WATER DROPLETS SEGMENTATION FOR HYDROPHOBICITY CLASSIFICATION

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ABSTRACT

In this paper, we propose an effective water droplets segmentation algorithm based on HSV color space and watershed method. Water droplets segmentation is the key issue to design an automatic hydrophobicity classification algorithm, and the challenge is two-fold: highlight spots on water droplets and the transparency of water. By decomposing the color images into HSV color space, water droplets are easy to be separated in the saturation channel, and watershed method is incorporated to reduce the side-effect of highlight spots. Experimental results on real images demonstrate the advantage of our proposed method.

Index Terms— edge detection, HSV color space, hydrophobicity classification, rubber insulators, watershed

1. INTRODUCTION

Polymeric insulation coating is widely used. It is painted to high voltage insulators to prevent flashover. It has been shown that water droplets will charge negatively and deform in high voltage ac field, which results in flashover [1]. Insulators with high hydrophobicity paint-coat, which can prevent water from adhering to the surface, are used in high voltage line to prevent flashover. However, hydrophobicity of insulators will degrade because of pollution deposits, wind, etc. If the insulator becomes hydrophilic, flashover would be easier to take place. Therefore, periodical hydrophobicity test of insulators in the field is very important.

The Swedish Transmission Research Institute (STRI) method [2] is widely used to measure the hydrophobicity of insulators. The steps of STRI method are as follows. First of all, distilled water is sprayed to the surface of the insulator or specimen. Secondly, the receding contact angles between water droplets and the surface are measured. For hydrophilic surface, completely wetted areas are also measured. And then the inspector attributes the surface to one out of seven hydrophobicity classes (HC), from HC1 (hydrophobic) to HC7 (hydrophilic). However, contact angles are hard to measure in field test. Therefore, it's better to find an alternative relationship of hydrophobicity and water droplets pattern [3].

Former researchers tried to find a robust monotonic function that can indicate the HC level of insulators. Berg used a function called average of normalized entropies(ANE) and its variations [3] to determine insulators' hydrophobicity. First of all, gray level differences of nearest-neighbor pixel in the horizontal direction are calculated and then the distribution of gray level differences is analyzed. Finally, Shannon information entropy of the distribution is utilized to indicate the specimen's hydrophobicity.

However, in practice, different parts of the insulator may have different HC levels, which needs to be detected. The monotonic function is helpless in this situation.To solve this problem, methods using shapes of water droplets are proposed. In [4], the authors investigated the relationship between areas of the water droplets and HC level, which is nearly monotonic, but they didn't give any method to detect water droplets. Based on this concept, Tokoro proposed circular factor[5], Li proposed area ratio[4] to estimate HC level.

In [6], the authors use fuzzy means clustering (FCM) to segment water droplets, but the images are taken indoor, with multi-lights in the room. As shown in Fig. 1(a), there is no apparent shadow and water droplets look bright and transparent in this condition. Such an illumination condition is rarely found outdoor, so that their algorithm is not suitable for field test. Besides, they only used the information in gray-scale channel.

However, the detection of water droplets is difficult for the following reasons: (1) Water is transparent and colorless, so that both its color and gray level are similar to the background. (2) Appearances of water droplets are sensitive to illumination. Since the water droplets are hemispherical, there are always highlight spots on different parts of the droplets, which is heavily dependent on the light sources and the view direction.

In this paper, we introduce a novel method that is suitable for water droplets segmentation in different illumination conditions. Positions and sizes of water droplets are estimated using highlight spots information. Then we apply edge detection method in both saturation and brightness channels to find accurate boundaries of water droplets. Experiments show that our algorithm works well in both indoor and outdoor condi-

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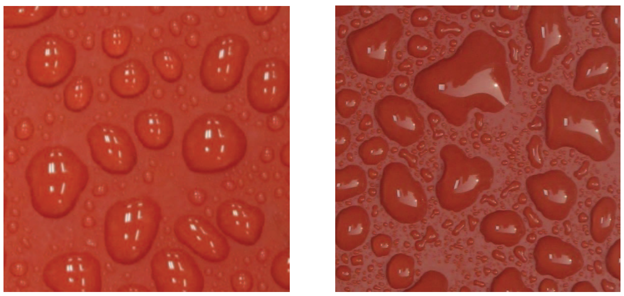
tions.

