Construction Safety Monitoring System Based on UAV Image

E. Yang(✉), Jing Yang, Kangyan Zeng, and Yan Zheng

Department of Architectural Engineering, Chongqing College of Architecture and Technology, Chongqing 401331, China
eyangYang26785@163.com

Abstract. In the process of construction safety monitoring, the construction image is not corrected, resulting in low monitoring accuracy and high false alarm rate. Therefore, a construction safety monitoring system based on UAV image is designed. The hardware framework of the system is designed by the camera mounted UAV module and stm32f103c8t6 as the system control core through wireless network communication technology. Based on the hardware design, the UAV image is corrected, and the image features are extracted by the brisk algorithm according to the preprocessing results. The kernel function SVM is introduced to classify the UAV images and realize the safety monitoring of engineering construction. The system test results show that the monitoring accuracy of the designed monitoring system is higher than 90%, and the false alarm rate is low. It can monitor the construction safety behavior in real time, and is more flexible and convenient in actual use.

Keywords: UAV image · Architectural engineering · Construction safety · Monitoring system · Brisk algorithm · Support vector machine

1 Introduction

The number of construction companies has grown rapidly, and the number of construction workers is also increasing. The construction area and investment amount have repeatedly hit new highs. The development of the construction industry has gradually diversified, and the design aspect has become more and more broad. Due to the characteristics of the construction industry, the diversity and complexity of employees in this industry, the cultural level is different, and the professional quality is also uneven [1]. The construction industry is characterized by complex production activity systems, long construction periods, and constantly changing processes, which make risks and potential safety hazards run through the project, with great danger and many unsafe factors. Urban and rural construction and development are inseparable from project construction and management. Whether it is survey and design before construction, or dynamic data monitoring and quality inspection during and after construction, measurement work runs through project construction and management. There are many hazardous areas in the

W. Fu and L. Yun (Eds.): ADHIP 2022, LNICST 469, pp. 546–556, 2023.
https://doi.org/10.1007/978-3-031-28867-8_40

modern building production process, which are difficult to achieve by human monitoring. Taking strict measures for construction site safety supervision is the main policy of construction site supervision. Focusing on the core of engineering quality and engineering safety issues, taking effective supervision is a compulsory course in the construction industry [2].

In recent years, it has become more and more difficult for on-site supervision to adapt to the increasingly complex construction environment. The main reason is that the number and energy of supervisors are limited, and they cannot cover every corner of the construction site. Therefore, the use of automated monitoring systems can comprehensively and quickly It is necessary to detect the unsafe behavior of workers to ensure the safety of engineering construction. In the current research on building construction safety management, there are various technical solutions. The early application of security surveillance technology was mainly based on video surveillance technology. The surveillance cameras used analog cameras, which could only control the safety of the construction site from the perspective of video surveillance. However, monitoring cannot be implemented for hazardous environments such as fire protection, lightning in high-rise buildings, and strong winds. With the popularization and use of sensor technology, sensors are gradually introduced into the field of construction engineering [3]. Such as fire monitoring. At this time, most of the sensors are wired sensors, and the sensors are both analog and digital. The use of wired sensors increases the type of on-site information monitoring, but it has the problem of deployment and wiring. In the field use, construction bumps also occur, resulting in the line being cut off, and even the sensor cannot be recovered in the end. The construction safety monitoring using wireless communication technologies such as RFID can realize multi-point distributed monitoring, but this monitoring system leads to a lot of controller nodes on site, and the deployment and wiring workload on site is huge, which is very inconvenient to use [4]. In the current construction project, the scale of the project is getting bigger and bigger, in order to ensure the construction period, a lot of manpower and material resources are invested at the same time. In addition, the height of building construction projects is more and more forecast, and the safety monitoring of high-rise buildings is more difficult. The performance requirements for security monitoring systems are further improved.

UAV technology is a multidisciplinary comprehensive technology born from the development of science and technology. It integrates GPS global positioning technology, remote sensing technology, communication technology and UAV driving technology. It can not only carry out precise remote control, but also confirm and record spatial geographic information. As UAV technology becomes more and more mature, and considering its advantages such as safety, high cost performance and mobility, more professional application projects have begun to use UAVs to complete [5]. The image files of the construction site captured by the drone can be processed to obtain relevant information on the construction site such as area, volume, slope, height, etc., so that the supervisor can supervise the construction site in the monitoring room. UAV images are relatively unrestricted by time and space, and the imaging effect is good. At present, there are many successful cases of using UAVs in aerial surveillance.

