The Auxiliary System of Video Surveillance in Smart Substation

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Abstract—With the continuous development of artificial intelligence technology, the current substation operation and maintenance personnel have more and more urgent needs for the visualization, remoteness and intelligence of the operation and maintenance system. In order to solve the existing problems and present situation, key technologies such as image acquisition, image recognition, and visual display are studied. A smart substation video monitoring auxiliary system was developed. The system is used advanced cameras and acquisition equipment to monitor and detect related electrical equipment such as hard pressure plate switches in the substation in real time. The goal of intelligent inspection is achieved. In the smart substation project, it has achieved good results and has a wide range of application prospects.

1. Introduction

In the field of the power industry, substations as an intermediate link connecting power plants, grids, and power users, perform the role of centralizing, transmitting and distributing electrical energy, and are an indispensable basic facility of the power system. In recent years, with the continuous improvement of the grid structure, the continuous development of substations, the continuous increase in the number of commissioning, and the gradual expansion of the infrastructure in the station, resulting in an increasingly significant contradiction between enterprise development and operation and maintenance management costs. With the development and application of information, Internet of Things, Robotics, Artificial intelligence and other technologies, substation operation and maintenance personnel have increasingly prominent requirements for operation and maintenance intelligence, visualization, and remoteness. How to combine various new technologies with the actual needs of operation and maintenance personnel to realize a practical intelligent operation and maintenance system is the challenge facing the current intelligent operation and maintenance of substations[1]. With the introduction and improvement of the concept of smart substations, the traditional "four remote" model no longer meets the needs of the continued development of today's power system industry. Under the continuous development of intelligent technology, a variety of operation and maintenance systems have appeared in substations in recent years[2], such as: outdoor laser navigation robot inspection system, three-position inspection system, etc. But these systems are passive operation and maintenance methods. The lack of interactivity between information leads to serious information islands.

Equipment inspection is a basic and important task for substation staff. Manual on-site inspection under the traditional mode has the inevitable shortcomings of inaccurate inspection data and low inspection efficiency, and cannot meet the requirements of informatization and intelligent inspection.
of electric power enterprises\cite{3}. In the resident operation and maintenance class of operation and maintenance personnel, there is a lack of effective monitoring methods for substation equipment\cite{4}. Therefore, the substation intelligent auxiliary system based on video surveillance technology was born in response to the requirements of the times, relying on visual equipment and its technology to provide reliable support for the management and operation of smart substations. Therefore, the research and practical application of smart substation video monitoring auxiliary system is of great significance in the future development of smart substation and power system industry!

2. Key Technology and Analysis of Video Surveillance System in Substation

2.1. Technology and Analysis on Image Acquisition

In the initial stage of the application of video surveillance technology in substations, it was mainly aimed at the monitoring and operation management of electrical switchgear such as hard press plates in the substation. Image acquisition technology consists of three parts: optics, imaging, and processing\cite{5}. Collecting images is the basis of image recognition, and high-definition and high-quality images will make image recognition more effective. Use cameras as the main means of video monitoring to monitor the real-time environment in the substation, monitor and detect the operation of the hard plate switch equipment in the station in real time, and then collect the monitoring information through the video transmission host and transmit it to the main control terminal. The staff of the substation realizes the panoramic monitoring of the station in the relevant monitoring room. The quality of the image collection is not only affected by the hardware of the camera quality, but also by multiple environmental factors such as the installation position of the camera, the sunlight and the mirror reflection, the camera shooting angle, etc, making the quality of the captured image not high. In order to improve the picture quality and make the picture clear, it needs to be processed in advance.\cite{6}. Therefore, in the image acquisition stage, multiple technologies need to be combined to ensure the accuracy and stability of the acquired images. For the mechanical errors caused by the rotation of the camera pan/tilt, it will cause inaccurate tracking and acquisition of images during the image capture process\cite{7}, using image correction technology to ensure that the shooting angle is the same every time, and the captured images are basically the same; for the mechanical error generated by the camera during the focusing process, the image blur retrieval technology is used to ensure the captured image clear and reliable; for the overexposure or underexposure of the image caused by light and specular reflection, the use of high dynamic lighting rendering technology, also known as HDR technology, ensures that the highlights and dark details of the image are clearly visible.