The remainder of the paper are organized as follows. We introduce data preparation in the next section. In section 3, the segmentation algorithm is proposed. Experimental results and conclusions are shown at last.

2. DATA PREPARATION



(a) Indoor, supplement lamp off (b) Outdoor, daytime

Fig. 1. Water droplets in different illumination circumstance.

The electric department requires workers to do field test. Workers climb on to utility poles to take photos of insulators sprayed with distilled water. Photos will be processed by micro-computer as soon as possible to classify the insulator into one out of seven HC levels.

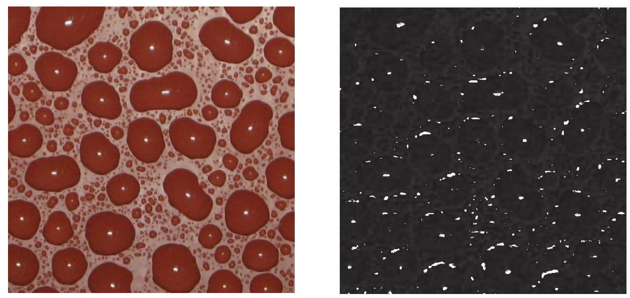
However, appearances of water droplets in photos depend heavily on light sources in the environment. Fig. 1(a) shows a photo taken indoor and there isn't apparent shadow. Illumination like this is rarely found outdoor.

To simulate conditions outdoor, in our experiment, we prefer to use a very bright supplement lamp (15cm$\times$10cm LED lamp) on the camera, which is much brighter than other lights indoor. While in outdoor at daytime, the lamp is much darker than sun light. In these conditions, photos we obtain are of similar interest features. Fig. 2(a) is taken indoor with supplement lamp on. The lamp is the main light source and the angle of incidence is nearly zero degree. Different from water droplets in Fig. 1(a), those in Fig. 2(a) look much darker than their surroundings. In this condition, there is one highlight spots on the center of each water droplet. If photos are taken outdoor in daytime, as shown in Fig. 1(b), sun light is much brighter than any other light sources, and the water droplets are darker than the background. The positions of highlight spots depend on the relative positions between the sun and the camera. Although the area of the highlight spot is bigger than that taken indoor, there is still one highlight spot on each water droplet. In a word, with the lamp on, water droplets have similar appearances. Water droplets look darker than their background and there is one highlight spot on each water droplet.

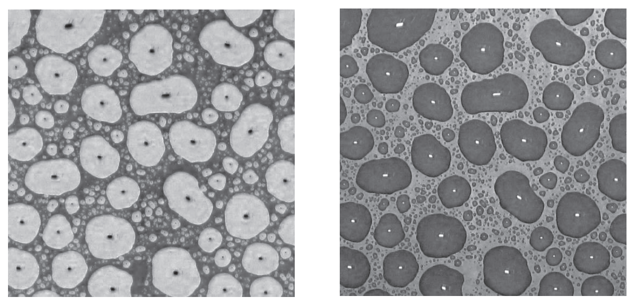
For portability, we use simple hand-held digital camera, such as Cannon G9, to take photos. Tripod isn't appropriate since that it's impossible for workers to carry. Photos are taken at a distance of 30cm to 60cm from the insulator. Then water droplets patterns are cut from them and resized to 512×512.

3. WATER DROPLETS SEGMENTATION ALGORITHM

3.1. Water droplets in HSV color space



(a) Indoor, supplement lamp on (b) Hue channel of (a)



(c) Saturation channel of (a) (d) Brightness channel of (a)

Fig. 2. Water droplets and its components in HSV color space.

HSV represents hue, saturation and brightness value. It's a color space based on human color perception wishing for user-friendly description of color values [7].

In HSV color space, the definition of saturation S and brightness value V are

$$S = 1 - \frac{\min(R, G, B)}{\max(R, G, B)} \quad (1)$$

$$V = \max(R, G, B) \quad (2)$$

where R,G,B represent red, green, blue value in RGB color space.