Based on the above analysis, this paper will design a construction safety monitoring system based on UAV images. Through the UAV module, the image data transmission and communication module, the operation control module and the surrounding circuit design system hardware part, the system software design will be completed by preprocessing the construction image data, extracting the feature points in the UAV images and identifying the dangerous behaviors in construction, According to the system hardware and software design, the construction safety monitoring system is designed and applied to the actual construction project management.

2 Design of Hardware Part of Construction Safety Monitoring System Based on UAV Image

The hardware part of the construction safety monitoring system designed in this paper is mainly composed of the UAV equipped with the UAV image acquisition device, the core control module of the monitoring system, the UAV data transmission communication module and the data processing module. The hardware framework of the engineering construction safety monitoring system is shown in Fig. 1 [6].

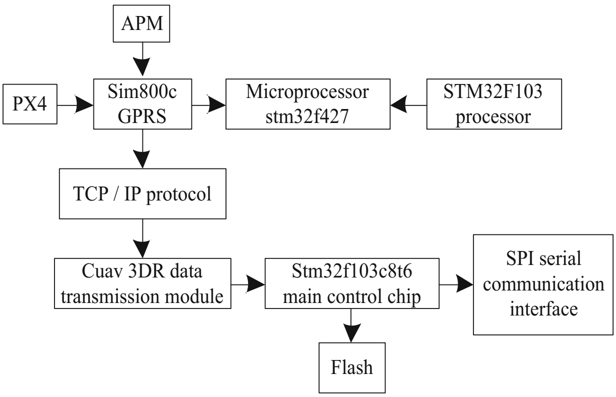

Fig. 1. Schematic diagram of the hardware framework of the engineering construction safety monitoring system

The flight control unit of sim800c GPRS is pixhawk flight control, which has APM and Px4 firmware and corresponding ground station connection. GPRS is connected to 32-bit microprocessor stm32f427 for flight control, and STM32F103 processor is used as additional fault protection standby controller. The GPRS of the UAV is embedded with TCP/IP protocol and connected with cuav 3DR data transmission module. Stm32f103c8t6 is selected as the main control chip for control. The design process of each hardware module in Fig. 1 will be described in detail below.

2.1 UAV Module

In order to ensure the safe and reliable operation of this system, it is first necessary to select a UAV that can fly stably and has strong wind resistance. Compared with fixed-wing UAVs, rotary-wing UAVs are smaller and simpler in structure. At the same time, they have lower requirements for flight space, can fly in different attitudes, and can hover in the air for a long time. In addition, the multi-rotor UAV offsets the additional rotational moment due to the different steering between adjacent rotors, and does not need to use the tail alone to achieve body balance, so it has better maneuverability and a simpler and more reliable structure. To sum up, this design chooses multi-rotor UAV to realize the safety monitoring of construction engineering.

Compared with the load capacity, this design has higher requirements for the endurance of the UAV, because the quadrotor UAV is selected. The flight control unit of the quadrotor UAV adopts PIXHawk flight control, which has two sets of firmware and corresponding ground station software, APM and PX4, and has an operating frequency of 168 MHz. It has a 32-bit microprocessor STM32F427 as the main controller, and a 32-bit STM32F103 processor with independent power supply as an additional fault-protected backup controller, and has a large storage space and various sensors [7].

The UAV remote control unit consists of two parts: the transmitter and the receiver. The transmitter is installed on the ground end, and the receiver is mounted on the UAV end and connected to the flight control. The transmission process of the control signal sends instructions to the receiver through the transmitter of the remote control, and the receiver decodes and transmits it to the flight control system, and the UAV makes corresponding actions according to the signal instructions.

This design chooses SIM800C GPRS to provide direction guidance for UAV flight. When the power supply voltage of the drone is under-voltage or the onboard monitoring terminal is powered off, the monitoring terminal cuts off the external power supply and enables the backup battery. When the external power supply restores the power supply, the backup battery can be charged.

