A Survey of Water Droplet Recognition Algorithms on Object Surface

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Abstract. The recognition and extraction of water droplets on object surface have important practical application value. This article focuses on summarizing the different water droplet recognition segmentation algorithms, mainly based on threshold, edge detection, region and morphology segmentation, and clustering and special model-based segmentation algorithms. Then, some shortcomings of the current algorithms are analyzed and the future research direction is prospected.

1. Introduction

Water droplets recognition technology has been widely used in fabric waterproof performance test, composite insulator hydrophobicity grade evaluation, crop planting. Most of the traditional water droplet recognition methods are based on human eyes, which needs a lot of time. With the development of computer technology, researchers have applied digital image processing technology to the recognition of water droplets on the surface of objects, and achieved very good results, which not only reducing the recognition time, but also ensuring the real-time recognition, at the same time, the accuracy of recognition is improved.

Water droplets recognition on object surface based on digital image processing technology mainly includes three basic processes: Image pre-processing, image segmentation and image feature extraction, as shown in Figure 1.

![Figure 1. The main steps of the application of water droplet recognition.](image)

The difficulty lies in the segmentation method of water droplet image. This paper summarizes different water droplets recognition methods, mainly including methods based on threshold segmentation, methods based on edge detection, methods based on Region segmentation and methods...
based on special models. Finally, the existing problems in the research of water droplet identification are summarized and the future directions of technical innovation are prospected.

2. Recognition method based on threshold segmentation

Threshold segmentation method is a common method in image segmentation because of its simple algorithm and stable performance. The principle of this method is to segment the object and the background by finding the optimal gray threshold, which makes use of the difference of the gray level between the object region and the background\(^1\)\(^2\). Many threshold segmentation algorithms have been proposed by researchers. Japanese scholar Otsu\(^3\) proposed adaptive threshold segmentation method in 1979, also called Maximum between-Cluster Variance(Otsu), which greatly improved the effect of image segmentation. However, this method has some limitations in the application of Water Droplets recognition due to the complexity of the background. Therefore, HU et al.\(^4\) proposed to carry out a series of pre-processing, such as averaging, average filtering, mold and processing, and gray stretching, and then they used dual threshold value to segment the water droplets in the image. LIAO et al.\(^5\) used wavelet transform to decompose the composite insulator image of water spraying into high and low frequency, then processed the high and low frequency coefficients. After inverse transform, enhanced image was formed and the image was further filtered and preprocessed. Finally, they used Maximum between-Cluster Variance to calculate the optimal threshold to segment the image into binary image. Chinese researchers LIU Jianzhuang and LI Wenqing\(^6\) proposed a two-dimensional Otsu threshold segmentation method. On this basis, WANG et al.\(^7\) enhanced the image using contrast-limited adaptive histogram equalization and mathematical morphology filtering, and then used two-dimensional Otsu automatic threshold segmentation method to separate the water droplets from the background, the result is quite satisfactory. SHANG\(^8\) used the Maximum between-Cluster Variance threshold segmentation method to identify water droplets. On the basis of the image preprocessing with Haar wavelet de-noising, RUAN\(^9\) optimized the parameter K of Nick Algorithm so that it could calculate the parameter FK adaptively according to the image, then, the local threshold of the improved Nick Algorithm and the global threshold of the Otsu Algorithm were fused to get the final threshold of the local region. Finally, the water droplet image was segmented by threshold value. Compared with Nick and Otsu Algorithm, the improved algorithm has better segmentation effect. Table 1 and Table 2 show the accuracy of the classification of hydrophobicity of insulators with different threshold segmentation algorithms.

