The Recognition and Detection Technology of Ice-covered Insulators under Complex Environment

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***Abstract:*In order to avoid the impacts of outer factors on the ice-covered insulators recognition, such as weather, seasons, outside illumination changes, acquisition time, image background and image contrast, a general algorithm which can recognize and detect the ice-covered insulator accurately in a complex environment is put forward in this paper. With the video monitoring device, the image information of insulators with or without covered ice can be acquired. The ice-covered insulator images under complex environment are regarded as the research objects. Morphological closing operation is conducted on the ice-covered insulator images firstly. Then the high frequencies in the image are removed by the Wavelet Domain. A kind of invariant background quotient image can be acquired by dividing the processed images and the original images, then after the camera calibration on the quotient images, the edge contours of insulators can be extracted using the wavelet edge detection method, and the icing thickness of insulator can be obtained by using template matching algorithm and geometric model. The method is verified in an artificial climate chamber, the results show that this method can eliminate the interference of the complex background weather, accurately identify icing insulators and calculate the insulator icing thickness. This method can be applied to recognition and detection of ice-covered insulators under complex environment.**

Key Words*: *icing insulators; monitoring device; quotient image; contour feature; template matching; geometric model

INTRODUCTION

Extreme weather conditions, such as freezing rain, heavy snow will cause insulators icing phenomenon. If the phenomenon is serious ,the transmission line will be pulled down ,threating the safe operation of power network and even cause huge economic losses and casualty accident . So it will be particularly important to recognize the situation of insulator icing timely and accurately. Under complex conditions, how the situation of transmission line insulators icing can be mastered real-timely in order to take measures to avoid the accident is a hotspot of current research [1-3]. The existing main recognition technologies of insulator icing are recognizing the transmission lines icing automatically through image processing technology[4], using the mechanical analysis method to identify the icing[5],online monitoring method for transmission line icing based on 3D reconstruction[6]. All the methods mentioned above are for the recognition of transmission line and insulators icing which are under single weather and background. It is difficult to recognize the ice-covered status of the insulators under complex environment for all-weather accuratly and effectively. Therefore, it's essential to propose a universal technology which can accurately detect the isulators icing conditions under complex environment.

In this paper, a general algorithm of morphological closing operation wavelet quotient image is proposed for accurately identify the icing conditions of insulators under complex environment. It can realize the accurate identification of the ice cover conditions of the insulator under the conditions of weather, season and image background, and has the advantages of simple principle, convenient operation, high accuracy and reliability. It has important significance to improve the reliability of the electric network operation for predicting the icing conditions of insulators.

I ALGORITHM IMPLEMENTATION PROCESS

In order to improve the monitoring accuracy of iced insulator under complex environment, the algorithm of morphological closing operation quotient image is used to process the collected insulator image, reducing the influence of complex environmental factors .The ice thickness of insulator is calculated, forecasting accurately and alarming timely.

II GRAY-SCALE PROCESSING

By gray scaling image, the influence of color depth difference on the wavelet domain and its inverse transform image is discarded, improving the speed of image recognition and reducing the computational quantity. By finding the point of a color in the RGB space, the projection of the origin to the point vector is calculated and the gray value of the color is obtained. In this paper, r, g, b components are represented by 8 bits, the value range is [0,255], gray value calculation formula is as follows [7]:

