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# Power Cabinet Door-opening State Recognition Technology Based on Edge Feature Extraction of Monocular Vision

Jianbao Zhu[1], Chuande Liu[2], Yuwei Sun[1], Yu Chen[1], Qingshan Ma[1] and Bingtuan Gao[2]

*Abstract*— **With the increasing intelligent demand of substations, more and more machine vision technologies are applied in smart substations. This paper deals with the power cabinet door-opening state recognition based on edge feature extraction. Firstly, the substation patrol robot with machine vision is introduced, and the image acquirement and main processing flowchart including image line segment fitting of the power cabinet door-opening state is presented. Secondly, main algorithms, such as grey scale, image denoising, edge feature detection and Hough transform, used in the image feature extraction are provided. Finally, the proposed power cabinet door state recognition is implemented with real image of typical terminal box state, and the experimental results show that the proposed technology can identify the power cabinet door-opening state with accuracy as high as 99%.**

## I. Introduction

A wide variety of cabinets are in substation that affect the stability of power system. With the increasing intelligent demand of substations, the open/close state recognition of the cabinet doors by machine vision technologies could ensure intelligent operation, which is attracting much attention.

For the door-opening state recognition, initial image-based recognition process mainly relies on the color difference between the door and the surrounding environment. This recognition method is difficult to widely use because of the negative influence of background brightness variation. To recognize the image state information well, it is indispensable to install the camera near the power cabinet or develop a robot with machine vision to move to the power cabinet. Since there are so many devices state in the power substation need to be detected and recognized, the patrol robot with machine vision is the first choice. For the patrol robot with machine vision system, early in the 1990s, Takahashi [1] introduced a patrol robot system that can automatically follow a fixed rail and plan inspections and collect inspection data. After that, in the 2000s, under the guarantee of electric automatic patrol robot technology, Canada researchers [2] and Brazil researchers [3] have also proposed an automatic inspection robot with monocular vision device, which make sure the automatic search for the position of the power cabinet door-opening become possible.

For the picture processing of cabinet door-opening, based on the geometrical line features and color features of the power cabinet door, it is usually necessary to first use the Hough transform [4] to capture the linear information of the power cabinet door in the image processing. Based on the Hough transform to extract the linear information of the cabinet door-opening, Shao $et.al$ [5] proposed a new Hoff forest idea to train the switch breaking state model and realize the state recognition of the isolating switch in the input image. In addition to the Hough transform [6], Chen $et.al$ [7] also gives a knife-gate state recognition method based on full convolutional neural networks. After the refinement of the geometric information of the knife gate is completed, the switch breaking state can be judged by geometric method. The convolutional neural network algorithm can be improved based on the literature [7], that is, the pooling operation is prevented by the pooling operation [8]. And Over-fitting is done while the trained switch state recognition model can use the Softmax full connection function to predict the input image [9].

For the experimental design, it is necessary to explore the different mobile trolley platforms, autonomous positioning navigation technologies and power equipment state detection functions. Exploring the different mobile trolley platforms, such as wheeled trolley platform, the State Grid of China [10] has developed the fourth generation of patrol robots. Aiming to implement the autonomous positioning navigation function, based on high precision laser sensor navigation, the Chongqing Electric Power Test Institute [11] proposed the AGV (Automatic Guided Vehicle) system in 2006, which could achieve accurate positioning in substations. To detect equipment conditions, a visual servo system can be developed based on image vision technology to accurately monitor other devices status such as cabinet doors.

This paper proposes an edge feature extraction algorithm based state recognition technology of the cabinet door-opening. Once the captured image of the the cabinet door is smoothed and binarized, the effectiveness of line segment combination is shown by Hough transform and the projection technique. The duty cycle ultimately determines the state of the the cabinet door-opening.

## II. Cabinet door-opening state intelligent recognition system

### A. System description

As shown in Fig. 1, the cabinet door-opening state recognition system is composed from modular units, such as monocular vision, storage module, calculation processing module, wireless communication module and power module.

