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The Research of Real-Time UAV Inspection System for Photovoltaic Power Station Based on 4G Private Network

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Abstract. With the development of unmanned aerial vehicle (UAV) technology, the inspection system which takes the UAV as the carrier is developed. The traditional UAV inspection systems often use radio station or 3G network to transmit data. Due to the limitation of the communication bandwidth, inspection image or video data mostly uses the way of local storage and post hoc analysis, which is not conducive to the resolution of the problem. Therefore, this paper proposes a photovoltaic power station UAV real-time inspection system based on 4G private network. The system realizes the stable real-time transmission of thermal image data and the communication scheme of the system is optimized. The feasibility of the system has been verified through many experiments.

Keywords: 4G private network, infrared thermal image, photovoltaic power station, UAV

1 Introduction

With the rapid development of aviation technology, unmanned aerial vehicle (UAV) has been widely used in the field of power system [1]. The application of UAV system in inspection of the photovoltaic power station can reduce the labor intensity and the risk of operation of the inspection personnel, and improve the efficiency of the inspection [2]. The information obtained from the UAV inspection system is usually high resolution image or video data. The data is too large to take up a wide bandwidth, so it is difficult to achieve high speed real-time image transmission [3].

The traditional communication scheme of UAV inspection system usually includes satellite communication, 3G mobile communication and coded orthogonal frequency division multiplexing (COFDM) wireless communication scheme [4]. The satellite communication scheme uses on-board satellite transmitting system to realize the remote image transmission. Satellite communication scheme has many shortcomings, such as limited link, high bit error rate, time delay and frequent interrupt, which can't meet the needs of the continuous real-time transmission of the image. 3G mobile communication scheme transmits the inspection data through the 3G access module and wireless network [5]. Photovoltaic power plants are usually built in remote areas, so the 3G mobile network is difficult to cover, which greatly limits the use and promotion of the scheme. COFDM wireless image transmission scheme mainly adopts COFDM modulation technology and MPEG2/MPEG4 digital compression coding technique to process the front-end collected image rapidly, and then return it to the control center. This scheme can't meet the requirement of real time transmission of large amount of data with the bandwidth of 5.6~9.4M and the transmission rate of 2~8 Mbps [6]. Therefore it is urgent to propose a new communication scheme to guarantee the reliable real-time transmission of the inspection data.

This paper presents a real-time UAV inspection system for photovoltaic power station based on 4G private network and a new 4G communication scheme is proposed. This scheme chooses 4G private network base stations and 4G wireless communication modules to establish a 4G private network data communication link. The scheme can realize the real-time transmission of the infrared image data collected in the inspection process to the ground monitoring station directly through the 4G private network. This scheme makes up for the deficiency of the traditional communication scheme, and realizes the integrated action of the detection and maintenance of the photovoltaic power station. After many field tests in the photovoltaic power station, the feasibility of the proposed system is verified.

This paper is organized as follows. In Section 2, a description of system overall structure is given. Section 3 introduces the UAV data acquisition system. Section 4 describes 4G private network data communication scheme. In Section 5, two experiment tests are conducted to verify the performance of the proposed system and the results are given. Finally, the conclusions are given in Section 6.

2 Overall Structure of the System

The overall design scheme of the real-time UAV inspection system for photovoltaic power station based on 4G private network is shown in Fig. 1. The system mainly consists of three parts: UAV data acquisition system, 4G private network data communication link and ground monitoring station.

