Research on 3D Measurement Technology of Substation Based on Monitoring Image Processing

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Abstract. Aiming at the problems of hard modeling and low-efficiency of safety control in substation, a new method that based on image processing is proposed in this paper. Calculating the collected images which is getting by existing monitoring equipment of the substation, and the coordinates of the equipment in the space are obtained. According to the actual point coordinates to build the 3D model of the substation, and then establish the site safety control electronic fence by draw the safe distance in 3D model to achieve the substation safety control. This paper launches the research from five aspects，which are the camera coordinate calibration, the world coordinate system establishment, space coordinate calculation of the substation equipment points, the hardware structure and software framework establishment, the intelligent monitoring system function realization. Compared with the modeling by laser point cloud which is more popular, this method is more efficient and convenient for practical application.

Keywords: Coordinate calibration, CNN, substation modeling, intelligent safety control.

1. Introduction

As the pivot of power grid system, the safe and reliable operation of substation equipment plays a vital role in the stable operation of power grid. Based on this, the maintenance and management of substation equipment becomes a key part in the operation and maintenance of power grid[1-2]. With the development of technology, substation has adopted various technical means to realize on-line monitoring of equipment. And the most common way is video-monitoring, which plays an important role in ensuring equipment safety, preventing fire and theft, remote inspection and accident tracing.

However, the current video monitoring is limited to the monitoring of plane images in fixed areas, and it is impossible to make specific perception and judgment of the field-equipment location. Also, it cannot quantify monitoring of the safety areas. At the same time, the monitoring data of video is very large. Even the single video of the abnormal information needs to take a large amount of bandwidth, which increases the great pressure on the limited communication bandwidth.

In this paper, a method is proposed to locate the coordinates of the collection points of video based on the original video monitoring, and then the three-dimensional modeling of all devices in the substation is carried out to divide the field which is safety operation area, so as to realize the all-wave intelligent monitoring of the scene in the substation. For reduce the bandwidth, the information is extracted and stored in the local database, which made from the discovered abnormal information. Key points of the station abnormal are packaged and uploaded.

2. Calibration of Camera Coordinates

From the substation image monitoring to the final image presentation, four steps of coordinate transformation are necessary, world coordinates, camera coordinates, image physical coordinates, image pixel coordinates. Among them, the world coordinates need to select the reference point in

substation, and the origin of coordinates of the calibration object is selected as the reference point to establish the world coordinate system in this paper.

In the substation, the monitoring camera only has the approximate position distribution, which cannot directly obtain the world coordinate information. For this point, it is necessary to accurate calibration the coordinates of the monitoring camera in the substation, and determine the three-dimensional coordinates of various equipment in the substation according to the relationship between the camera position coordinates and the world position coordinates in the substation.

2.1 Calibration Image Physical Coordinates

In the monitoring image, the object is transformed into a two-dimensional image by three-dimensional imaging, and the coordinates of each point in the image are still physical coordinates. Because these are not one-to-one corresponding to pixels, the original physical coordinates are scaled to pixel coordinates with a certain proportion correspondingly.

At the same time, the origin of the pixel coordinates is usually located in the upper left corner of the pixel image, and the imaging main point should be located in the center of the pixel image (because of the camera manufacturing process, the imaging main point will have some deviation), the origin of pixel coordinates is related to the imaging main point in Fig. 1.
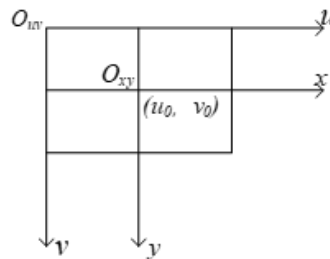

Fig. 1 The relation between origin of pixel coordinate and imaging principal point

As shown in Fig. 1, each point in the image has, $u0$, $v0$ are the origin coordinate of pixel, x , y are the physical coordinate of the image, nx and ny denote the number of pixels contained in the unit length of the x and y directions[3-4].

$$x = \frac{u - u_0}{n_x}$$

$$y = \frac{v - v_0}{n_y}$$

And then, the physical coordinates of the image can be determined.

2.2 Calibration Camera in World Coordinate

There is a direct relationship between the physical coordinates of the image and the coordinates of monitoring camera. Different imaging models will affect the coordinate calibration of the camera, so it is necessary to select a suitable camera model.

