been difficult to meet the performance requirements of this application, and when the ARM, DSP, FPGA and other integrated design are used, the difficulty to design the architecture and the development is surged. With the continuous development of the X86 hardware architecture, its power consumption and size have been gradually approaching to the embedded platform, and the X86 platform usually has a higher performance. In addition to the power consumption, size and performance, it is necessary to consider the development environment, openness and availability in the implementation. Many practical applications show that the X86 platform is superior in computing terminals [9].
In the specific selection, the Intel J1900 platform [10] is selected, and its dominant frequency is 2.0GHz, supporting Intel 7th-generation display core; in addition to the high dominant frequency, the GPU is used for parallel algorithm development and video hard coding. The entire board peak power consumption of Intel J1900 is 10W, and it has more common data peripherals to fully meet the requirements of the system.

2.3.2. Software architecture and design
In the integrated information terminal part, the software architecture diagram is shown in Figure 2.

![Software architecture diagram](image)

**Figure 2.** Software architecture diagram of the data information processing system
During the software architecture, it is divided into the information stream processing module and the control module. With the video stream, for example, the audio and data class multi-channel information processing and control modes completely refer to the software architecture of the video stream part. In the video stream processing module, first the multi-channel video stream of the module networking is buffered and received through the network, and then the data of each frame is extracted in the cache for processing. In the video stream control protocol, complete each video stream switching, parameter settings, and other operation based on the standard protocol in the built-in TCP server.

For each video stream, there are a customizable image preprocessing interface, an algorithm processing and analysis interface, an image fusion interface and a video compression interface. The image processing interface is mainly used for cutting, scaling, binarization and other processing. The algorithm processing and analysis interface is mainly used for algorithm analysis of different video streams, such as visible light video object recognition, infrared video temperature analysis, UV video photon counting and other algorithm. The image fusion interface is mainly used for information exchange and fusion between different devices. The video compression interface is mainly used for multi-channel H.264/H.265 compression to reduce the amount of information transmitted. In the video stream processing process, it can store the intermediate variables and the result files to achieve the

Figure 3. Software flow chart of the data information processing system
localized data storage, and also can be called by other devices through RTSP or RTP network protocol in real time. In addition, it provides the TCP server for internal running mechanism switching and parameter settings of other devices in real time.

During the specific development, the multi-threaded writing is used, the integrated development environment is VS2013, and the software flow chart is show in Figure 3.

After the software is initialized, the system opens a video stream acquisition thread for obtaining the video stream and the data stream of the access system. When the corresponding information is acquired, a service thread is created, the obtained video stream is decoded, the data stream is unpacked, and the processed information is pushed to the corresponding buffer channel. At this time, start the processing thread that has received the channel data for the UV, infrared and data processing. While the video stream processing thread is running, the control command thread is running at the same time for real-time configuration and selection. The control thread is essentially a TCP server, and is used to monitor the control and query commands sent from the fixed port for parsing, verification, processing, and response.

3. Equipment light-duty design

At present, the infrared and visible UAV equipment has been basically matured, but the UV UAV equipment is still in the exploratory stage. This paper presents the UV detector miniaturization example and successfully implements based on the industry experience.

3.1. UAV airborne UV imaging module

The system chooses the optical material with the fused silica and calcium fluoride as the lens, and these two materials have good transmission performance to the solar blind UV band. After that, the UV lens was optically designed and optimized according to the requirements of UAV.

The UV module mainly consists of the UV CCD, UV lens, control circuit board, fixed structure and other sub-modules. Since the rigidity of the baseboard will directly affect the stability of the UV module, in order to increase the rigidity of the baseboard and reduce the assembly error, the baseboard of the UV module adopts the integrated design. All the sub-modules are directly fixed on the baseboard, so the assembly error is greatly reduced. Its strength is taken into account while reducing the weight. The baseboard is made of 7075 aviation aluminum material, and its wear resistance and corrosion resistance are increased through the surface oxidation.

At present, the overall weight of the UV module is less than 1kg, which can meet the needs of UAV. Figure 4 shows the physical diagram for the UV imaging module.

![Figure 4. Physical diagram of the UV module](image)
The technical parameters of the UV module are shown in Table 1, and the performance parameters have reached the international front.

**Table 1. Technical parameter list of the UV module**

| Performance          | Technical Parameter |
|----------------------|---------------------|
| Sensitivity          | $2 \times 10^{-18}$ W/cm$^2$ |
| Working band         | 240-280nm           |
| Perspective          | $10.4^\circ \times 7.8^\circ$ |
| Focal length         | 78mm                |
| Frame frequency/Hz   | 25                  |
| Weight               | 1kg                 |
| Focusing mode        | AF mode             |

The test results of solar-blind performance and UV sensitivity are shown in Figure 5.

**Figure 5.** Solar-blind (left) and sensitivity (right) performance of UV module, which is working in combine mode (UV (white point) & Visible))

These results show that the performance of the UV module meets the requirements.

3.2. Infrared and visible module selection

At present, UAV infrared and visible imaging modules have been matured, and the infrared/visible module parameters used in the system are shown in Table 2 and Table 3.