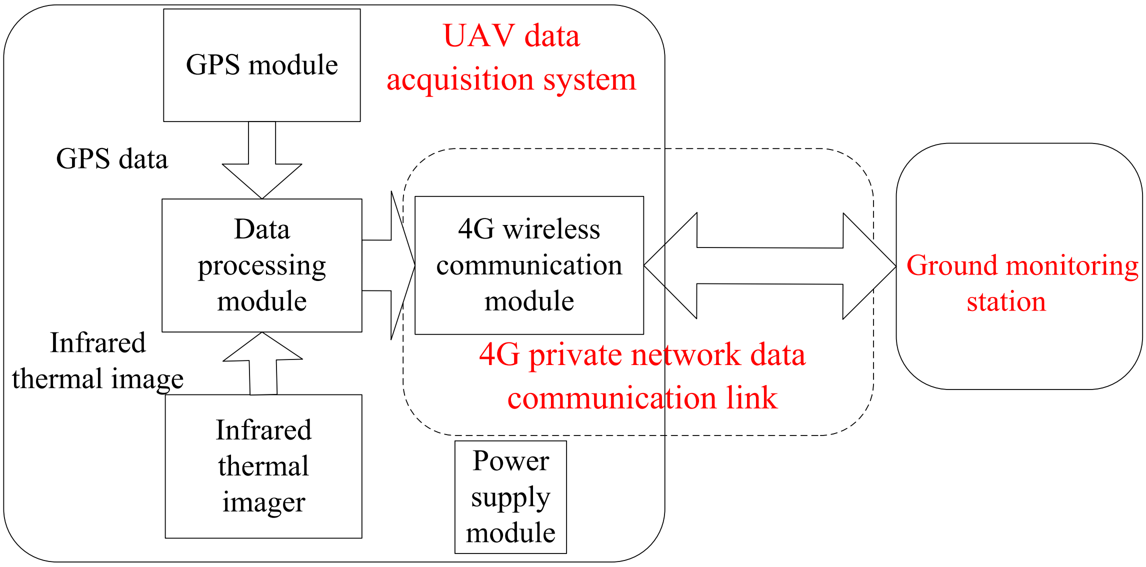

Fig. 1. The overall design structure diagram

UAV data acquisition system chooses six rotor UAV as a platform, equipped with infrared thermal imager, GPS module and the 4G wireless communication module to achieve image data acquisition and real-time transmission. After integration, the thermal imaging data and GPS data are output to the 4G wireless communication module through the Ethernet interface.

4G private network data communication link is composed of 4G private network base stations and 4G wireless communication modules. 4G private network base station based on TD-LTE should be installed in the photovoltaic power plant to ensure 4G signal coverage. After 4G wireless communication module dial-up is successful, the data communication link of whole system is established. The 4G wireless communication module is essentially like a 4G wireless network router. It is responsible for the real-time and high speed return of infrared thermal imaging data collected in the inspection process to the ground monitoring station directly through the 4G private network.

Ground monitor station is mainly used for UAV flight state monitoring and control, also the ground control personnel can detect and eliminate hidden troubles according to the real-time return of infrared image data.

3 UAV Data Acquisition System

3.1 UAV Platform

The inspection work in photovoltaic power plant requires that UAV should be equipped with certain level of wind resistance, enough flight endurance and a vibration and anti-shake pan–tilt for infrared thermal imager. To obtain a better inspection effect, UAV need to have a fixed point hover function when the UAV inspection system reaches a certain height or suspicious hot spot. In order to meet the requirement of the system, we choose a six rotor UAV as the platform which is more suitable for photovoltaic power plant inspection work with longer fixed point hover time. After the infrared thermal imager is mounted on the vibration and anti-shake pan–tilt, the direction of lens is always kept vertical downward. The specifications of the UAV are shown in Table 1.

Table 1. UAV specification parameters

Items	Specification parameter
Maximum load mass (kg)	4
Flight endurance (min)	30
Standard cruising speed (m/s)	5
Maximum takeoff altitude (m)	3000
Relative maximum flight height(m)	2000
Hover accuracy(m)	horizontal direction: ±1.5 vertical direction: ±0.5
Wind resistant grade	work: three level wind safety: five level wind

Considering the UAV platform should be equipped with GPS module (10g), infrared thermal imager (440g), 4G wireless communication module (65g) and the battery (2000g), totally 2515g, so the maximum load mass of the UAV is 4kg. Because the UAV inspection system in this paper is mainly used in most regions of the country except for some plateau sections like Qinghai and Tibet, the maximum takeoff altitude can select 3000m. As flight endurance of the system is 30min and the field angle of the infrared thermal imager is 25°×19°, if the UAV inspection system cruises with a speed of 5m/s, the system can patrol the area of about 2133333 square meters. It is enough to accomplish the inspection work in vast majority of photovoltaic power plant. The UAV platform is shown in Fig. 2.