In the monitoring camera model, the most ideal model is the pinhole imaging model. However, there are many deficiencies, such as insufficient light cannot be collected by the hole, and interference phenomenon of light will be caused if the hole is small enough, which will seriously affect the imaging effect. Therefore, it is necessary to use a lens to collect more light and achieve the focusing effect practically.

The actual camera contains a number of parameters, a rotation and shift matrix that caused camera coordinates to coincide with world coordinates, and various distortion coefficients, which together constitute the camera's parameter matrix.

According to the perspective change method,

$$z \begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = M \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix} \begin{bmatrix} m_{11} & m_{12} & m_{13} & m_{14} \\ m_{21} & m_{22} & m_{23} & m_{24} \\ m_{31} & m_{32} & m_{33} & m_{34} \end{bmatrix} \begin{bmatrix} X \\ Y \\ Z \\ 1 \end{bmatrix}$$

$[X\ Y\ Z\ 1]^T$ is the three-dimensional world coordinate vector. $[u\ v\ 1]^T$ is the corresponding image physical coordinates. m_{ij} is the elements of *M,* which is perspective transformation matrix[5-6]. Because $z = Z$, M_{34} constant is 1.

After transformation of *M,*

$$m_{11}X + m_{12}Y + m_{13}Z + m_{14}$$
$$- um_{31}X - um_{32}Y - um_{33}Z = um_{34}$$

$$m_{21}X + m_{22}Y + m_{23}Z + m_{24}$$
$$- vm_{31}X - vm_{32}Y - vm_{33}Z = vm_{34}$$

For each point in three-dimensional space, there are two equations. When the number of marked points is *n*, there are *2n* equations. But its unknowns consist of 11 parameters (6 rotation and translation parameters, 5 distortion coefficients). When *2n≥11*, the *M* matrix can be obtained by least square method. Set the calibration coordinates to world coordinates, the location of the camera in the world coordinates (*x, y, z*) can also be calculated, calibration work completed.

3. 3D Modeling of Large Scenes in Substation

It is impossible to obtain the whole picture of the substation, which covers a large area, with a monitoring camera. Due to the limitation of image acquisition ability, remote scene image will result in poor quality. In addition, the volume of internal equipment is generally too large, and a monitoring camera cannot obtain the three-dimensional image of the equipment fully.

The modeling of substation needs to calculate all the three-dimensional coordinates of the points on the equipment in the space According to the previous section, if the internal and external parameter matrix M of the monitoring camera is known, the coordinates (*u , v*) in the image pixel coordinate system can be calculated for any point P in space according to its world coordinates $[X, Y, Z\ 1]^T$. However, if the image pixel coordinates of a point in space and the matrix M are known, the corresponding space coordinates are a ray, which cannot be determined uniquely[7-8].

To solve these problem, multiple cameras from different angles are used to take pictures together, and the image is processed automatically by using convolutional neural network.

3.1 Image Fusion Based on Convolution Neural Network

Convolutional neural network is a method of deep learning of artificial intelligence, which has great advantages in image feature information analysis.

In particular, convolution calculation and weight sharing mechanism can greatly preserve the image features while reducing the calculation of parameters. In this paper, actually, the calculation of spatial point coordinates is the analysis and calculation of information in images, and the essence is image analysis. Therefore, this design uses the convolution neural network to complete the extraction and calculation of coordinate information in the image.

The image is recoded as X coordinate image and Y coordinate image according to X and Y coordinate data. Taking these images, which is recoded, as the input layer of the operation. The same part of the same device in different images is marked out as the output layer, and the coordinates of points that make up these same parts are stored for later calculation[9].

Convolution operations are used for X coordinate image and Y coordinate image respectively,

$$x_{ij}^{fm1} = \sum_{u}^{m}\sum_{v}^{n} a_{uv}x_{i-u+1,j-v+1}$$

$$y_{ij}^{fm1} = \sum_{u}^{m}\sum_{v}^{n} b_{uv}y_{i-u+1,j-v+1}$$

Pooling the feature map,

$$Max\left(x_{ij}^{fm1}\right), i \in (d_{x1}, h_{x1}), j \in (d_{x2}, h_{x2})$$

$$Max\left(y_{ij}^{fm1}\right), i \in (d_{y1}, h_{y1}), j \in (d_{y2}, h_{y2})$$

After several convolution pooling operations, after full connection layer, the same parts of the same device are marked in different images[10].