[1]J. Zhu, Y. Sun, Y. Chen and Q. Ma are with Nantong Power Supply Company, State Grid Jiangsu Electric Power Co., Ltd., Nantong, Jiangsu 226006, China (e-mail: ntzjb@js.sgcc.com.cn, 313226908@qq.com, chengyujx@js.sgcc.com.cn, ntmaqsh@js.sgcc.com.cn).

[2]C. Liu and B. Gao are with School of Electrical Engineering, Southeast University, Nanjing, Jiangsu 210096, China (e-mail: liuchuande@seu.edu.cn, gaobingtuan@seu.edu.cn; corresponding author: Bingtuan Gao; phone: +86-15951803720).

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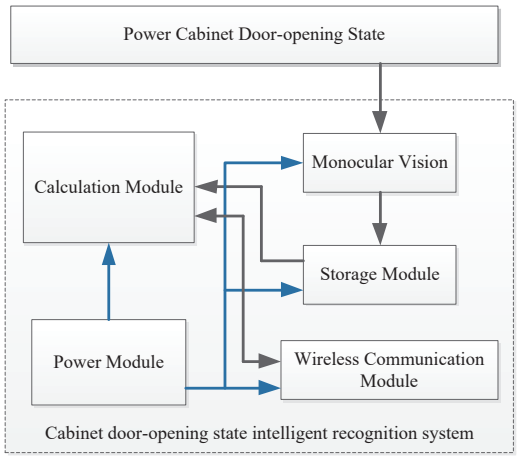


Fig. 1. Cabinet door-opening state intelligent recognition system.

Firstly, for the monocular vision, the position of the power cabinet door-opening must be a given coordinate, and then the position of the power cabinet door can be captured. Usually, this process could be realized by operating the following typical patrol robot, which is with navigation and positioning functions, as shown in Fig. 2.

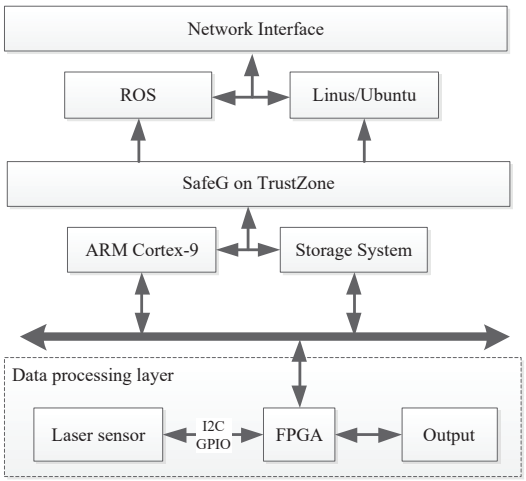


Fig. 2. The power patrol robot system architecture.

In Fig. 2, the ARM-FPGA hybrid architecture controller is used to form a hybrid real-time mobile robot platform (HRMRP), which has obtained good performance and hardware flexibility. The HRMRP mainly consists of a data processing layer, a real-time control layer and a high-performance processing layer. The main task of the data processing layer is to acquire and preprocess of laser sensor information. The main work of the real-time control layer is to take the real-time operating system as the key to realize the robot basic behavior, which is equal to the "neural system" for HRMRP. Similarly, the high-performance processing layer is the "brain" for HRMRP. Meanwhile, it uses the source code to compile the ROS kernel, and uses ROS to organize multiple nodes to plan and decide the behavior of the robot.

### *B. Analysis of cabinet door-opening state recognition*

After getting the position of the power cabinet door, door-opening state should be identified. Therefore, the calculation module in cabinet door-opening state intelligent recognition system is the key to realize the power cabinet door-opening state recognition. The design process of the calculation and identification method as shown Fig. 3.