2.2 Image Data Transmission and Communication Module

The communication between the UAV and the ground station, the communication between the ground station and the monitoring terminal adopts wireless data transmission mode, the data transmission communication adopts UART serial communication, and the baud rate is set to 115200. The communication process is to send one byte at a time, and send 30 consecutively, among which there are data flag bits and various data. The UAV digital radio is a professional data transmission radio with the help of digital signal processing and software radio technology. The data transmission station used in this article is the CUAV 3DR data transmission module, with a maximum transmission distance of 5000 m. The UAV image transmission module adopts channel coding, video compression, modulation and demodulation and signal processing technology to transmit the video obtained by the camera in the quadrotor UAV to the ground station in real time by wireless transmission. This design uses 5.8 GHz analog image transmission to transmit analog video, transcodes the high-definition video obtained by the camera on the UAV into 1080P, and finally converts it into a digital signal and transmits it to the video display interface of the ground station.

The GPRS of the drone is embedded with the TCP/IP protocol, and the GPRS communicates with the ground station and the drone flight control through the TCP protocol. The data sent by the drone to the ground monitoring mainly includes flight status information, flight control setting information, running status information, etc. The total data volume is relatively large, about 300 bytes. In actual communication, the above data information is divided into multiple data packets according to the requirements, and the corresponding data packets are returned according to the request information of ground monitoring. The communication protocol data frame format of downlink data is shown in Table 1.

Table 1. Data frame format of downlink data link communication protocol

Project	Numerical value	Illustrate
STX	2 Bytes	Data frame header, indicating the beginning of the data packet sent to ground monitoring
Length	1 Byte	Total packet length
CmdID	1 Byte	Feedback command ID to ensure that the command is sent successfully
PacketID	1 Byte	Packet ID, used to distinguish different packets
DataPacket	n Bytes	Valid data, used to represent data information,
CheckSum	2 Bytes	Sum check to ensure the correctness of the data

The communication protocol format of the uplink data sent by the ground station to the UAV is similar to the downlink data protocol format.

2.3 Operation Control Module and Surrounding Circuit Design

According to the design requirements of the control system, the proposed cost, and the future scalability, the concentrator circuit selects the main control chip model STM32F103C8T6, which is a 32-bit microcontroller based on the ARM Cortex-M3 core of the STM32 series, 2 V~3.6 Wide voltage supply range of V, the maximum operating frequency is 72 MHz. It also features single-cycle multiply instructions and hardware divides, as well as a priority programmable interrupt system. The chip also has 64 KB of Flash memory and 20 KB of SRAM memory. In addition, it also integrates a wealth of on-chip peripherals, multiple timers, DMA controllers, serial ports, ADC, SPI interfaces, etc., with low cost, high speed Fast and cost-effective.

The external Flash chip W25Q128 is a 128 M-bit large-capacity serial flash memory device. It uses the SPI serial communication interface and connects to the STM32 on-chip SPI interface to realize the control read and write of the W25Q128. It has 8 pins, only four signal lines are needed for communication, and the design requirements can be met by configuring these four signal lines accordingly. The W25Q128 connection circuit is shown in Fig. 2.

The power supply voltage of the main control chip is 2–3.6 V, and 3.3 V is selected as the power supply voltage; the working voltage of the GPRS module is required to be in the range of 3.3–4.8 V, and 4 V is designed for power supply; in the TTL to USB interface circuit, the CH340G chip needs 5 V power supply; The storage module requires a 3.3 V supply voltage. According to the voltage requirements of the above modules,

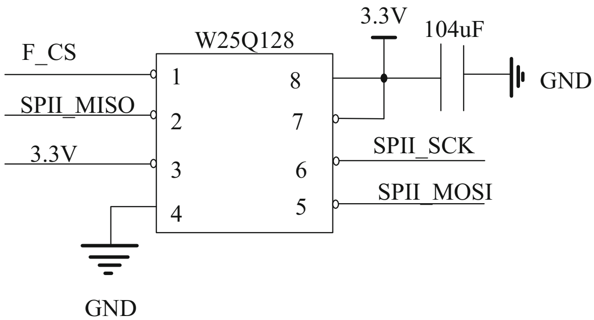

Fig. 2. W25Q128 connection circuit

the concentrator circuit is designed to output 3 V values of the power supply to ensure the normal operation of the circuit. The specific design is as follows:

The power module adopts 12 V input, and the on-off of the concentrator circuit is controlled by the module power switch. First, the DC step-down conversion chip MP2359 is stepped down to obtain the 5 V voltage required by the TTL to USB module. The 5 V voltage passes through two forward low dropout voltage regulator AMS1117 chips respectively, and obtains a 3.3 V voltage for the STM32F103C8T6 main control chip. The design power supply voltage of GPRS module SIM800C is 4 V, and its working peak current is close to 2 A, so DC-DC step-down chip MP2303 is selected for step-down, and the required 4 V power supply voltage is obtained.