Fig. 2. The UAV platform

3.2 GPS Module

The size of most photovoltaic panels is more than one square meters, so the positioning accuracy of the system only need be up to less than 1m. We only need to find which photovoltaic panel has appeared the problem, and then notify the relevant personnel to deal with it. The system selects the GPS module with a positioning accuracy of submeter. The weight of the GPS module is 10g and the power is 2W, which meets the needs of the whole system.

3.3 Infrared Thermal Imager

In order to realize the real-time transmission of infrared thermal imaging data, the infrared thermal imager should be able to communicate with ground station through serial port or wireless. Taking into account the limited endurance ability of the UAV inspection system, the weight of the thermal imager should be as light as possible, so the weight of the selected thermal imager is 440g. The main parameters of the thermal imager are shown in Table 2.

Table 2. Main parameters of the thermal imager

Items	Specification parameter
Pixel	640×480
Weight	440 g
Pixel size	17μm
Field angle	$25^{o}\times19^{o}$
Focal distance	25 mm
Angular resolution	0.68 mrad
Temperature range	-20~150 ℃
Thermal sensitivity(NETD)	< 0.06 ℃
Temperature measurement accuracy	±2 ℃

4 4G Private Network Communication Scheme

The 4G private network communication scheme proposed in this paper is shown in Fig. 3.

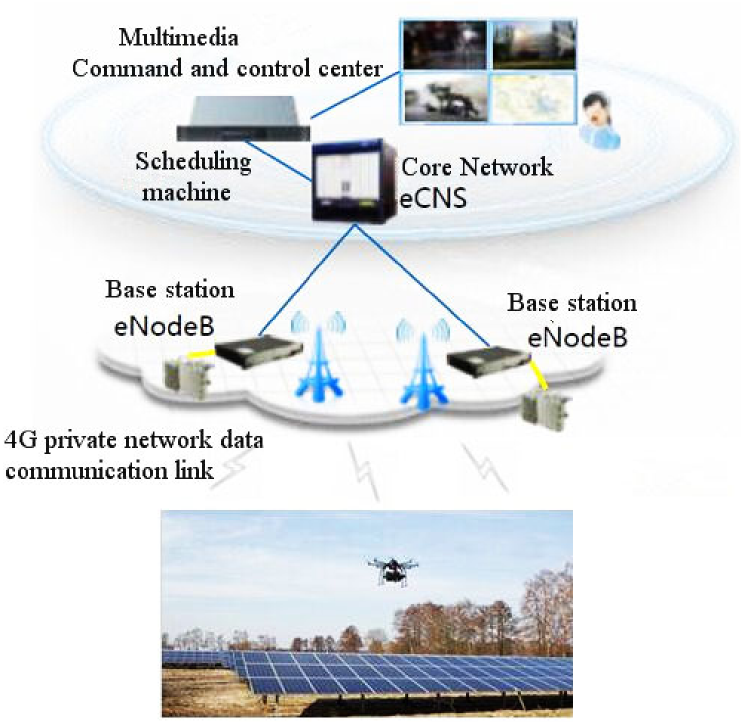

Fig. 3. The 4G private network communication scheme

The 4G private network communication scheme based on TD-LTE technology adopts a variety of advanced wireless communication technologies, such as orthogonal frequency division multiplexing (OFDM) and multiple input multiple output (MIMO) technology. It enhances the coverage and data throughput effectively. In addition, TD-LTE technology reduces the data transmission delay greatly using flat networking scheme.