2.2. Technology and Analysis on Image Recognition

Image recognition is a technology that uses machine learning, pattern recognition and other methods to process, analysis and understand images to automatically identify targets and objects in various patterns in the image\cite{8}. It is an important branch of artificial intelligence. Traditional image recognition technologies include: image acquisition, pre-treatment, feature extraction, classification, etc.\cite{9}. Compared with traditional methods, image recognition technology based on deep learning can provide feature representation based on learning, and has a good performance in automatic feature extraction and segmentation recognition accuracy\cite{10}. Therefore, the basic core of image recognition can be simply summarized as eight characters, namely: feature extraction and step-by-step approximation. After acquiring the original image, it needs to be identified. The first is the pre-treatment process. The image pre-treatment technology includes: image transformation and correction technology, ROI (interest) region creation, image enhancement technology, image smoothing and denoising technology, Image morphology processing, etc.; the feature extraction process generally includes: regional shape feature extraction, feature extraction based on grey-scale value, feature value extraction based on image texture, etc. However, there is no clear dividing line between pre-treatment and feature extraction. In general circumstances, pre-treatment and feature extraction are performed
and used at the same time to gradually approach the final region of interest to obtain target tasks and data.

2.2.1. Three-Channel Image Split
The original image is generally an RGB image composed of three channels of red, green and blue. R is Red, G is Green, and B is Blue. Each pixel block in the RGB image is shown by the brightness changes of these three colours and their superposition. A pixel block needs to be saved by multiple matrix elements, and the columns in the matrix will contain multiple sub-columns, and the number of sub-columns is equal to the number of channels. The matrix of the saved colour image is generally as shown in Figure 1:

![Fig.1 Matrix form of colour image](image1.png)

After splitting, it is split into 3 single-channel images. Each pixel block in each single-channel image only needs one matrix element to save, and the pixel value is generally 0–255, as shown in Figure 2, it is a single matrix form of the channel image. Finally, select the corresponding single-channel image according to the needs.

![Fig.2 Matrix form of colour image](image2.png)

2.2.2. Image Transformation and Correction Technology
For two-dimensional images, in order to correct the distortion of the image during shooting, some simple geometric transformations can be performed on the image, such as translation, rotation, and scaling, can be performed on the image. Suppose that the position of a point $P_0$ in the image can be represented by two coordinates $(x_0, y_0)$. Before performing simple geometric transformation, it needs to be transformed into $P(x, y, 1)$ by homogeneous transformation. Equation 1 is translation transformation, equation 2 is rotation transformation, and equation 3 is scaling transformation.

$$P_t = T \ast P = \begin{bmatrix} 1 & 0 & x_t \\ 0 & 1 & y_t \\ 0 & 0 & 1 \end{bmatrix} \ast P$$  \hspace{1cm} (1)

$$P_r = R \ast P = \begin{bmatrix} \cos \alpha & -\sin \alpha & 0 \\ \sin \alpha & \cos \alpha & 0 \\ 0 & 0 & 1 \end{bmatrix} \ast P$$  \hspace{1cm} (2)

$$P_s = S \ast P = \begin{bmatrix} s_x & 0 & 0 \\ 0 & s_y & 0 \\ 0 & 0 & 1 \end{bmatrix} \ast P$$  \hspace{1cm} (3)

where $T$ is the translation matrix, $P_t$ is the coordinate after translation, $x_t$ is the pixel distance moved by the original point along the $X$-axis, and $y_t$ is the pixel distance moved by the original point along the $Y$-axis.