With the hardware support of the safety monitoring system designed above, the image analysis and processing of the construction work images collected by the UAV is carried out to realize the safety monitoring function of the entire construction project.

3 Software Part Design of Construction Safety Monitoring System Based on UAV Images

On the basis of the above system hardware design, this paper designs the software part of the system. First, it corrects and stitches the distortion difference of the building engineering construction image data collected by the UAV, and then uses the classifier to identify the dangerous behaviors of engineering construction in the UAV image, and distinguishes the construction scene with dangerous factors from the normal scene, so as to complete the safety monitoring of building engineering construction.

3.1 UAV Image Processing

UAVs are easily affected by airflow, wind speed and wind direction. Therefore, the influencing factors of its own structure on image quality can be divided into three points: poor camera objective lens distortion, pixel size and resolution, and flight stability. The data processing function is mainly to correct and splicing the image data collected by the UAV, and then generate digital orthophoto images, digital elevation models, etc. deal with.

Camera lens correction is based on camera calibration to correct the error between the camera and the lens. Due to certain errors in the design, production, assembly and other technical aspects of the camera lens, the image obtained by the camera will have a certain optical distortion, which further affects the reliability and accuracy of the aerial triangulation results. Therefore, eliminating the optical distortion error of the lens to the greatest extent is a key link before the air-to-three encryption, and it is also a prerequisite for ensuring the quality of the UAV image data. After determining the internal orientation elements, optical distortion parameters and area array deformation parameters of the digital camera, photogrammetry can be performed. However, before the obtained digital image is used in actual production, the distortion difference of the image needs to be corrected according to the camera calibration parameters. The total correction model for camera distortion is [8]:

$$\begin{aligned} \Delta X &= \Delta x\left(q_1 r^2 + q_2 r^4\right) + 2p_1\left[r^2 + 2\Delta x^2\right] + 2p_2 \Delta x \Delta y + \xi \Delta x + \zeta \Delta y \\ \Delta Y &= \Delta y\left(q_1 r^2 + q_2 r^4\right) + 2p_1\left[r^2 + 2\Delta y^2\right] + 2p_1 \Delta x \Delta y \end{aligned} \tag{1}$$

Among them, ΔX, ΔY are the correction values of the image point; Δx, Δy are the coordinate differences between the image point coordinates and the image principal point coordinates in the image coordinate system; r is the radial distance; q_1, q_2 are the radial distortion coefficients; p_1, p_2 are the tangential distortion coefficients; ξ is the CCD non-square scale coefficient, and ζ is the CCD non-orthogonality distortion coefficient.

The main task of radiation correction is to reduce the influence of image distortion and noise as much as possible by eliminating the chromatic aberration between images, restore the most original state of the image, improve the contrast between the images, and better match and stitch the subsequent UAV images. to prepare. Histogram equalization and histogram matching are the most commonly used image enhancement methods.

Evenly distributing the histogram of the original image is the basic mechanism of histogram equalization, so as to achieve the purpose of expanding the dynamic range of the gray value of the image, thereby improving the overall contrast of the image. The gray value of the UAV image can be regarded as a random variable in the interval [0, 1]. Let the gray value be $g(0 \le g \le 1)$, the gray value of the transformed pixel is g', and P_g and $P_{g'}$ are the probability of random variables g and g'. Density function, the transformation function is T, then there is the following formula [9]:

$$\begin{cases} g' = T(g), (0 \le g \le 1) \\ P_{g'} = P_g \left| dg / dg' \right| \end{cases} \tag{2}$$

The gray value g corresponds to the gray value g' one-to-one, and the transformation function T must meet the following conditions:

(1) T is uniquely determined in the interval [0,1] and increases monotonically;
(2) $0 \le T \le 1$ ensures that the pixel gray value after mapping is within the valid range.