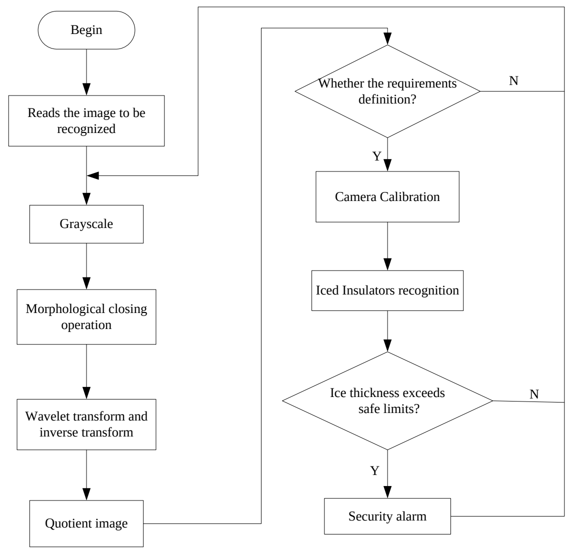


Figure 1: Algorithm flowchart

$$y = \frac{(r,\ g,\ b)\bullet(255,255,255)}{|(255,255,255)|} \tag{1}$$

In the formula, (r, g b) represents the coordinate vector of a color in the color space, (255,255,255) represents the vector of the diagonal in the color space, $|\bullet|$ is the modulus of the vector.

After the vector operation, the formula (1) can be simplified to:

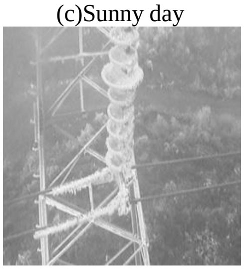
$$Y = \frac{r+g+b}{\sqrt{3}} \tag{2}$$

According to the formula (2), the insulator icing images on the scene of the fog day, cloudy day, sunny day are shown in Figure 2 (a) (b) (c), their corresponding gray processing results as shown in Figure 2 (d) (e) (f).

The color of each pixel in the insulator's color image is determined by R, G, B three components, each component has 255 values, and a pixel can have the changing range of 255^3 colors. After grayscal processing, the pixel points of the changing range of a image is reduced to 255. By contrasting the images unprocessed and processed, the same as color image, the gray image also reflects the distribution and feature of an image's whole and local color and intensity grade accurately. The color's intensity information of the insulator image is removed by grayscal processing, reducing the amount of the original data, diminishing the amount of the follow-up calculation remarkably.


(a)Fog day (b)Cloudy day


(c)Sunny day (d)Fog greyscale




(e) Cloudy greyscale (f)Sunny greyscale

Figure 2: Greyscale comparison photograph

III WAVELET DOMAIN QUOTIENT IMAGE

Based on the gray closing processing, wavelet transform is introduced [8]. In the frequency domain, the high frequency information of the greyscale image is filtered. Through the inverse transformation to the space domain， clear background of ice-covered insulators image can be obtained by quietening with the original image

A. *Gray-closing operation*

In this paper, to solve the problems such as holes, no cohesion which are produced in the process of photographing and transmission, the gray closing operation(X•S) in morphology is used to process the acquired images, doing the pre-treatment for wavelet transform and quotient image acquisition.

The definition of the gray-closing operations [9]: firstly using the structural element S_1dilatate image X to obtain the image X_1,then using the structural element S_2 erode image X_1, gray-closing operation is represented by a symbol $X \bullet S^+$ and its formalized definition is:

$$X \bullet S^+ = (X \oplus S_1)\Theta S_2 \tag{3}$$

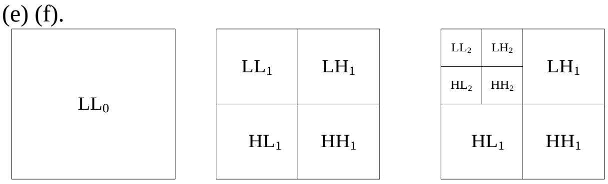
In order to improve the resolution of target, two different structural element S_1 、 S_2 are used in the two gray operations , $S^+ : \{S_1, S_2\}$;the relationship between S_1、 S_2 is S_1>S_2 the structural element S_1 is larger than S_2.

