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AREA OF WATER DROPLET FOR HYDROPHOBICITY LEVEL CLASSIFICATION OF POLYMERIC INSULATOR

[1]Usiholo Iruansi, and [2]Oshevire Patrick.

[1]Computer Engineering Department, Faculty of Engineering, University of Benin, Benin City, Nigeria.
[2]Department of Electrical and Electronics Engineering, Federal University of Petroleum Resources, Effurun, Delta State, Nigeria.

Abstract

Hydrophobicity is an important characteristics to evaluate the performance of polymeric insulators. It is used to ascertain the level of degradation or aging of polymeric insulators, but extremely depends on human subjective judgement. Therefore, image processing and computer vision has been identified and is being investigated as a tool to solve this problem safely, accurately and speedily.In this paper the area of water droplet is used for hydrophobicity level classification of polymeric insulator. Result shows the classification of polymeric insulators into different hydrophobicity level described by the Swedish Transmission Research Institute. Also, confusion matrix is used to visualize the performance of the hydrophobicity classification level of the polymeric insulators.

Keywords: Area, Classification, Hydrophobicity, Insulators, Water droplet

1.0 Introduction

Insulators are materials that support conductors and do not allow the flow of electric current. There are different types of insulating materials for insulators, but this paper focuses on polymeric insulators. The main advantages of polymeric insulators over conventional porcelain and glass insulators in outdoor high voltage insulation applications are light weight, superior vandal resistance and better contamination performance [1]. New polymeric insulators may exhibit a high level of hydrophobicity due to mold-release compounds that remain on the insulator surfaces after manufacturing and after a short time in the field, these mold-release compounds generally wear off and the polymeric insulator loses its initial hydrophobicity [2]. However, hydrophobicity wear-off due to oxidation of surface, build-up of pollution layers and the aging process of polymer insulators [3, 4]. Over a period of time, it becomes hydrophilic, and this gives rise to better leakage current and flashover that would lead to major degradation [3, 5]. It is therefore important to periodically evaluate the hydrophobicity of insulators.

Different methods of hydrophobicity measurements are stated in [3, 6, 7]. One very popular and widely used method is the Hydrophobicity Classification (HC) method in the Swedish Transmission Research Institute (STRI) guide [8]. The STRI method offers a simple procedure for obtaining a collective estimate of the hydrophobicity of insulator surface in the field which is regarded as an authoritative standard [6, 8].

HC is performed by firstly spraying distilled water on the surface of the insulator. Secondly, the receding contact angles between the water droplets and the surface are measured. According to STRI guide[8], seven classes of hydrophobicity (HC1-7) have been defined. HC1 correspond to a completely hydrophobic (water-repellent) surface and HC7 to a completely hydrophilic (easily wetted) surface [8]. The intermediate classes are defined by receding angles of the majority of the water droplets and the size of wetted areas in each case. Then the inspector attributes the surface to one of the seven HC, from HC1 to HC7. As a help, the inspector has a set of reference images of typical wetting patterns representing each HC level [3].

To the best of our knowledge few researchers have applied image processing and computer vision to water droplets segmentation and its classification. Some researchers in the areas are; in [9], a function called average of normalized entropies (ANE) and its variations were used to determine insulators hydrophobicity. This was done by calculating the gray

Corresponding Author**:** Usiholo I., Email: uiruansi@gmail.com, Tel: +2348067708701

level differences of nearest-neighbor pixel in the horizontal direction and then distribution of gray level differences was analyzed, after which Shannon information entropy of the distribution was utilized to indicate the hydrophobicity of the specimen. However, in practice different parts of the insulator may have different HC levels, which need to be detected and therefore the monotonic function is helpless in this situation [6]. In [11], area ratio and shape factor were proposed to estimate HC level, but no method was mentioned to detect water droplets. In [12], the authors used a new Fuzzy Means Clustering (FCM) approach to segment water droplets in grayscale channel and from the images in their paper, there is no apparent shadow and water droplets that is as bright and transparent in this condition, and such illumination condition is rarely found outdoor, so that their algorithm is not suitable for field test [5]. In [13], textures images were created from mixtures of isopropyl alcohol and distilled water in proportions. Based on these solutions, the contact angles of the drops were measured and the textures were used as pattern for fractal dimension calculations. However, this is also subject to human judgement for contact angle measurement and therefore it is not fully automated. In most cases, distilled water is used and the performance will be poor since water is transparent and colourless. However, neither of them were able to obtain a mathematical relationship which may define HC comprehensively.