When the image gray value is K order, the transformation result can express the formula:

$$g'_k = T(g_k) = \sum_{K=1}^{K} P_g^j = \sum_{K=1}^{K} \frac{N_j}{N} \tag{3}$$

In the formula, k represents the gray level of the image; N represents the total number of pixels; N_j represents the number of pixels on the j gray layer; P_g^j represents the probability density of the j gray layer; $T(g_k)$ represents the transformation of the pixels in the k gray layer function; g'_k is the final transformation result. UAV images can not only get the grayscale histogram equalization result of one image, but want to get the color image equalization result, then it is necessary to first divide the color image into RGB components, and realize the histogram equalization of each component separately. Then combine the three components.

Histogram equalization can only automatically enhance the contrast of the entire image to obtain a globally equalized histogram, but the calculation process cannot adjust the parameters and is not easy to control. The histogram matching can select an image with excellent effect as the matching object, and correct the histogram of the original image to make it into a specified shape. After processing the images collected by the UAV, the classifier is used to identify the images, so as to realize the function of engineering construction safety monitoring.

3.2 Engineering Construction Hazard Identification

Before using the classifier to identify the dangerous behaviors or factors of engineering construction in the UAV image, the features in the image are extracted as recognition vectors. In this design, the brisk algorithm is used to extract the feature points in the UAV image, and the expression is:

$$S(I) = \frac{g'_k(\Delta X, \Delta Y)}{T(g_k)} \tag{4}$$

According to the feature extraction results, identify the construction risks of the project. The specific process is as follows [10]:

1) Construct n octave layers (denoted by c_i) and n intra-octave layers (denoted by d_i). Assuming that there is an image I, the octave layer is generated: the c_0 layer is the original image, the c_1 layer is 2 times downsampling of the c_0 layer, the c_2 layer is 2 times the downsampling of the c_1 layer, and so on. The generation of the intra-octave layer: the d_0 layer is 1.5 times the downsampling of I, the d_2 layer is 2 times the downsampling of the d_1 layer (that is, the 2 * 1.5 times downsampling of I), the d_3 layer is 2 times the downsampling of the d_2 layer, And so on.
2) Perform FAST9-16 corner detection on the image to obtain an image with corner information, and perform FAST5-8 corner detection on the original image I once
3) According to the above steps, the position and scale of the image feature points are obtained, and the two-dimensional quadratic function interpolation is performed on

the FAST score value at the position corresponding to the layer where the extreme point is located and its upper and lower layers, and the real score extreme value is obtained. The point and its precise coordinate position are used as the feature point position; then one-dimensional interpolation is performed on the scale direction to obtain the scale corresponding to the extreme point as the feature point scale.

After extracting the image features from the UAV image, the support vector machine model is used to classify the image features. The essence of SVM is a model for classifying two types of samples, and the optimal classification hyperplane of the samples is calculated to maximize the distance between the classification boundaries between the two classes. The basic expression of SVM can be written as:

$$\begin{aligned} &\min\ 0.5\|\delta\|^2 \\ &s.t.\ \ y_i\left(\delta^T x_i + \eta\right) \geq 1 \end{aligned} \tag{5}$$

Among them, x_i is the sample; y_i is the classification label of the sample; δ is the slope of the expression of the classification hyperplane; η is the intercept of the expression of the classification hyperplane. The optimization objective of the above equation is quadratic and the constraints are linear, which is easier to solve when it is converted into a Lagrangian dual problem. The kernel function is introduced to reduce the influence of image dimension on classification. The discriminant of SVM is as follows:

$$f(x) = K(x_i * x)\mathrm{sgn}\{a_i y_i (x_i * x) + b\} \tag{6}$$

Among them, $K(x_i * x)$ is the kernel function of SVM; a_i is the Lagrange multiplier; b is the mapping function. Using hyperplane UAV image classification to distinguish construction scenes with risk factors from normal scenes. When images containing construction risk factors are classified in the classifier, an alarm is issued to facilitate timely supervision by construction managers. The above software program for realizing construction safety monitoring function is transplanted into the hardware module of the UAV remote monitoring system, and the design and research of the construction safety monitoring system based on the UAV image is completed.

4 System Performance Test Experiment

The construction safety monitoring system based on drone images is designed above. Before applying the system to actual project management work, it is necessary to accurately test the operation of each module of the system and the performance of the system to ensure that the system can be used in practical applications. to achieve the expected design targets.