4G private network base station based on TD-LTE should be installed in the photovoltaic power plant to ensure 4G signal coverage. 4G wireless network base station uses the TD-LTE wireless network access equipment eNodeB, including eBBU (baseband control unit) and eRRU (remote radio unit). The configuration of bandwidth is 20MHz and the frequency range is 1785~1805MHz. The maximum throughput of a single eNodeB is up to downlink: 450Mbit/s, uplink: 300Mbit/s. In addition, a portable 4G base station can be selected which can greatly reduce the cost of its laying. Compared with ordinary base station, it owns more flexibility. Base station antennas are generally hung at 60m in order to have a good coverage area.

4G wireless communication module is used as a broadband access CPE device based on TD-LTE technology. A variety of acquisition data or video monitoring data can be accessed to the TD-LTE broadband cluster network through the Ethernet port or WIFI of the 4G wireless communication module. 4G wireless communication module can provide high-speed data services and support for the maximum transmission rate of downlink: 100Mbit/s and uplink: 50Mbit/s. It can be used to realize high speed real-time transmission of the image data. Table 3 shows the comparison of 2G, 3G and 4G communication scheme.

Table 3. The comparison of 2G, 3G and 4G communication scheme

	2G	3G	4G
Technical scheme	GSM	CDMA	OFDM
Signal bandwidth	200 kHz	5 MHz	100 MHz
Transmission rate	9.6 kbit/s	2 Mbit/s	100 Mbit/s

Table 3 points out the advantages of the proposed 4G communication scheme. The communication speed of 4G is faster and the fastest speed can reach 100Mbit/s. The network spectrum is wider. Each 4G channel will occupy 100MHz of spectrum, equivalent to 20 times of 3G network. Owing to the use of MIMO technology, compared with the 2G and 3G communication schemes, 4G communication greatly improve the capacity and reliability of the channel, reduce the bit error rate, and its spectrum utilization has been largely improved [7].

5 Experiment Test and Results

5.1 Preparation for Test

Test preparation: six rotor UAV, infrared thermal imager, submeter GPS module, 4G wireless communication module (1.8GHz band), portable 4G network station (20MHz bandwidth), artificial “hot spots” markers. Due to the limitation of the conditions, we directly put the printed paper on the photovoltaic panels to simulate the “hot spots”, as shown in Fig. 4.

5.2 Hover Test

When the distance between the thermal imager and the photovoltaic panel is l (m), the calculated formula of the minimum size s (cm) of the hot spots which can be identified is shown as (1):

$$s = \frac{40 \times l \times dps}{f} \quad \textbf{(1)}$$

where dps is the pixel size of the thermal imager(here: 17μm), f is the focal distance of the thermal imager (here: 25mm).

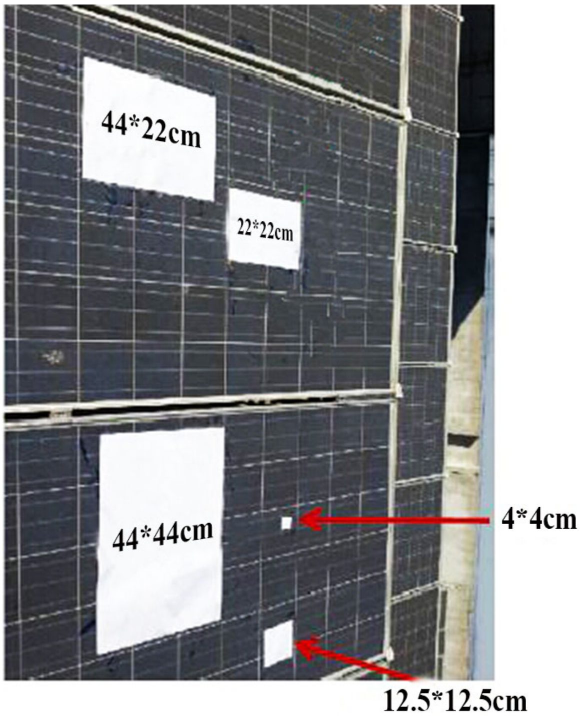

Fig. 4. Experimental artificial "hot spots"

The hover test is carried out to measure the minimum size of the hot spot which can be identified in different hover height (here the hover height is equivalent to the *l* mentioned above). In the test, we let UAV inspection system hovering in the relative photovoltaic plate height of 10m, 40m, 50m, 70m and 80m. Hover test results are shown in Table 4.

