Platen State Recognition Method Based on S-component Clustering Segmentation

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Abstract: The inspection of the state of the platen in substation relay rooms is a tedious task of power operation and maintenance. Machine vision can effectively increase inspection efficiency, but its recognition accuracy requires improvement. Considering this problem, a platen state recognition method based on S-component clustering segmentation is proposed in the present study. Perspective transformation is first conducted to rectify the original platen image, and the image is then converted to HSV space. Next, the effective platen area is segmented accurately through S-component clustering, and morphological filtering and feature analysis are then conducted. Finally, the state information of the platen is judged by analysing the feature of the minimum circumscribed rectangle of the platen. Experiments were carried out on platen images of different cabinets, and the results demonstrate that the proposed method can quickly and accurately recognize the platen state.

1. Introduction

With the development of machine vision technology, image recognition methods have been widely used in power inspection [1][2][3]; computers are used to analyze and process collected images to determine the state information of platens. This method not only reduces manual intervention, but also does not require equipment modification. Deng et al. [4] used 3/4 clustering to remove image noise, and then used edge detection technology to identify the state of a platen. However, edge detection methods are greatly affected by lighting; when lighting conditions are weak or there are shadows in an image, the positioning effect is poor, which greatly affects the recognition of the platen state. Lu and Liu [5] used color template-matching technology to identify the states of all platens on a panel. Nevertheless, the shooting angles of the platens were different and the rotation angle of each platen was variable, resulting in certain differences in the size and shape of each platen, and ultimately a poor recognition effect. Fu et al. [6] set the RGB threshold to extract the platen area, and finally determined the state information of the platen by analyzing its morphological features. A disadvantage of this method, however, is that the components in the RGB color space are highly linearly correlated under different lighting conditions. In addition, the RGB values of the same color are different. These factors both greatly hindered the positioning and state recognition.

In recent years, machine learning has gradually become a popular research topic. Recognizing the state of a platen via machine learning can greatly improve the recognition accuracy, and researchers [7][8][9] have previously used SVM decision classifiers to judge the platen states. Mou et al. [10] used divided platen images to train a CNN model, and then used this model to identify the platen state. Although this method was found to have a high recognition accuracy, it is characterized by the following disadvantages: the platen image must first be divided, many data sets are required to train the classifier, and when there are environmental changes, there is a lack of corresponding generated samples, and the recognition rate decreases significantly.

To solve these problems, a state recognition method based on S-component clustering segmentation is proposed in this paper. The experimental results demonstrate that the proposed method achieves the accurate recognition of platen images under different lighting conditions, and provides technical support for the inspection of platens in intelligent substations.

2. Platen State Recognition Technology

To overcome the effects of the shooting angle and lighting conditions, perspective transformation is first used to correct a distorted image. Then, S-component clustering combined with a K-means algorithm is used to segment the effective color block areas, and morphological filtering and morphological feature analysis are conducted to remove the invalid areas and obtain a binary image that can reflect the state of the platen. Finally, the state information of the platen is determined by the characteristics of the circumscribed rectangles of the binary image of the platen image. The flow chart of the specific process is presented in Figure 1.

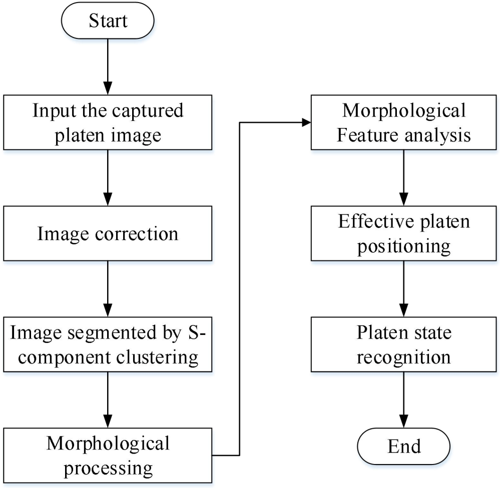


Figure 1: The flow chart of state recognition.