B. *Wavelet domain transformation*

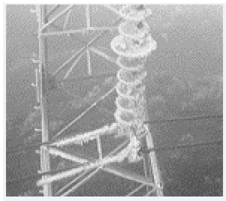
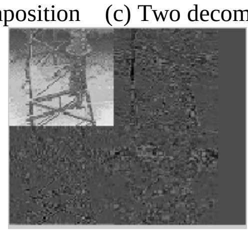
In the aspect of digital image processing, wavelet transform is used to transform the image signal in the spatial or temporal domain into the wavelet domain, making it the multi-level wavelet coefficients. In the view of the feature that the energy distribution of ice-covered insulator greyed image is concentrated, after the secondary decomposition of wavelet coefficient, the inverse transformation method is used to improve the image contrast. Processing procedure is shown in figure 3.

Figure 3: Wavelet analysis diagram

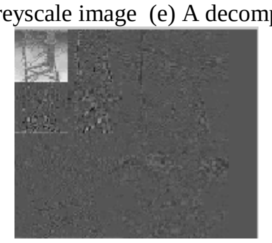
Two-dimensional wavelet transform is used to analysis the iced insulator gray image at the frequency domain [10].First, the first wavelet decomposition of the original image is carried out to obtain horizontal low frequency vertical low-frequency information LL1, horizontal low frequency vertical high-frequency information LH1, horizontal high frequency vertical low-frequency information HL1, horizontal high frequency vertical high-frequency HH1. The LL1 low-frequency sub-image shows the main features of the image; and then the secondary LL1 wavelet decomposition of LL1 is carried out. The corresponding image after two times decomposition coefficient matrix is shown in Figure 4 (b) (c) The decomposition effect of the original gray image is shown in Figure 4 (e) (f).



(a) Original image (b) A decomposition (c) Two decomposition

(d) Original greyscale image (e) A decomposition image



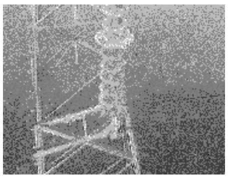
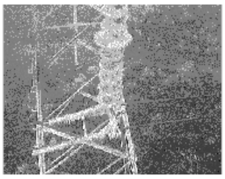
(f) Two decomposition image

Figure 4: Wavelet transform decomposition

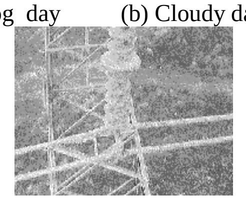
By the decomposition diagram, the distribution of wavelet coefficients in space has good correspondence with the original image. The energy will be re allocated in the frequency space after the wavelet transform [11]. The low frequency sub-band contains the low-frequency information of the image, but part of the edge details are lost .These missing details was assigned to the other three sub-diagrams, so the upper left corner sub-diagram is blurred than the original image, and the dimensions of length and width also dropped to 1/4 of its original with its resolution down to 1/16 of the original. The displayed sub-band image is reconstructed by decomposing the low frequency after the inverse transformation, figure 5 is the reconstruction of three cases renderings.

C. *Quotient image*

Based on the Algorithm of Morphological Closing Operation Quotient Image is proposed in this paper. After the ice insulator image is processed by the gray closing operation, the high-frequency sub band of the image is removed at wavelet domain, and the results are estimated as the background of the icing insulator image [12]. By wavelet domain transformation, the image is 2D image, the original image must be converted into 2D image and then can be processed by quotient image processing. The background estimation images and the original image after processing the 2D image dividing, and a higher resolution target image is obtained by the method of synthesis.

(a) Fog day (b) Cloudy day



(c) Sunny day

Figure 5: Wavelet transform renderings

The definition of the wavelet quotient image of the morphological gray level close operation is:

$$MWQI = \frac{Gray(I)}{IDWT(LPF(DWT(Close(Gray(I)))))} \tag{4}$$

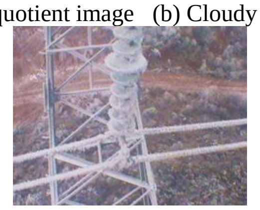
In the formula, Gray represents grayscal processing; Close represents gray closing operation; DWT represents discrete wavelet transform; LPF represents low pass filter; IDWT represents inverse discrete wavelet transform; division operation is between pixels by dividing.