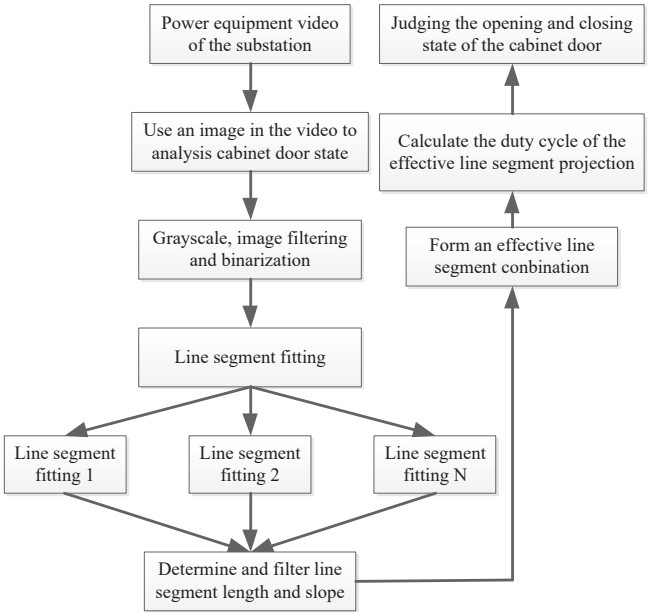


Fig. 3. Cabinet door-opening state identification flow chart.

The specific steps in Fig. 3 are as follows.

1) Extracting power equipment video.

Based on the position of the power cabinet door, the process is automatically addressed by the aforementioned power patrol robot is locked to complete the imaging.

2) Image pre-processing.

This processes, for example, grayscale, image filtering and binarization, are intended to complete the fit of the effective line segment where the the power cabinet door is located. After the image pre-processing operation is completed, the effective line segment projection duty ratio can be calculated.

3) Analysis and judgment.

Based on the obtained duty ratio of each valid line segment with the set threshold duty ratio, judge the opening and closing state of the power cabinet door.

## III. Cabinet Door-Opening Image Processing Method and State Recognition Algorithm

The power cabinet door-opening state recognition algorithm is a basic kind of image recognition algorithms. Based on the description of the power cabinet door-opening state recognition flow chart, as shown in Fig. 4, the power cabinet door-opening state recognition algorithm used in this paper mainly consists of the image preprocessing, door-opening state identification, and door-opening state determination.

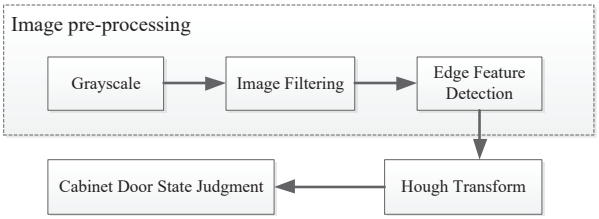


Fig. 4. The power cabinet door-opening state recognition algorithm.

### A. Grayscale and binarization

Traditionally, the images captured by monocular vision are RGB color pictures, where the picture data is huge. To simply the RGB picture data, let each pixel point in the original image from the original Red, Green, Blue three component information be compressed. The converted image has a gray level of 256 levels. The number of bits occupied by one pixel is reduced from the original 24 bits to 8 bits, which simplifies the picture data and called "grayscale".

As we all know, there are three kinds of grayscale processing commonly used in digital image processing, such as weighted average, maximum and average. In this paper, the weighted average method is used to gradualize the color image, and the Maximum Inter-Class Variance Method (OTSU) method is used to binarize the gray image.

For the weighted average, the pixel brightness of the grayscale image is assigned different weights according to the three primary color channel components of Red, Green and Blue, and the weighted sum is obtained to obtain the corresponding gray pixel luminance value, so we can get

$$Gray(x, y) = 0.282R + 0.578G + 0.142B \qquad (1)$$

where $Gray(x, y)$ is the pixel point coordinate information, Red, Green and Blue primary color components of the pixel, and Gray is the grayscale information of the pixel. Let the corresponding weights be 0.282, 0.578 and 0.142, respectively.

Binarization means that the pixel brightness of the grayscale image is determined by a certain threshold value, and is uniformly set to pure black or pure white, that is, the grayscale value is rewritten to 0 or 255, and the generated image is a black and white binary image. For the threshold setting, the adaptive threshold selection binarization strategy is better. In this paper, the widest inter-class variance method widely used in image processing is adopted as the binarization strategy.