2.1.Image Correction

Due to the limitations of the installation positions of platens, the collected images have certain degrees of distortion; this not only increases the difficulty of positioning the platen, but also has a great impact on the accuracy of recognition. Therefore, the platen images must be rectified, which is achieved primarily through Hough transform to extract the calibrated straight line in the image. Based on this, the pixel coordinates of the four corner points of the edge of the platen area in the image are determined. This is then used as a reference point for correction and perspective transformation [11] to transform the deformed platen image into a rectified platen image. The calibration process of a platen image is presented in Figure 2.

(a) Original image (b) Rectified image

Figure 2: Image rectification.

2.2.S-component Cluster Segmentation

After image correction, the coordinates of the four corner points on the red rectangular frame in the image are determined, through which the platen area is extracted. It can be seen from the image of the platen area in Figure 2 that the colors of the platen are primarily yellow, red, and white. White is the optional platen that is the invalid platen, and yellow and red are both effective platen. Therefore, only the red and yellow areas in the image must be extracted to determine the effective platen position area. The current segmentation methods based on color images primarily include the RGB color clustering segmentation method [12], the RGB threshold segmentation method, and the mean-shift color segmentation method. These algorithms have achieved good results in platen positioning under ideal conditions. However, when the shooting environment and angle change, there are shadows in the captured image, which results in poor positioning results and severely hinders the recognition results of the platen image. To address these problems, via the combination of the color characteristics of a platen, a state recognition method based on S-component clustering segmentation is proposed. The algorithm flow chart is presented in Figure 3.

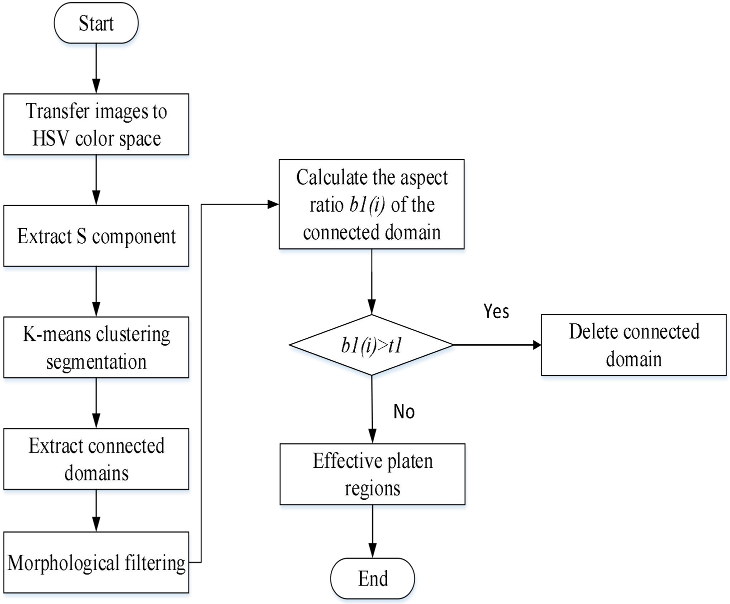


Figure 3: Flow chart of effective platen extraction.

2.2.1. HSV Color Space

The HSV color space [13] is extensively used in computer image analysis by rearranging the geometric distribution of RGB, and comprises the three elements of hue, saturation, and brightness. Compared with the RGB color space, it is closer to human perception. The independences of the three components in the HSV color model are greater than those of the three components in the RGB color model. In the proposed method, collected platen images are converted to the HSV space via nonlinear transformation, the conversion formula of which is as follows.

$$V = \max(R,G,B) \tag{1}$$

$$S = \begin{cases} \dfrac{V - \min(R,G,B)}{V} & if\,(V \neq 0) \\ 0 & else \end{cases} \tag{2}$$

$$H = \begin{cases} \dfrac{60(G-B)}{V - \min(R,G,B)} & if\,(V = R) \\ 120 + \dfrac{60(B-R)}{V - \min(R,G,B)} & if\,(V = G) \\ 240 + \dfrac{60(R-G)}{V - \min(R,G,B)} & if\,(V = B) \end{cases} \tag{3}$$

In the formula above, max and min respectively indicate the maximum and minimum values in the RGB model.