The algorithm of morphological gray closing operator wavelet image can be described as follows:

(l)The original image is carried out by gray closing operation according to the 4 type; (2) Wavelet transform is carried out on the basis of (1); (3) Threshold is selected making the high frequency sub-band coefficients below the threshold value are set to zero; (4) Through the wavelet inverse transformation，the result image is regarded as a background image.(5) the background image is divided by the original image obtaining the gray closing operation quotient image. Treatment effect is shown in figure 6.(Clarity refers to the clarity of the detail in the image and its boundaries .By looking at the clear degree of the image to compare the image quality.)

(a) Haze days quotient image (b) Cloudy quotient image



(c) Sunny quotient image

Figure 6: Compare before and after image effects processing

Table 1: Comparison of sharpness of the image before and after processing

	Fog Day %	Cloudy Day %	Sunny Day %
Before treatment	30	35	50
After quotient image processing	75	80	85

Insulator image clarity has obvious enhancement by quotient image processing results figure, the contour lines of ice insulators are more obvious relatively to the background. From the table 1we can see, the processed image clarity has an obvious enhancement, improving the highest is the fog days 45%, the lowest is sunny day, also achieved 35%. The background of gray closing operation quotient image is relatively stable and clear. Compared to a single processing algorithm, this gray closing operation quotient image can better identify ice insulator image information under complicated conditions, and has high clarity.

IV ICED INSULATOR RECOGNITION

A. *Camera calibration*

The research of camera calibration technology is mainly on the positioning cameras in computer vision system and the problems of parameter recognition of internal and external [13]. Computer stereo vision system used in this paper obtained image information from the camera, calculating the position and shape of 3D environment insulator geometry information. Producing and the inherent character of the information carried by the image is through the 2D image formed from the 3D scene by the geometrical model, the imaging model is shown in 7 below.

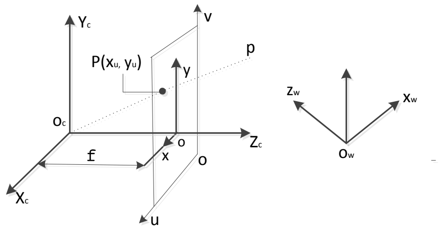


Figure 7: Camera imaging geometry

To recognize and detect the un-iced and iced insulator using camera calibration not only can correct the camera distortion, but can realize conversion between image coordinate and world coordinate, so that the actual ice thickness of the transmission line insulator can be accurately recognized under the Metric unit of the world coordinate system. .

B. *Recognition Algorithm*

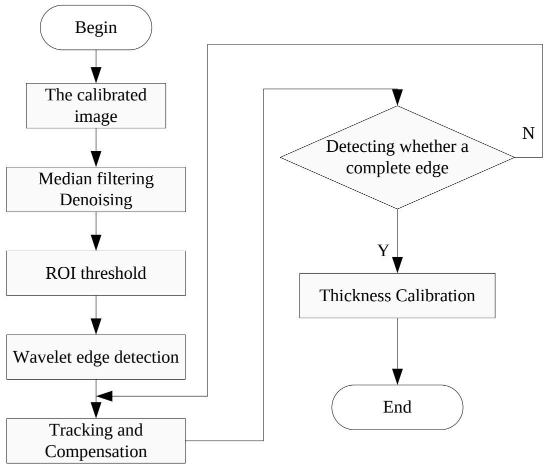


Figure 8: Algorithm recognition flowchart

The image noise is eliminated by the median filtering method with nonlinear smoothing technology. The noise is generated in the collection, transmission and the change process of closing operation quotient image

The region of interest ROI is extracted by local adaptive segmentation algorithm. The processing unit of the algorithm is generally based on the pixel or sub-block, each pixel or sub-block in the image is to strike a threshold [14-15], in order to construct a threshold value plane of the entire image, denoted as T(x, y). Then, the ROI region is segregated by the threshold value plane, the formula is expressed as:

$$g(x,y) = \begin{cases} black & if \quad f(x,y) \le T(x,y) \\ white & if \quad f(x,y) > T(x,y) \end{cases} \tag{5}$$

By calculating the mean $m(x, y)$ and standard deviation $s(x, y)$ of the current points in the window of w×w obtain the corresponding threshold. .