Therefore, an algorithm which is automated, accurate, speedily and not subjected to human judgement is proposed. The proposed algorithm involves image segmentation and hydrophobicity level classification; to identify regions of water droplets on insulator surfaces and then analyzes each segment based on its geometric parameter, which is the area ratio.

The rest of the paper is organized as follows. Section 2 discusses the methods and materials for the proposed method. Section 3 presents the validation of the proposed model. Conclusion and future works are outlined in section 4.

2.0 Methods and Materials

2.1 Equipment

The material employed in the experiment is a silicone rubber (SIR) insulator that is gray in colour. An ordinary spray bottle, a digital camera and a computer for image analysis.

2.2 Experiment

Experiment is based on STRI guide [8]. Distilled water is sprayed on a fixed insulator surface with a spray bottle. Then, a digital camera is used to capture images with water droplets as it approaches a steady state. This procedure above is repeated until the images of all samples were obtained. Finally, all the images are transferred to a computer for further analysis based on image processing and computer vision.

First is the conversion of the captured images from coloured to a grayscale image, then segmentation of water droplets from insulators. The edge-based segmentation of an image is based on discontinuities in the intensity, while region-based looks for uniformity within a sub-region, based on desired property such as colour and texture [15], [16]. However, the region-based properties cannot be used to indicate the hydrophobicity status because; water is transparent and colourless, which affects the use of colour parameters and secondly, variation of the gray level of pollutants on the insulator surfaces, which affects the use of texture parameters [11]. Hence, both colour and gray level of water droplet are similar to the background. Therefore, the boundary or edge of the water droplets is useful for indicating the water droplets from insulator surfaces.

As stated in the STRI guide, HC level is based on two criteria; the contact angle and the area. HC1 to HC3 is based on the contact angle and HC4 to HC7 is based on the area. However, in this experiment, it was fully based on the area since the contact angles cannot be calculated or measured from a digital image.

Figure 1 shows the reference images from the STRI guide. These images are used to create a standard template for maximum area of water droplets for different HC levels(see Figure 2).

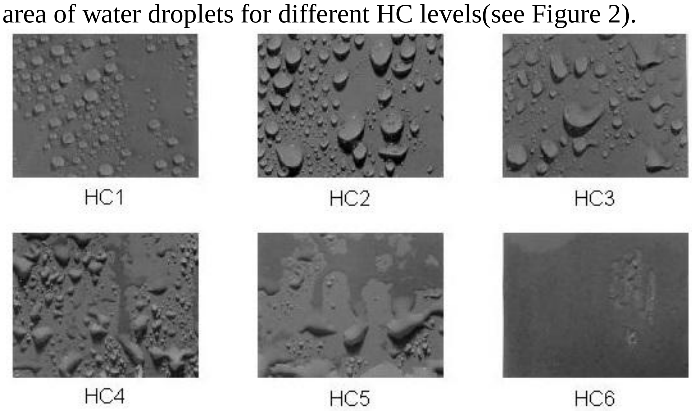

Figure 1: Original template from the STRI guide.

From the STRI guide, images of different HC levels were cropped out to a size of 300x256 pixels. The edges or boundaries of each water droplets in each HC levels were properly traced out by experts (see Figure 2) in order to have a binary image that is set as a standard template to estimate maximum area for calculating area ratio. Therefore, the maximum area is used as reference to classify other images into different HC levels. Also, other water droplets outside this are not of much concern. Then the maximum area from the reference image is used to set the range of each HC level. Also, Figure 3 shows the water droplets with maximum area.