3.2 Scenes Modeling in Substation

In order to make every point in the image correspond to the coordinate information in the actual station, and solve the problem of incomplete imaging with single camera and inability to calculate coordinates. We need to use different angle camera imaging as shown in Fig. 2.

The point coordinates, which have marked as the same by the convolutional neural network in different images, are calculated by using the camera coordinate system of different positions. Firstly, the coordinates of point Q (x_1, y_1) can be calculated by using the coordinates of camera 1 (x_1, y_1, z_1), and then the coordinates of point Q (x_2, y_2) can be calculated by using the coordinates of camera 2 (x_2, y_2, z_2). Since the optical path of the two cameras is not parallel (the Z axis is not parallel), the coordinates of Q can be calculated from the point (x_1, y_1) and the point (x_2, y_2) after being brought into the same world coordinates. For the areas that cannot be covered by two cameras, more cameras (such as camera 3) images need to be used for auxiliary judgment and calculation.
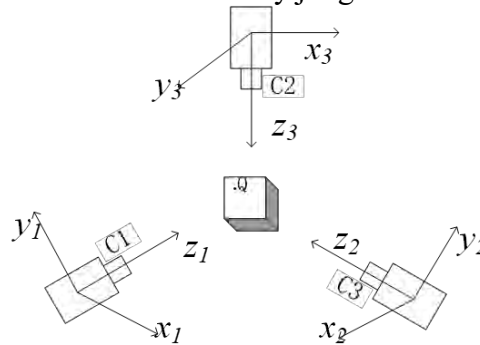

Fig. 2 Schematic diagram of different angles

When all the device point coordinates in the actual station are established, the real-time station model can be built by using the point coordinates. And then, an intelligent three-dimensional electronic fence can be built based on image by using the relative position of the model. When there are intrusions and live operations on substation, the relative position of the target object in space can be accurately judged. If the limit value of safety distance is reached, the alarm will be triggered. It can detect intrusions in real time, regulate the route of inspection and prevent the entry of charged intervals effectively[11].

4. Construction of Intelligent Monitoring System

The intelligent monitoring system is mainly to connect the monitoring signals, and then establish the three-dimensional station model database by calculate and analyze these signals. The intelligent monitoring and analysis of safe distance is realized by analyzing the three-dimensional model of image signal that collected in real time. The report of the safe operation of the substation is automatically given by the system to reduce the burden of the operators in the substation.

In order to ensure that energy consumption can be reduced as much as possible when the above functions are implemented efficiently, it needs select appropriate Hardware structure and software framework to build the system.

4.1 Hardware Selection

The current popular methods of large-image processing are GPU and FPGA, using hardware circuit instead of software to solve the calculation, which can not only speed up the calculation, but also reduce the waste of resources. For the convolutional neural network, there are hardware support such as TPU and NPU. Among them, TPU is developed by Google which built for accelerating neural network computing specially, and NPU chip uses bionics to imitate neural construction, which can greatly reduce the instruction of neural processing.

In this paper, we first solved the camera coordinates, and then conducted the point classification modeling by the way that compare with actual coordinates. Therefore, the way that combine with GPU and NPU is adopted. For the part of the coordinate solution, GPU is calculated because it is basically a matrix operation. When it comes to the classification of the same parts, it is necessary to use NPU to assist convolution neural network operation[12-15]. The block diagram is shown in Fig. 3.
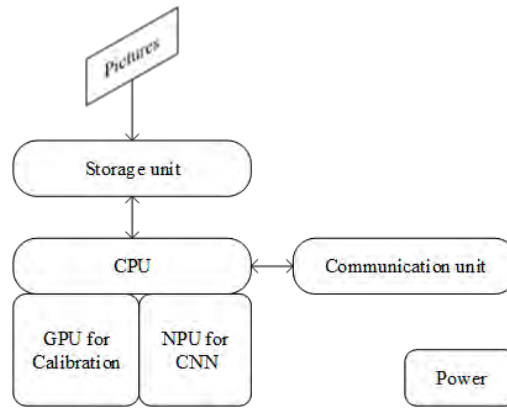
Fig. 3 Hardware block diagram