Then, the edge of iced insulator is extracted by wavelet edge detection [16]. By multi-scale characteristics of wavelet, the noise can be suppressed in the large-scale of wavelet, identifying the edge reliably; positioning in the small-scale of wavelet accurately. Extraction results are obtained integrating the edge image of different scales. According to the feature that the edge of the image is local feature discontinuity, using the wavelet transform of the mutation signal sensitivity, and it has good localization performance in the time domain and the frequency domain, the detection of wavelet can be used to analyze the singularity and realize the location of singular points, so as to achieve the purpose of edge detection. The wavelet edge extraction is superior to other methods in improving the edge location accuracy and reducing the noise.

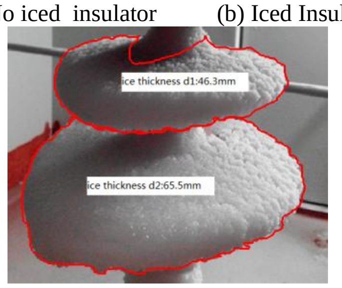
Finally, by edge tracking and compensation, the weak edges which are not detected can be further detected. The module value of the weak edges is less than the threshold which is set at the edge detection. These values are lost in edge detection at selecting edge points. But compared to the surrounding pixels, a local peak of the weak edge can be detected.

V EXAMPLES AND RESULTS ANALYSIS

The recognition method in this paper is verified in the artificial simulate iced laboratory. In indoor condition, by simulating the insulator at a humidity of and a temperature of under sunny, cloudy, fog and snowy four kinds of situations' insulator icing status and monitoring real-timely. Then the ice thickness identification method mentioned in this paper is used to recognize the insulator icing image. The thickness of the ice through experiment measured and algorithm identified are shown in Table 2 .Taking the icing status of the insulator in sunny days as an example and the recognition diagram is shown in Figure 9.

Obtaining from Figure 9, when sunny, the edge information of the iced insulator can be judged accurately by the algorithm. The thickness of the iced insulator can be recognized accurately by the algorithm. From Table 2, the maximum relative error of the thickness of the iced insulators in the four cases is the snowy day4.8 %, and the lowest is the sunny day, only1.5 %. This fully shows that the algorithm of this paper can adapt to all kinds of complex environment, and can recognize the ice thickness of insulator accurately.

(a) No iced insulator (b) Iced Insulator



(c) Ice thickness recognition

Figure 9: Recognition of insulator on sunny day

Table 2: Measurement values and Recognition values of the icing insulators' thickness /mm(20mm)

Experimental conditions	Insulation sheet (up)			Insulation sheet (down)		
	Measurement values	Recognition values	Δ/%	Measurement values	Recognition values	Δ/%
Sunny Day	45.9	46.3	1.5	64.4	65.5	1.7
Cloudy Day	45.8	47.1	2.8	64.6	66.5	2.9
Fog Day	46.9	48.7	3.8	65.1	67.7	3.9
Snowy Day	47.1	49.2	4.4	65.4	68.6	4.8

VI CONCLUSION

1) The grayscal closing operation quotient image used in this paper can process the complex background of a image into relatively uniform background mode, solving the problem existing in the traditional methods that need to use different recognition algorithms under different backgrounds. This algorithm is simple and feasible, and has the characteristic of low cost. Besides, it can save a lot of human resources cost and improve the utilization rate of the on-line monitoring system.

2) This recognition method can recognize the icing status of the insulator under different conditions accurately, and the maximum relative error of the recognition method is only4.8 %.This recognition method is feasible and accurate.

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