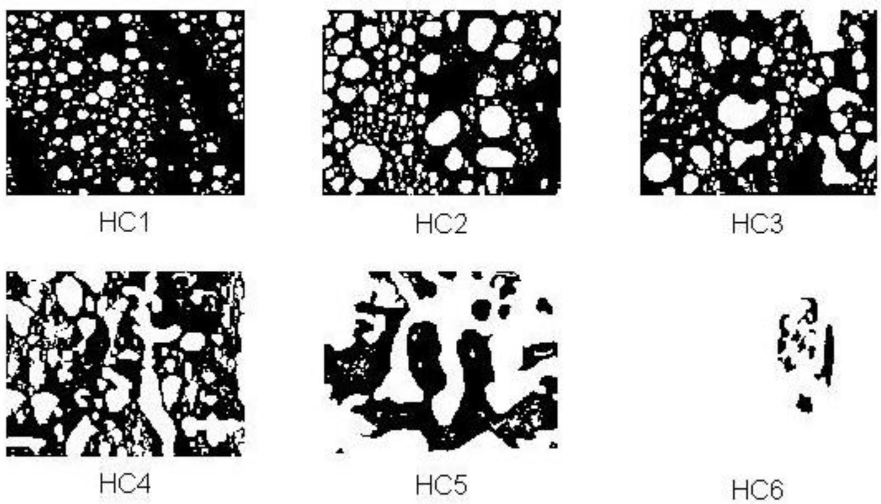

Figure 2: Binarized STRI guide reference images with different HC levels from HC1 to HC6 by Experts

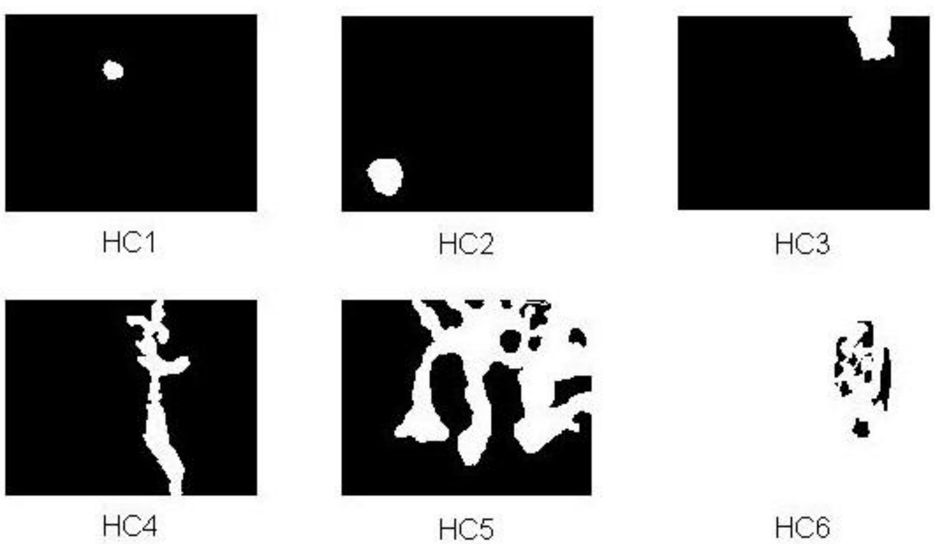

Figure 3: Maximum area for STRI guide reference images with different HC levels from HC1 to HC6

Image acquisition is the process of obtaining a digitized image from a real world source [17]. In image acquisition, noise may be introduced which is random changes in the values of the pixels in the image. In this paper, RGB (Red, Green, and Blue) images are converted to grayscale images. In order to remove noises and to further enhance the image, a series of morphological operations [15], [18] are used, such as erosion, dilation close operation, and morphological reconstruction. This was used to remove small pixels and keep the original shape of the rest pixels and fill some narrow breaks and holes in the water droplets.

The complete flow chart of our proposed method for HC of polymeric insulator has been rendered in Figure 4.