One of the difficulties of threshold segmentation method is how to find the best segmentation threshold accurately. Some researchers introduce the concept of entropy\(^10\) into image segmentation, and put forward many image threshold segmentation algorithms based on entropy. The principle of the algorithm is that the segmented binary image should retain the information of the original image as much as possible. Therefore, the information of the segmented image should be lost at least after using the optimal threshold. ZHOU et al.\(^11\) first processed the image with adaptive filtering\(^12\), and then got the Water Droplets area by entropy-based automatic thresholding method. GAO et al.\(^13\) combined the entropy theory and the Fuzzy set theory and proposed to use two-dimensional maximum pattern and entropy to segment image, this method can extract the shape information of water droplets more accurately. WANG et al.\(^14\) proposed to convert the surface RGB image of the composite insulators into HSV image, and calculated the gradient value of the V component in the HSV image. Some image enhancement technologies were applied on the gradient image. And the edges of the water droplets in the image were identified by the adaptive threshold segmentation method according to the maximum entropy. This method is suitable for smaller images. Feng\(^15\) proposed a TMSD algorithm with the most detailed features, which combined with entropy to complete the water droplet image recognition, and can be better applied in engineering projects.
Table 1. Accuracy in judgment of hydrophobicity grade of insulator after treatment with different segmentation methods.

| Level | Method         | LIAO | WANG et al. | RUAN et al. | SHANG |
|-------|----------------|------|-------------|-------------|-------|
| HC1   | 85.0%          | 97.0%| 96.4%       | 92.9%       |       |
| HC2   | 70.0%          | 90.0%| 95.8%       | 92.9%       |       |
| HC3   | 75.0%          | 87.0%| 92.6%       | 92.9%       |       |
| HC4   | 90.0%          | 90.0%| 90.5%       | 96.4%       |       |
| HC5   | 95.0%          | 93.0%| 94.4%       | 96.4%       |       |
| HC6   | 100.0%         | 90.0%| 90.0%       | 100.0%      |       |
| HC7   | 100.0%         | 97.0%| 89.4%       | 100.0%      |       |

Table 2. Average accuracy of determining hydrophobicity grade of insulators with different edge detection methods.

| Method   | Average accuracy |
|----------|------------------|
| LIAO     | 87.86%           |
| WANG et al. | 92.00%           |
| RUAN et al. | 92.73%           |
| SHANG    | 95.92%           |

In order to get the best segmentation threshold more accurately, the researchers try to combine some classical algorithms such as genetic algorithm to find the optimal solution, and have made some progress. WANG\[16\] proposed a genetic image based on the Maximum between-Cluster Variance. The genetic algorithm was used to solve the maximum variance, and a better segmentation threshold was obtained. CHENG et al.\[17\] used the improved genetic algorithm based on the Maximum between-Cluster Variance to segment the image. Compared with the traditional genetic algorithm, this algorithm not only improves the quality of image segmentation, but also improves the operation speed of the Algorithm.

The method based on threshold segmentation is simple and practical, but it can’t solve the noise problem caused by non-uniform illumination and the adaptive ability of segmentation algorithm is poor.

3. Recognition method based on edge detection

The edge detection algorithm was first proposed by Jules in 1959. Since then, a large number of image segmentation algorithms based on edge detection have appeared. Among them, the Canny algorithm which was proposed by an American scholar named John Canny has attracted the attention of many scholars because of its good segmentation effect. The traditional Canny algorithm has some defects in the application of water droplets recognition because it does not have the self-adaptive ability. Researchers have proposed many edge detection based on improved Canny operator, aiming at the defect that the Gaussian filtering coefficient of the traditional Canny algorithm needs to be manually set. Peng Liang\[18\] proposed to use a multi-scale adaptive Gaussian filtering method for smoothing operation. Experimental results show that this algorithm is better than the traditional Canny algorithm in the accuracy of edge location, SNR and the stability of edge detection. YAN et al\[19\] introduced the gray morphological open-close filtering method and the OTSU adaptive threshold setting method to replace the traditional Canny algorithm of gauss filtering and high-low threshold manual setting method, so that it can be better applied to the detection of water droplets image and improving the precision and accuracy of edge detection. DONG et al.\[20\] found that the gradient direction of the water
droplet edge points generally points to the normal direction or has a small angle with it, while the isolated noise points usually have no specific gradient direction, therefore, the edge points can be further filtered by synthesizing the gradient direction information based on the traditional Canny algorithm. This improved algorithm can improve the recognition effect to some extent, but it will also lead to the deterioration of edge closure, so we still need to combine the threshold segmentation method. The traditional Canny operator uses 2x2 neighborhood to calculate the gradient amplitude and direction by finite difference with first order partial derivative, which is very sensitive to noise and may produce false edges. Therefore, CAI et al.\textsuperscript{[21]} proposed using 3x3 neighborhood to calculate the gradient. the gradient amplitudes are calculated not only in the horizontal x and vertical y directions, but also in the 45 and 135 directions, that is, the diagonal direction of the Pixel is taken into account, which effectively reduces the influence of noise.