4.1 Experimental Content

Run test and performance test on the monitoring system designed above. In the operation test, the data transmission between the UAV and the ground in the system, the connection of hardware modules, etc. are mainly tested, so as to verify whether the system can operate normally after assembly. In the system performance test, the monitoring accuracy rate, false alarm rate and algorithm running time are counted, and the alarm accuracy rate and alarm real-time performance of the system are tested, so as to judge whether the system meets the reliability and real-time performance of construction safety monitoring.

4.2 Experimental Results

Power on each hardware module of the system separately to make sure that the hardware modules are connected properly. After the control core loads the test program, the indicator light flashes according to the program requirements, indicating that the system is running normally.

In the system performance test, the drone is used to shoot the simulated construction scene in the simulated scene. After adding the interference image to the image collected by the drone, the system recognizes and counts the alarm correct rate, false alarm rate and response time of the system. Table 2 below shows the system performance test results.

Table 2. System performance test results

Interference image ratio/%	Correct rate/%	False alarm rate/%	Response time/s
5	98.5	0.02	0.8
10	98.2	0.02	1.1
15	97.6	0.04	1.2
20	97.1	0.08	1.2
25	95.8	0.06	1.4
30	93.7	0.07	1.3
50	93.3	0.09	1.4

According to the above system performance test results, the construction safety monitoring system based on UAV imagery designed in this paper not only improves the operating performance of the system significantly, but also has an accuracy rate higher than 90% for monitoring dangerous events during the construction process, and false alarms The rate is low, and the construction danger alarm interval is short. It can give early warning of dangerous events in time, and has the convenience of use. It has a good auxiliary role in the construction safety monitoring work.

5 Concluding Remarks

The comprehensive quality of construction practitioners is not high, the management level of managers is low, the safety identification ability is low, and the safety operation ability is low. Many hidden dangers cannot be sent information and dealt with in a timely manner, and they often focus on the progress of the project in order to pursue interests. To maximize, in order to be able to deliver work on time, we will not hesitate to take risks and fail to meet the requirements of safe operation. In addition, there are many manual operations, high-altitude operations, and cross-operations in construction projects, resulting in many hidden dangers and accidents. Frequent occurrence. In recent years, the application scope of UAVs has been continuously expanded, and currently three major research fields of military, civilian and scientific research have been formed. The application of UAV technology in construction quality management is one of the effective auxiliary means to reduce the unsafe behavior of workers and ensure the safe production of construction projects. Therefore, this paper designs a construction safety monitoring system based on UAV images, and tests the performance of the system to verify that the performance of the system can meet the needs of practical applications.

References

1. Xu, L., Fu, M., Wang, C.: Research on the application of BIM technology in safety management of prefabricated buildings. Constr. Econ. **42**(04), 53–56 (2021)
2. Hu, Q., Tian, X., He, Z.: Risk assessment for the green building construction safety based on the five-element connection number set analy-sis model. J. Saf. Environ. **21**(05), 1880–1888 (2021)
3. Yang, J., Chen, D.: Dual channel remote video synchronization monitoring method based on embedded web. Comput. Simul. **38**(02), 477–481 (2021)
4. Yang, K., Ahn, C.R.: Inferring workplace safety hazards from the spatial patterns of workers' wearable data. Adv. Eng. Inform. **41**(AUG.), 100924.1–100924.11 (2019)
5. Ye, X., Wang, T., Zhao, Z., et al.: Upgrading design and function innovation of safety risk monitoring system for rail transit construction. Urban Rapid Rail Transit. **34**(01), 110–114 (2021)
6. Rodrigues, S., Costa, D.B.: Integrating resilience engineering and UAS technology into construction safety planning and control. Eng. Constr. Archit. Manag. **26**(11), 2705–2722 (2019)
7. Liu, L.: Design of agricultural UAV remote monitoring system based on DER communication technology. J. Agric. Mech. Res. **43**(07), 230–234 (2021)
8. Sun, L., Wang, Q., Shi, K., et al.: Overview of computer vision research in construction safety field based on knowledge graph. Saf. Environ. Eng. **28**(02), 44–49 (2021)
9. Xu, Q., Chong, H.Y., Liao, P.C.: Collaborative information integration for construction safety monitoring. Autom. Constr. **102**(JUN.), 120–134 (2019)
10. Li, J., Zhang, J., Yu, Y.: Intelligent ground monitoring system of UAV inspection based on power grid industry. Inf. Technol. **44**(06), 134–138 (2020)