4.2 System Building

The system mainly realizes the real-time extraction of monitoring video data of substation, and then make the video into images. Each frame will be calculated and analyzed to determine the actual position of each point in the real world. According to the world coordinates of each point, a three-dimensional model of equipment in substation is built. Then an electronic fence also has built in the model, which is handed over to the intelligent video surveillance system for real-time detection. And then it is necessary to establish the historical database of 3d models and intelligent detection results. If there is any abnormal situation, send the alarm in real-time and upload the first level control center. The schematic diagram of the system is shown in Fig. 4.
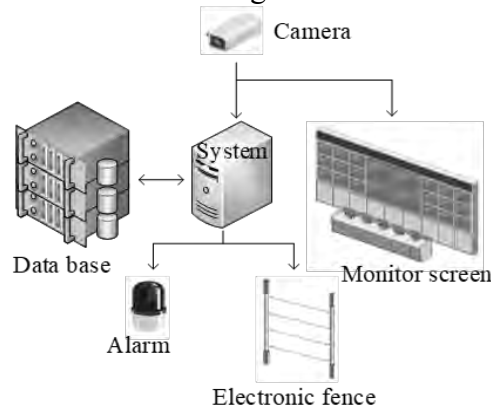

Fig. 4 System block diagram

General, the scene of the substation will not change all the time. If every frame of the video is extracted for calculation, the workload is very large, because of the abnormal video, which is useful information for safety control, is also a small part of the whole video. And length of the most abnormal video is longer than 1s. In this case, select 30%-50% of the image frames of the video at the same interval. By using this method, if the video rate is 30 FPS, and the images number is 10, which are much larger than that required for calculation. Therefore, such image extraction method can effectively reduce the calculation amount of image processing on the premise of guaranteeing the calculation quality and security control.

5. Application Effect

At present, video surveillance can only realize plane image surveillance, and the existing surveillance methods make many cameras in substations scattered and independent, which unable to achieve real-time quantitative monitoring for the security area. And the huge amount of data needs a lot of bandwidth for transmission of remote monitoring, which leads to the low real-time efficiency of monitoring equipment and intrusions in the station. This paper proposes to deploy a three-dimensional security management and control system for substation modeling based on monitoring image processing, which can get the three-dimensional model instantly and update quickly, so as to

meet the needs of real-time control and intelligent operation and inspection of the ultra-high limit problem of substation field safety operation.

5.1 Device Deployment

The device collects images by using the existing video monitoring probe deployed at various points and angles in the substation. Sometimes it is necessary to adjust the Angle of monitoring probe, which makes it realize 3d space modeling better. And then add background image analysis and fusion device system, build hardware resources to meet the requirements of three-dimensional measurement and calculation of substation which based on monitoring image processing. That is to say, the new background processing device shares the image data with the original monitoring system. By this way, the data will be maximized utilization and the waste of resources will be reduced. The technology of the research in this paper can be widely used in conventional stations and unattended stations.

5.2 Comparing with The Traditional Way

Compared with the traditional mode of on-site control after modeling, the device has the advantages such as, simple and safe equipment construction, short modeling time and fast real-time updating. For comparison is shown in Table 1.

Table 1 Comparisons with traditional schemes

Comparison Items	Different Methods	
	Laser radar modeling	Monitoring image processing
modeling time	About two weeks	Monitoring real-time imaging
Modeling convenience	Scanning in the substation	Completing with video Surveillance
model updating speed	Related to scan time cycle	Real-time updating
safety management	Related to speed of model updating	Real-time
modeling funds	Repeated modeling funds for each update	Equipment technology upgrade for the first time

6. Conclusion

It takes a long time to build the model of substation by laser point cloud imaging, which needs to be done in the station and restored by specialized personnel. Its security cannot be guaranteed during modeling operation, and according to the characteristics of laser point cloud imaging, the model cannot be updated immediately.

This paper, according to the characteristics of field station monitoring, takes a new way to calculate the coordinates of the equipment by the existing equipment. It is only need to install a calculating device at the signal terminal to realize the field station modeling and site safety control in this way. At the same time, a method of real-time monitoring and calculation of substation based on neural convolution network is proposed, which can greatly improve efficiency and reduce power consumption.

The system of this paper has a faster update speed and better applicability for substation models. It provides a new method for substation modeling and intelligent safety control.

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