Table 4. Hover test results

Hover height (m)	Theoretical minimum size *s*(cm)	Actual minimum size *s* (cm)
10	2.72	4
40	10.88	12.5
50	13.6	12.5
70	19.0	22
80	21.8	22

Table 4 shows that the minimum size of the hot spot which can be identified is basically consistent with the theoretical value within the limits of error.

5.3 Cruise Test

The flying length of the return video is fixed at different heights. The length of a frame video in this system is 13.6 cm. However, the image scale is different at different heights, so the actual distance L which a frame video represents is not the same. The relationship between the image scale and UAV flight height h is 1: $(24 \times h/10)$.

In order to ensure that all the data can be collected in the flight process of the UAV inspection system and achieve the best inspection effect, the UAV inspection system in flight process must meet (2):

$$V \times t \leq L \tag{2}$$

where *V(*m/s) is the cruise speed, and t is the processing time of each frame video. As the processing time for per frame video real return needs 1.67 s, *t* equals 1.67 s in this system. *L*(m) is the actual distance which a frame video represents.

Also because L need satisfy formula (3):

$$L = 0.136 \times 24 \times \frac{h}{10} \quad \textbf{(3)}$$

Therefore, in order to ensure the full collection of data, the cruise speed *V* should meet (4):

$$V \le \frac{L}{t} \approx 0.195 \times h \quad \textbf{(4)}$$

Three groups of cruise tests have been conducted. Cruise test results are shown in Table 5.

Table 5. Cruise test results

	Group one	Group two	Group three
Flight height *h* (m)	50	40	40
Ideal cruising speed *V* (m/s)	≤9.75	≤7.8	≤7.8
Actual cruising speed *V* (m/s)	10	10	5
Cruise results	Lost frame Data is not complete	Lost frame Data is not complete	No lost frame Data is complete

6 Conclusion

A real-time UAV inspection system for photovoltaic power station based on 4G private network is presented in this paper. The system uses the six rotor UAV as the platform, equipped with thermal infrared imager and GPS module, which constitutes the UAV data acquisition system. A new 4G communication scheme is also proposed. This scheme chooses 4G private network base station and 4G wireless communication module to establish a 4G private network data communication link. The use of TD-LTE technology can achieve the transmission rate of downlink: 100Mbit/s and uplink: 50Mbit/s, which is enough to meet the current demand of image data's reliable real-time return for photovoltaic power plant UAV inspection system. After many field tests in the photovoltaic power station, the feasibility of the proposed system is verified. Because the system can realize the real-time transmission of high precision image data, ground control personnel can timely lock the location of hot spots and promptly sent technicians to repair. The UAV inspection system is playing a more and more important role in the field of electric power. This paper has a certain reference value for the research and design of communication scheme in UAV real-time inspection system in the future.

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References

[1] X. Peng, Z. Liu, X. Mai, A transmission line inspection system based on remote sensing: system and its key technologies, Remote Sensing Information 30(1)(2015) 51-55.

[2] W. Zheng, Research on distribution network inspection system based on infrared image technology for UAV, [dissertation] Shengyang: Shenyang Agricultural University, 2014.

[3] Z. Gao, J. Deng, Progress and current state of image wireless transmission system for MUAV and its key technologies, Science & Technology Review 25(16)(2007) 68-72.

[4] H. Wang, Study on object detection system of MINI UAV, [dissertation] Zhejiang: Zhejiang University, 2004.

[5] Y. Fu, Z. Li, H. Jiang, The development and application of UAV line inspection, Heilongjiang Science and Technology Information 30(2014) 25-27.

[6] Z. Guan, The design of wireless image transmission system based on COFDM, [dissertation] Anhui: Anhui University, 2010.

[7] S. Zhou, Coverage and networking analysis of TD-LTE system, in: Proc. Communication Technology and Application (ICCTA 2011), 2011.