2.2.3. Image Smoothing and Denoising Technology
There are three main methods of smoothing filtering, which are mean filtering, median filtering, and Gaussian filtering.
Mean filtering is also called linear filtering. The main method used is neighborhood averaging, that is, its principle is: surrounding square pixels centered on the target pixel constitute a filtering template, and the average value of all pixels in the selected template is calculated instead of the original target pixel value.

\[ X = \frac{1}{n} \sum_{j=1}^{n} x_j \]  

(4)

where \( n \) is the number of pixels in the filter template, \( x_j \) is the pixel value of each pixel area in the filter template, and \( X \) is the pixel average value, that is, the latest pixel value of the central target pixel after average filtering. The side length of the selected square pixel filter template is generally an odd number of unit pixel blocks, because an odd number can ensure that the target pixel is in the middle of the filter. From the point of view of the frequency domain, mean filtering is a low-pass filter, high-frequency signals will be removed, so it can help eliminate sharp noise in the image, and achieve image smoothing, blurring and other functions.

Median filtering is a non-linear smoothing technique. Median filtering is based on ranking statistical theory. Its basic principle is to use the value of a point in a digital image or a digital sequence. The median value of each point in a neighborhood is replaced, so that the surrounding pixel values are close to the true value, thereby eliminating isolated noise points.

\[ Y = Med[x(z - N), \ldots, x(z), \ldots, x(z + N)] \]  

(5)

where \( x(z-N),\ldots,x(z),\ldots,x(z+N) \) are the \( 2N+1 \) pixel values in the neighborhood of the target pixel block, and \( Y \) is the value of these \( 2N+1 \) pixels. The median value is the latest pixel value of the central target pixel after median filtering. This filtering method is very effective for removing some isolated noise points, and it can also retain most of the edge information. However, it is necessary to pay attention to the size of the selected square pixel filter template during use. If the size is too large, it is easy to cause blurring of the image.

Gaussian filtering is a linear smoothing filter, which can be simply understood as Gaussian filtering denoising is a weighted average of image pixel values. The area of the target pixel area is selected as a square pixel filter template, then the new pixel value of the target pixel area is the weighted average of its own value and other pixel values in the neighborhood.

\[ G(x) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{x^2}{2\sigma^2}} \]  

(6)

\[ G(x, y) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{x^2+y^2}{2\sigma^2}} \]  

(7)

Equation 6 is a one-dimensional Gaussian distribution, and equation 7 is a two-dimensional Gaussian distribution, where \( x \) is the coordinate point in the X-axis direction, \( y \) is the coordinate point in the Y-axis direction, \( \sigma \) is the standard deviation, and \( G(x) \) is the one-dimensional coordinate the new value after Gaussian filtering, \( G(x,y) \) is the new value after Gaussian filtering in two-dimensional coordinates. The Gaussian smoothing filter is very effective in suppressing the noise that obeys the normal distribution.

In image recognition and processing technology, dynamic threshold segmentation technology is often combined with filtering technology. The filtered image often becomes blurred, and it does not perform a further precise search for the target area, and the dynamic threshold segmentation is to further confirm the search for the target area under the premise of filtering. Dynamic threshold segmentation is generally divided into: brightness area selection, darkness area selection, median area selection, non-median area selection, respectively, as equation 8-11:

\[ g_0 \geq g_t + \text{Offset} \]  

(8)

\[ g_0 \leq g_t - \text{Offset} \]  

(9)

\[ g_t - \text{Offset} \leq g_0 \leq g_t + \text{Offset} \]  

(10)
\[ g_t - \text{Offset} > g_0 \&\& g_0 > g_t + \text{Offset} \]  \hfill (11)

where \( g_o \) is the pixel value after filtering; \( g_t \) is the pixel value before filtering, and \( \text{Offset} \) is the set parameter value. Choose different dynamic threshold segmentation methods to select different image regions.

3. Test and Analysis

The research in this article mainly involves three-channel image conversion, ROI region creation, smoothing filter processing, dynamic threshold segmentation, image morphology processing, target task feature extraction and other technologies.

The image acquisition is shown in Figure 3, and the switch state of the hard plate is judged according to the target task.

![Fig.3 Image acquisition](image)

First, perform grayscale processing on the color image. Since the target task contains red and yellow, the channel separation method can be used to convert the three-channel image to convert the obtained color image into three single-channel images of red, green, and blue. For the red and yellow switches, the red channel image is selected for processing. The grey value difference between the two is large, and it is easy to extract separately. Figure 4 shows the red channel image.