**Table 2. Technical parameter list of the infrared module**

| Performance          | Technical Parameter |
|----------------------|---------------------|
| Sensor type          | Non-cooled          |
| Working band         | 8-14um              |
| Perspective          | $8^\circ \times 6^\circ$ |
| Resolution           | 640×512             |
| Frame frequency/Hz   | 50                  |
| Weight               | 200g                |
| Focusing mode        | AF mode             |

**Table 3. Technical parameter list of the visible module**

| Performance          | Technical Parameter |
|----------------------|---------------------|
| Focal length         | Zooming             |
| Resolution           | 1920×1080           |
| Image size           | 1/4 in              |
| Frame frequency/Hz   | 30                  |
3.3. Information processing module
The information processing module mainly consists of the X86 platform, power management and network module. The information processing flow chart is shown in Figure 6.

![Image processing flow chart](image)

The main functions in the processing terminal are divided into three parts: the data stream link, the control stream link and the processing container. Where the data stream link is mainly used for information collection, compression and transmission of the inspection equipment accessed to the system. The control stream link is mainly used for parameters setting, function switching and other interaction of the inspection equipment. The processing container is mainly used for the information processing, integration and analysis of the inspection equipment.

In all the information processed, the image and video information has the highest requirements for the platform. The related performance indicators for average 1080P image processing after several tests under the Intel J1900 platform are shown in Table 4.

| Item               | Content         | Time spent (fps) | Consumed memory |
|--------------------|-----------------|------------------|-----------------|
| Video compression  | H264            | 0.0297s          | 215.2Mb         |
|                    | MPEG4           | 0.0343s          | 307.6Mb         |
| Image processing   | Crop            | 0.0173s          | 8.7Mb           |
|                    | Shifting        | 0.0091s          | 9.2Mb           |
|                    | Fusion          | 0.0315s          | 17.3Mb          |
| Image analysis     | Photon counting | 0.0464s          | 8.5Mb           |
|                    | Fault zone analysis | 0.0382s        | 9.1Mb |

4. Practical application
Figure 7 shows the physical diagram of the photoelectric pod, which is sealed with metal and window glass. Each module of the multi-spectral inspection system has a separate window.
Figure 7. Photoelectric pod

Figure 8 (left) shows the schematic diagram of the inspection site. Figure 8 (right) is a picture of the integrated UAV during inspection.

Figure 8. Schematic diagram of the inspection site (left) and integrated UAV during inspection (right)

Figure 9 shows sample of UV images. After the inspection, we find a burr where the UV image shows.

Figure 9. Sample of UV image

Figure 10 shows sample of VIS and IR images, where bad connection is found at the hot point shown in the IR image.
Figure 10. VIS (left) / IR (right) Image

When the inspection equipment is turned on, the handheld terminal has a connection notification and describes the relevant information of the equipment. On the handheld terminal, set the automatic fault analysis mode of the UV detector. When the questionable fault point is detected, the alarm information is displayed at the handheld terminal. It can meet the needs of all-day inspection. After the system is used, during the inspection, the inspection equipment is easy and fast to use, and the inspection human/times are significantly reduced; the inspection information on each equipment is under linkage response, and it can automatically identify and analyze the fault, and fault detection rate is greatly improved.

5. Conclusion and Outlook
This paper designed and implemented a set of UAV power inspection system, and presented a new and efficient power line inspection mode. A set of open hardware and software standard interface is designed for the entire inspection system, which can support access to the inspection equipment of different technical means for unified management, storage, analysis and report generation; the system can also support handheld terminals and remote network access. This paper gives an example of UAV UV imaging equipment, and is more lightweight and internationally advanced while meeting the performance requirements of similar products in the market. This paper gives the overall solution of the information processing platform in the inspection system, completes the platform selection, software design, development and debugging, and implements the full functions on the intel J1900 processing platform and tests out the specific performance indicators. The UAV power inspection system realized in this paper greatly improves the efficiency and quality of the power line inspection work, satisfies the practical needs of the field operation and maintenance personnel and ensures the safe operation of the grid equipment.

References
[1] DL/T 741-2010 Overhead Transmission Line Operating Procedure
[2] Li L 2012 Discussion on UAV inspection technology on overhead lines Changsha University of Science and Technology p 44-47
[3] Xiong D 2014 Study and application of UAV inspection line for transmission lines Wuhan University of Science and Technology 2014
[4] Cao X, Yue T, Lin X, Lin S, Yuan X, Dai Q, Carin L, and Brady D 2016 Computational Snapshot Multispectral Cameras: Towards Dynamic Capture of the Spectral World IEEE Signal Processing Magazine 33 (5): 95-108, 2016
[5] Li X, Zhu C, Zhu X, Xu Z, Zhuang X, Ji X, and Yan F 2013 Background limited ultraviolet photodetectors of solar-blind ultraviolet detection *Appl. Phys. Lett.* 2013 103,171110

[6] Ding J, Li X, Zhu X, Cao X, and Yan F 2015 Solar-irradiated leakage of UV camera for daytime corona inspection *Electrical Insulation and Dielectric Phenomena (CEIDP), 2015 IEEE Conference on* 10.1109/CEIDP.2015.7352117

[7] Liang Y, Zhang S, Cao X, Lu Y, and Xu T 2017 Free-standing plasmonic metal-dielectric-metal bandpass filter with high transmission efficiency *Scientific Reports* 7 (4357), 2017

[8] Zhang B 2008 Design and implementation of intelligent inspection management system *Shenyang University of Technology*

[9] Xu Y 2010 Design and research of wearable computing terminal hardware based on X86 architecture *University of Electronic Science and Technology*

[10] 2013 How To Choose AMD and Intel CPU Processor *Computer and Network* 2013, 39(9)

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