One specimen and its HSV components are shown in Fig. 2, it is taken indoor, with the supplement lamp on. Fig. 2(b) is the hue channel of Fig. 2(a), it looks like noise. For example, colors that are nearly white can have hue value in the whole range, making it unstable, so that hue channel is discarded in our algorithm. Fig. 2(c) shows the saturation channel of Fig. 2(a), different from the hue channel, values of water droplets in saturation channel are higher than background, making them discriminative. Fig. 2(d) shows the brightness channel of Fig. 2(a), it is similar to widely used gray-scale image. Compared with saturation channel, there is more noise in the brightness channel.

The most significant features in Fig. 2 are that highlight spots are of low values in saturation channel while in the brightness channel, their values are very high. At the same time, boundaries of water droplets are apparent in both saturation channel and brightness channel, especially in saturation channel. These two features are inductive in our segmentation method which will be introduced in the following section.

Similar results can be obtained in HSI color space, which is also based on human color perception. Experiments in this paper are performed in HSV color space.

3.2. Water droplets segmentation algorithm

In section 2, we showed that there is one highlight spot on each water droplet. In our algorithm, highlight spots are used to count and locate water droplets roughly. Highlight spot is the area with low saturation and high brightness. They are brighter compared with their surroundings. With these features, we can locate parts of them easily, then marker-controlled watershed algorithm [8] is used to segment them accurately. This algorithm is shown in algorithm 1.

Algorithm 1 Highlight removing.

1: **Color space conversion.** Convert image from RGB color space to HSV or HSI color space. Get the saturation plane and the brightness plane.
2: **Highlight seed selection.** Pixels with saturation lower than threshold thS and brightness higher than threshold thB are selected.
3: **Highlight detection.** Use marker-controlled watershed algorithm to detect highlight spots.
4: **Highlight verification.** Highlight areas with mean saturation higher than threshold $thS2$ or brightness lower than threshold $thB2$ are discarded.
5: **Substitute highlight pixels.** Substitute highlight pixels with mean value of their surroundings in both saturation and brightness channel.

In Fig. 2(c) and Fig. 2(d), we can see that boundaries of highlight spots are stronger than edges of water droplets. Highlight removing can eliminate strong edges caused by highlight spots, making edge detection of water droplets easier.

After highlight removing, Canny edge detector [9] is used to find edges of water droplets. Edges detected may be discontinuous. Then edges near to each other are linked to form closed boundaries of water droplets. Steps of the algorithm are shown in Algorithm 2.

Algorithm 2 Water droplets segmentation.

1: **Highlight removing.** See Algorithm 1.
2: **Edge detection.** Perform Canny edge detector to find edges in saturation channel and brightness channel separately.
3: **Noise elimination.** To avoid noises, edges no longer than a threshold, such as 10 pixels, are eliminated.
4: **Edge fusion.** Combine edges in saturation channel and brightness channel.
5: **Water droplets extraction.** Fill holes to get the water droplets.

In our algorithm, water droplets connected to the boundaries of the image are discarded because incomplete water droplets are useless for HC level analysis. Although the algorithm above detects edges in both saturation channel and brightness channel, edges in saturation channel can give a good result in most cases.