In the HSV space, the color information of an image is primarily reflected in hue *(H)* and saturation *(S)*. S represents the purity of a color; when the purity is higher, the color is more vivid, and vice versa. In addition, this component is not sensitive to light, and can therefore be used to eliminate the effects of light during the positioning of the platen. The distribution of the S-component range in the HSV space is presented in Table 1.

Table 1: S-component range distribution in the HSV space.

	Black	Gray	White	Red	Orange	Yellow	Green	Cyan	Blue	Purple
Smin	0	0	0	43	43	43	43	43	43	43
Smax	255	43	30	255	255	255	255	255	255	255

Note: the subscripts max and min respectively indicate the maximum and minimum values of S component in the HSV model.

As can be determined from Table 1, excluding those of white, gray, and black, the S-component ranges of the other colors are the same, namely 43-255. Therefore, by selecting the S component as a clustering sample, the effective color block can be extracted from the panel.

2.2.2. K-means Clustering Method Based on the S Component

The K-means algorithm [14] classifies objects that are closer to each other according to Euclidean distance, and classifies them into the same class by comparing the similarity of the objects. It is the most common clustering algorithm. In the proposed method, the K-means algorithm is used to cluster the image. The clustering point is determined by the S component in the HSV space. The specific algorithm steps are as follows.

Step 1: Extract the S-component value in the HSV space corresponding to each pixel as the cluster sample point $X = \{X_1, X_2, ..., X_m\}$, and select $K = 2$. Conduct the random selection of the initial clustering center by the algorithm.

Step 2: Perform clustering according to the selected clustering center. For sample X_j, if Eq. (4) is satisfied, it is determined to be in the first category; otherwise, it is in the second category.

$$(X_{j,S} - C_{1,S})^2 \le (X_{j,S} - C_{2,S})^2 \quad (0 < j \le m) \tag{4}$$

Step 3: Adjust the clustering center according to Eq. (5) and repeat Step 2.

$$C'_{i,S} = mean(X_{j,S} \mid X \in C_i) \tag{5}$$

Steps 2 and 3 are repeated until all samples are divided into the most suitable class according to the principle of the minimum Euclidean distance, and the iteration stops.

2.2.3. Extract Effective Platen Area

After segmentation by S-component clustering, a binary image of the target is obtained, as shown in Figure 4(b). Due to the presence of pseudo-targets and noise, the segmentation result contains many invalid connected domains. Therefore, morphological filtering is implemented to optimize the platen image, and large-area pseudo-target areas are removed by morphological analysis. The corresponding process is as follows.

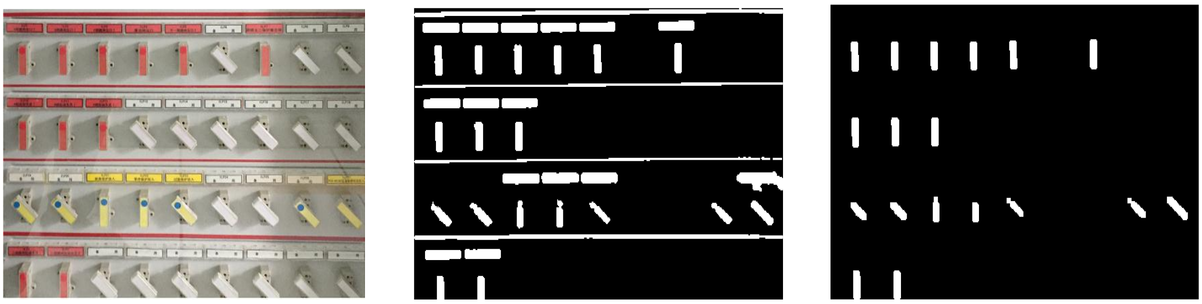
Step 1: Calculate the size of the connected domain in the binary image. Let *X(i)* and *Y(i)* be the boundary length and width of the *i*-th connected domain, respectively, and calculate the aspect ratio *b(i)* according to Eq. (6).

$$b(i) = \frac{X(i)}{Y(i)} \tag{6}$$

Step 2: Set the threshold $t1$. As given by Eq. (7), when *b(i)* is greater than $t1$, it is classified as the background; otherwise, it is classified as the target area.

$$\begin{cases} b1(i) > t1 & background\ region \\ b1(i) < t1 & object\ region \end{cases} \tag{7}$$

Finally, the binary image of the effective platen area is segmented. The result of the use of morphological feature analysis to delete the false target area is presented in Figure 4(c).