![Fig.4 Red channel image](image)

In the process of machine vision image processing, the research area that needs to be processed is outlined in a geometric shape from the processed image, which is called the region of interest, abbreviated as ROI (region of interest). ROI technology can ignore the images that do not need to be processed, and greatly improves the efficiency of image processing\[11\]. Due to the complex environment and other conditions, it is necessary to create an ROI area for it. Due to the large difference in gray value, it is necessary to create an ROI area for the red switch and the yellow switch separately. Figure 5 shows the red switch ROI area, and Figure 6 shows the yellow switch ROI area.

![Fig.5 Red switch ROI area](image)  ![Fig.6 Yellow switch ROI area](image)

Aiming at the fine particle noise in the image, this thesis selects the mean filter. This thesis selects \( n \) as 49 to form a pixel area filter template with a length and a width of 7 pixels. Figure 7 shows the red switch ROI area after averaging filtering, and Figure 8 shows the yellow switch ROI area after averaging filtering.
Mean filtering also has its inevitable shortcomings, that is, its fuzzification. Therefore, the mean filter is often used in conjunction with the dynamic threshold local segmentation algorithm to further find the approximate target area. The Offset setting parameter value in this article is $11~12$. Figure 9 shows the red switch area segmented image, and Figure 10 shows the yellow switch area segmented image.

Because the local dynamic segmentation image will produce more particles and impurities, the region division operation is first performed on it, that is, the connected parts are divided into the same area, and the unconnected parts are divided into different areas. Then select the area based on the area characteristic value to exclude particulate impurities. Finally, join the regions.

The main methods of morphological processing are: corrosion and expansion, opening and closing operations, top hat operations and bottom hat operations, and so on. In this thesis, the method of combining erosion and expansion and opening operation and closing operation is used to enhance the target of the dynamic threshold local segmentation image, and prepare for the subsequent target task feature extraction. Figure 11 shows the processed image of the red ROI region, and Figure 12 shows the processed image of the yellow ROI region.

4. Test Results

The target task feature extraction is selected according to the task requirements. The main feature extraction includes: target area rotation angle extraction, target area extraction, target area central point extraction, and so on. The task of this article is to accurately determine the switch state of the hard plate. Due to the influence of some factors such as the shooting angle, the area selection is often inaccurate. Therefore, this article uses the rotation angle to determine the switch state. When the switch is closed, the rotation angle is about 90°, and when the switch is open, the rotation angle is about 135°:

$$
\begin{align*}
\text{if} & \quad 75° \leq \phi \leq 105°, \quad \text{Switch closed} \\
& \quad 120° \leq \phi \leq 150°, \quad \text{Switch on} \\
& \quad \text{else}, \quad \text{Wrong judgment, Alarm in time}
\end{align*}
$$

(12)

where $\phi$ is the rotation angle of the target area. Due to some inevitable minor errors such as mechanical errors, there should be a margin of 15° when judging the switch state based on the angle. Figure 13 shows the red switch test results, and Figure 14 shows the yellow switch test results.
Before the switch state is judged, the recognition of the number of regions is also added. As shown in Figure 11 and Figure 12, the number of red switches is 9 and the number of yellow switches is 8. If it is detected that the number of red switches is not equal to 9, and the number of yellow switches is not equal to 8, the system will alarm in time to remind the relevant staff to check whether the system is abnormal or the state of the switch is abnormal. This further improves the detection accuracy and reduces the occurrence of errors. It can be seen from Figures 13 and 14 of the test results that the test results are correct and accurate.

5. Conclusion
The intelligent substation video monitoring auxiliary system adopts advanced cameras and acquisition equipment to achieve stable capture of the environment, so that the angle of multiple shots is consistent, and the captured images are consistent. Then, through a series of image recognition technologies such as pre-treatment technology and feature extraction, stable monitoring and judge whether the switch status of the hard pressure plate is correct, and display it on the main control terminal, which reduces the intensity of inspection work of related staff, and realizes unmanned inspection, automated operation and less humanized maintenance of the smart substation operation and maintenance system.

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