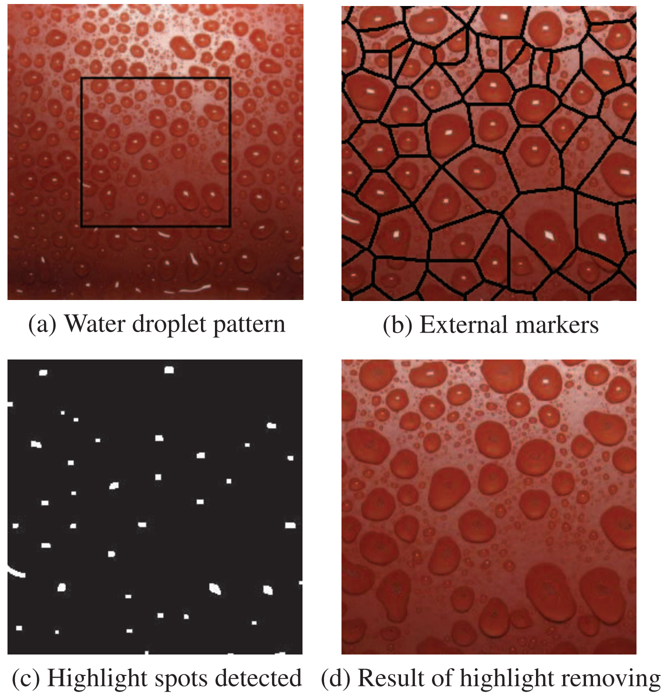
4. RESULTS AND DISCUSSIONS

A result of highlight removing algorithm is shown in Fig. 3. We apply Algorithm 1 to Fig. 3(a), but only results in the black square are shown here for visibility. Fig. 3(b) is the external mark. Because there is one highlight spot on each water droplet, the external mark separate water droplets coarsely. Most of highlight spots are detected as shown in Fig. 3(c). On the top part of the image, edges of water droplets are stronger than highlight spots. In this condition, water droplets are detected instead of highlights. But they are excluded in the highlight verification step. Since that edges of water droplets in this part are strong enough, they can be detected effectively. Fig. 3(d) shows the image with highlight removed. And most strong edges are at the boundaries of water droplets now.

Fig. 4(b) shows one of the segmentation result. Fig. 4(a) is a image taken indoor at a close distance. The top part of the specimen is very bright, while the down part is much darker. Even though the illumination is non-uniform, most of the water droplets can be segmented correctly. Fig. 4(c) is an insulator with black surface. Intuitively, the saturation of black pixel is small, making edge detection unstable. But the results show that our algorithm works well for it. Large water droplets are all marked. It doesn't matter that some small droplets are not detected, since the HC level is determined by large droplets.

5. CONCLUSIONS

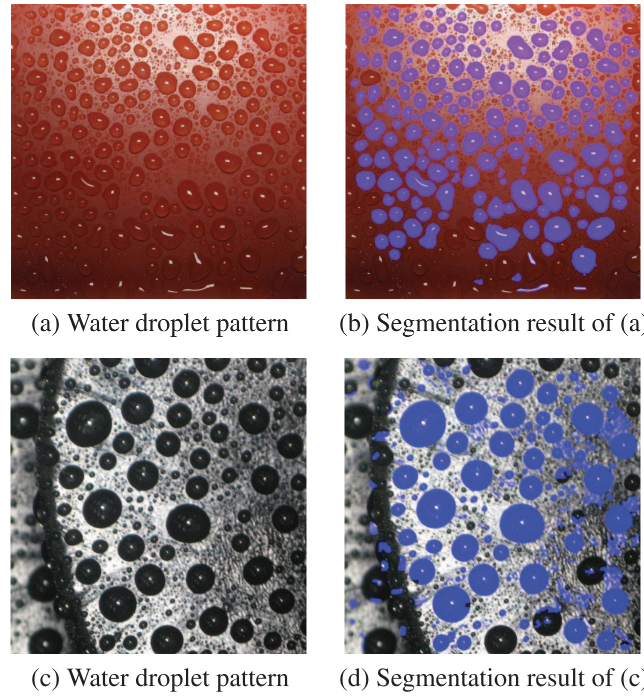
We have proposed an effective method based on HSV color space. Inspiring from apparent saturation change caused by



(a) Water droplet pattern (b) External markers

(c) Highlight spots detected (d) Result of highlight removing

Fig. 3. Highlight removing using marker-controlled watershed.



(a) Water droplet pattern (b) Segmentation result of (a)

(c) Water droplet pattern (d) Segmentation result of (c)

Fig. 4. Results of water droplets segmentation with blue component of water droplets set to maximum value.

water droplets, we mainly utilize edges in saturation channel rather than brightness channel to segment the image. Highlight spots are detected and water droplets can be segmented correctly even in uneven illumination condition. The external mark in the highlight removing algorithm segments water droplets coarsely, which can be used to enhance the continuity of edges in the future. Results show that our method is suitable for field test of the HC level of insulators.

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