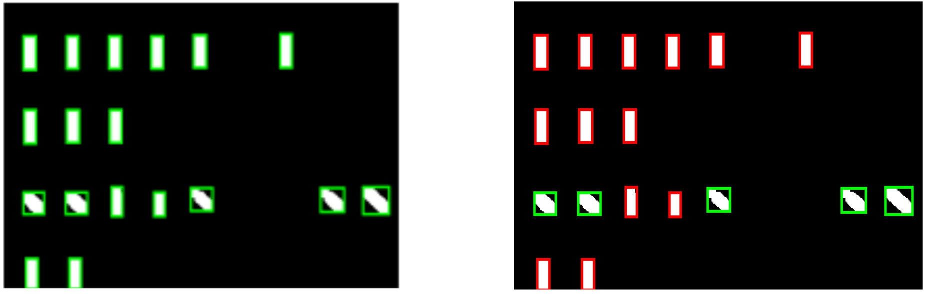


(a) Platen area image (b) S-component clustering results results (c) Effective platen area extraction

Figure 4: Extraction process of effective platen area.

2.3.Platen State Recognition

After image segmentation is completed, each effective platen area is located via the smallest circumscribed rectangle, as shown in Figure 5(a).



(a) Effective platen area positioning result (b) Platen state recognition result

Figure 5: Effective platen area positioning and recognition results.

It can be determined from the positioning results that the outer rectangular frame of the platen can be divided into two types according to its aspect ratio. Therefore, the state of the pressure plate can be judged by the circumscribed rectangular shape characteristics of each pressure plate. The judgment method is as follows. The length-to-diameter ratio of the circumscribed rectangle is determined, and the threshold value $t2$ is set. When the aspect ratio is greater than the threshold, the platen state is judged to be off; otherwise, it is judged to be on. The state recognition result is presented in Figure 5(b), in which the red rectangular frames indicate the "on" state of the platen, and the green rectangular frames indicate the "off" state.

3. Experimental Test and Analysis

Three platen images collected under different conditions were selected for state recognition accuracy tests. Moreover, the method proposed in this paper was compared with the HOG+SVM classification method and the template-matching method, and the results are exhibited in Table 2.

Table 2: Comparison of platen identification results.

Number of effective platens	Number of correctly identified states			Recognition accuracy		
	HOG+SVM	Template matching	Proposed method	HOG+SVM	Template matching	Proposed method
18	16	10	18	88.9%	55.5%	100%
27	25	18	27	92.6%	66.7%	100%
6	6	4	12	100%	66.7%	100%

According to the comparison of the recognition results presented in Table 2, the proposed method achieved a higher recognition rate and exhibited better robustness than the HOG+SVM algorithm and the template-matching method for the recognition of different panel images collected under different conditions.

4. Conclusions

To improve the accuracy of the visual inspection of platens in substations, a platen state recognition method based on S-component clustering segmentation was proposed in this work. The S component is combined with the K-means algorithm to segment the effective platen area, and the circumscribed rectangular shape feature is then used to determine the platen state. Compared with the existing technology, the proposed method is characterized by the following advantages. 1) The insensitivity to light of the S component improves the accuracy of the positioning of the platen image. 2) The division of platen images is not required. 3) A large amount of training sample data is not required to accurately identify the state information of the platen. 4) It can achieve high recognition accuracy and displays good robustness. However, there remain some limitations of this method. For example, when there are no red demarcation lines in the platen area, correction is difficult to achieve, which may affect the positioning and recognition results. Subsequent in-depth research on the automatic correction of the platen will be carried out to further improve the level of intelligent platen inspection.

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