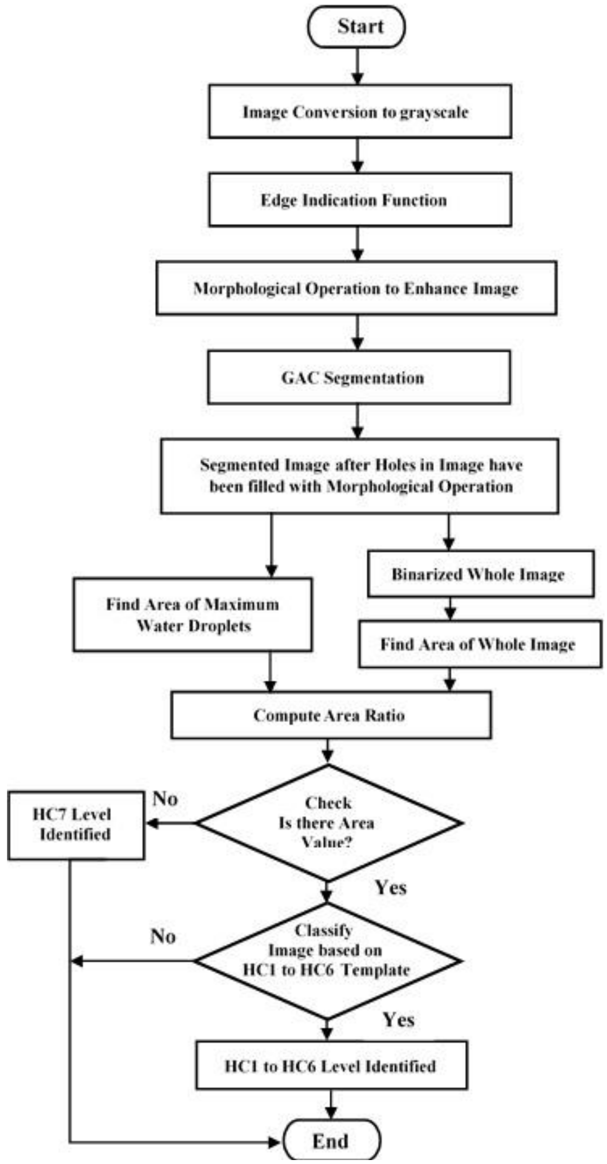

Figure 4: Flowchart of the proposed method

2.3 Water Droplet Segmentation

The model presented in this research work for water droplet segmentation on insulator surface images is based on [14]. Geodesic Active Contour (GAC) is expressed as:

$$\frac{d\Gamma}{dt} = v(m)\kappa \bar{R}(\nabla v \bullet \bar{R})\bar{R} \tag{1}$$

where $\bar{R}$ is the unit normal vector of the curve Γ, κ is the Euclidean curvature, $v(m)$ is the stopping function and ∇v is the gradient of the potential edge indication function v expressed as:

$$v = \frac{1}{1+|\nabla(\theta_\sigma * m)|^2} \tag{2}$$

where m is the given image, θ_σ is the Gaussian filter, $(\theta_\sigma * m)$ is the smoothed version of m and c is a constant.


(a) (b)

Figure 4: Image transformation. (a) Original image (b) Output of edge indicator function

From Figure 5, the original image *m* is smoothed by convoluting with a Gaussian filter θ_σ because it is noisy. Then the gradient of the smoothed image is squared and added to value 1 to give the regularized image. The denominator has a value 1 in order not to have zero at the denominator. If there are edges, the regularized part of the equation is very high and the reciprocal of the regularized part is very small which define the local edges for the active contour to travel through.


(a) (b)

Figure 5: Geodesic transformation. (a) Initial curve (b) Final curve from GAC (best viewed in colour)

The images in the STRI guide are used as a standard template for classification of HC level. The edges of the water droplets in each image in the STRI guide are properly traced out and binarized. However, interest is based on the maximum area value of the water droplets of each image in the STRI guide. These values are used to calculate the area ratio for estimating the range of each HC level. The area is the actual number of pixels in the water droplets. Also, the area of the whole image is computed by thresholding with a value, in order to have a white background all through in the image. The maximum area value and the area of the whole image is computed using MATLAB commands.

2.4 Hydrophobicity Classification

The area ratio is one parameter for hydrophobicity classification. The area ratio is the ratio of the water droplets to the whole image. This describes the uniformity of areas covered with water. It represents the size of the water droplets and the bigger the water droplets, the bigger the area value and worse evenness of distribution. The area ratio also help to maintain the fact that each image size will not be define before use. In other words, it will not be made to same size as the template size for classification. The formula for calculating the area ratio is:

$$A_R = \frac{A_D}{A_W} \quad (3)$$

where, A_R is the area ratio, A_D is the maximum area in pixel of water droplet and A_W is the area in pixel of the entire or whole image.

3.0 Experimental Results and Discussion

The data used consist of 50 images of polymeric insulator surfaces captured with a digital camera. The entire 50 images were used for confusion matrix visualization of HC level.

Figure 6 shows the segmented images of water droplets on insulator using the proposedmethod. Segmentation results; a1 represent the original images, b1 represent the GAC and morphological operation on a1 and c1representthe final result. Figure 7(a) shows the inverted image of Figure 6(c1) in order to be able to compute the maximum area of water droplets. This is so, because the white pixel is required for computation. Figure 7(b) shows the maximum area of water droplet from Figure 7(a).