### B. Image Filtering

The median filtering method is used to preprocess the image, because of this method can better retain the edge information of the tool gate to be detected and filter noise at the same time. For the median filter, the core idea of median filtering is to count the pixel values of local regions and sort them according to the gray level. The pixel values of the center points are equal to the median values of the neighborhood after sorting.

$$Gray(x, y) = med\{f(x + i, y + j), i, j \in W\} \qquad (2)$$

where $Gray(x, y)$ is the coordinate information of the central pixels, Med is the median operation, W is the domain template defined by the filtering algorithm, $(x + i, y + j)$ is the coordinate of the pixels in the domain template.

### C. Edge detection

In this section, Canny operator detection method is used for that it is a multi-level edge detection algorithm. Compared with other operators, Canny operator has the advantages of good signal-to-noise ratio and detection accuracy, strong anti-interference and stable performance.

The processing of Canny edge detection algorithm can be divided into the following four steps:

1) The image is smoothed using a Gauss low-pass filter.

2) The gradient of the image is calculated by the finite difference of the first-order partial derivative, and the magnitude and angle of the image edge are calculated according to the gradient.

3) Non-maximum suppression of gradient amplitude.

4) Using double threshold method to detect and connect

### D. Hough transform to determine the cabinet door status

The steps of Hough transform of the cabinet door line are as follows.

1) Establish a Cartesian coordinate system for the image to find all valid pixel points $(x, y)$ in the image.

2) For each effective pixel point, substituting the $(x, y)$ coordinate values according to the following equation

$$y \sin\theta + x \cos\theta = \rho \qquad (3)$$

where $\rho$ establishes a sinusoid about $(\theta, \rho)$ in the transformation coordinate space.

3) Record the $(\theta, \rho)$ value of the intersection of the curves and count the number of intersections of the intersections.

4) Set the intersection threshold to extract the peak point and extract the target line, that is, complete the line identification of the cabinet door edge.

## IV. Experiments and Discussion

Based on the above the power cabinet door-opening recognition algorithm, an original image of the corresponding cabinet door for identification is selected as shown in Fig. 5.


Fig. 5. Original image of power cabinet door.

The key is to identify the line at both ends of the cabinet and the door, and determine the duty ratio of the line, and the duty ratio and the threshold are occupied. Compare the phase to determine the state of the power cabinet door.

As shown in Fig. 6 to Fig. 10, the original image of the power cabinet is sequentially subjected to grayscale, filtering, and binarization processing according to the flow in the previous section to obtain the following image results.


Fig. 6. Grayscale image of power cabinet door.


Fig. 7. Filtered image of power cabinet door.

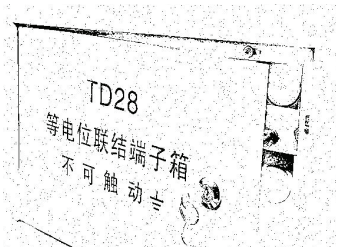


Fig. 8. Binarization image of power cabinet door.


Fig. 9. Edge feature extraction of power cabinet door.

In the above example, the opening angle can be determined to be no more than $1.8°$ when the power cabinet door is closed, and the angle is $2.6°$. Therefore, the power cabinet door is in the open state, which is consistent with the actual

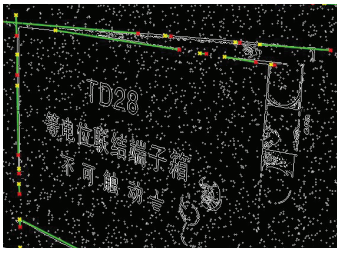


Fig. 10. Recognition results of power cabinet door.

cabinet door state. Moreover, a lot of evidence showed that the error can be controlled within $1\%$ in the test case. Therefore, the proposed cabinet door identification method established in this paper has good accuracy and widely application.

## V. Conclusion

In this paper, based on image preproccess and Hough transform, an edge feature extraction based image state recognition method for identifying the cabinet door state is presented. The robotic system with monocular vision and main process flowchart are introduced, and main algorithms are provided in detail. Experimental results on real images of substation isolation switch show that the proposed robotics system and image process algorithms can recognize the cabinet door state with error no more than $1\%$, which could be improved in the future.

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