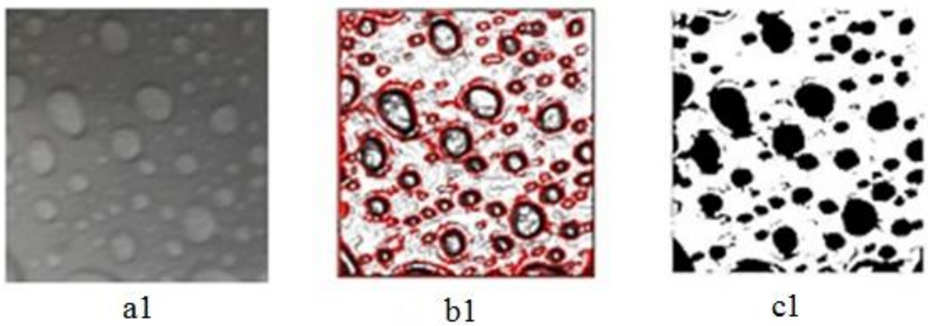

Figure 6: Segmentation result of some insulator images; a1 represent the original images, b1 represent the GAC and morphological operation on a1 and c1 represent the final result(Best viewed in colour).

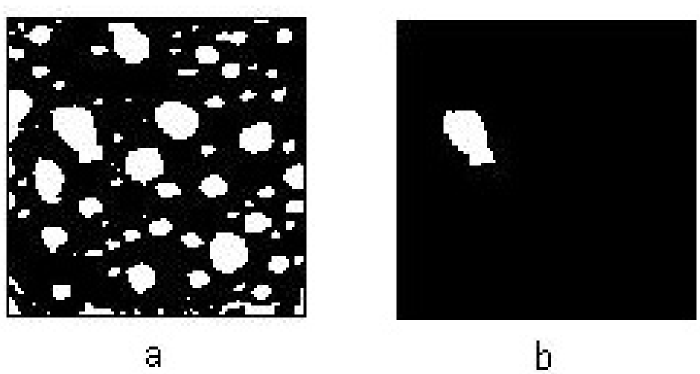

Figure 7: (a) Segmentation of water droplet from insulator, (b) Maximum area from (a),

The accuracy of the proposed model is computed using the statistical criteria in [19]. The accuracy is defined as:

$$Acc(\%) = (TP + TN)/(TP + TN + FP + FN) \quad (4)$$

where TP is true positive, TN is the true negative, FP is the false positive and FN is false negative.

Table 1 is the confusion matrix of the proposed method. It is a multiclass classification, one against all approach was used to estimate the TP, TN, FP and FN. The ground-truth of HC1, HC2, HC3, HC4, HC5, HC6, and HC7 are ten (10), fourteen (14), ten (10), five (5), five (5), four (4) and two (2) respectively. The seven diagonal cells shows the number of correct classifications. Considering HC1 of Table 1, it means that seven (7) insulators are properly classified with three (3) insulators miss-classified. The accuracy of HC1 classification is shown in Table 2 as 88.24%. Same principle goes through HC2 to HC6. In class HC7, the ground-truth values of two (2) is correctly identified, but having accuracy drop because of misclassification from another class to this class, resulting to false negative. The accuracy of HC7 classification is shown in Table 2 as 96.77%. The average of all the accuracy is stated in Table 2 as 84.48%.

Table 1: Confusion Matrix of Proposed method

	HC1	HC2	HC3	HC4	HC5	HC6	HC7
HC1	7	3	0	0	0	0	0
HC2	1	9	4	0	0	0	0
HC3	0	1	7	2	0	0	0
HC4	0	0	2	2	1	0	0
HC5	0	0	0	1	2	2	0
HC6	0	0	0	0	2	1	1
HC7	0	0	0	0	0	0	2

Table 2: Performance Analysis

	HC1	HC2	HC3	HC4	HC5	HC6	HC7	AVERAGE
ACC	88.24%	76.92%	76.92%	81.08%	85.71%	85.71%	96.77%	84.48%

However, there is misclassification as a result of under-segmentation and over-segmentation, thereby affecting the maximum area of the water droplets for HC. That is, the expected maximum area of water droplet is either too large or too small. This is as a result of not having proper defined edges, thereby having poor segmentation. This is the reason why segmentation play a vital role in image processing and computer vision.

4.0 Conclusion

In this paper, hydrophobicity classification of polymeric insulator using active contour and geometric parameter such as the area ratio has been presented. Also, it is faster, accurate and automated in classification if the template is properly design instead of manual operation.

It is proposed that to have a better performance for edge based segmentation, color liquid can be used to spray the insulator which will present a strong gray difference with background for easy segmentation, unlike distilled water that is transparent and difficult to segment.

In future, more characteristic parameters such as area ratio, cover ratio and shape factor will be combined for the classification of HC levels.

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