In addition, some other edge detection algorithms are also used in water droplets recognition. LI et al.\textsuperscript{[22]} used LOG\textsuperscript{[23][24]} operator to get a good result of edge extraction. In view of the characteristics of water droplet images, TAO et al.\textsuperscript{[25]} put forward the use of median filtering, gray stretching and other algorithms to pre-process to remove high-frequency noise, then, the water droplets were separated from the background using Robert Operator edge detection and iterative optimal threshold region segmentation algorithm. Dong et al.\textsuperscript{[26]} proposed an algorithm based on effective average membership. This algorithm is efficient to distinguish the real water drop boundary from the spark pot and shadow edge. Table 3 shows the accuracy of the classification of hydrophobicity of insulators with different edge detection algorithms.

| Method       | Average accuracy |
|--------------|------------------|
| YAN et al.   | 90.0%            |
| DONG et al.  | 88.0%            |
| CAI et al.   | 97.8%            |
| DONG et al.  | 98.0%            |

Edge detection is an early technique in image processing. Besides the algorithms mentioned above, there are Sobel operator, Prewitt operator, Laplace operator and so on. However, there are some common defects in the water droplet recognition methods based on edge detection: The segmented image is easy to have many broken edges, and it is difficult to get continuous edges\textsuperscript{[27]}. Therefore, the effect of using edge detection technology alone to identify water droplets is not good, and other image processing technologies still need to be combined.

4. Recognition method based on region and morphology segmentation

Region growing is an image segmentation method which is widely used in computer vision. This method divides an image into many small regions, computes all the boundaries of the adjacent regions and then merges them into the regions to which they belong, such an iterative process will have similar pixels together to form a region, that is, the similar nature of the pixel region continued to increase, and finally get a good segmentation of the region.

The key of the region growing method is the selection of seed location, growing criterion and growing sequence. The simplest form of this method is to give a seed point manually, and then extract all the pixels with the same gray value as the seed point. YU et al.\textsuperscript{[28]} first used the iterative dual-threshold method for primary segmentation of the image to determine the seed points. Then, an image segmentation algorithm based on the similarity of the target region was used to grow the region according to the principle that the water droplets have the similarity of gray level and gradient level. This method is effective to complete the image segmentation, but the growth threshold of the algorithm is still estimated by a large number of experimental verification, which need to be further
improved. Liu Li\cite{29} proposed an algorithm of automatic seed region growth based on histogram. The improved algorithm used histogram to analyze the edge information of the image. According to the gray distribution of the histogram, the automatic selection of seed points in regional growth was completed. Which solves the defect that the seed point needs to be given manually and improved the adaptability of the algorithm.

In addition, other researchers have used mathematical morphology processing methods, such as expansion, corrosion, open and close operations\cite{30}, which are generally further refined based on other image segmentation techniques. MEI et al.\cite{31} have found that ambient light has a reflective effect on water droplets, resulting in some small white holes in the water droplet region after threshold segmentation. This problem can be effectively solved by morphological algorithm, at the same time, the noise effect of the background area is reduced. XIE\cite{32} proposed image enhancement and adaptive do-noising method based on NSCT and Retinex theory, and then more accurate water drop shape was extracted by morphological processing. RUAN\cite{33} combined with the improved edge extraction algorithm and image morphology segmentation algorithm has also played a good effect of water droplet morphology extraction.

Watershed transform is a relatively new region segmentation algorithm, which borrows from the segmentation method of morphology theory. In essence, it uses the region characteristics of the image to segment the image, combining the advantages of edge detection and region growth, a single pixel wide, connected, closed and accurately positioned contour can be obtained. Researchers have proposed many improved watershed algorithms according to the characteristics of water droplet images. LIU et al.\cite{34} used watershed transform to segment water droplets with smaller area and more adhesion, so as to extract water droplets and water traces from hydrophobic images accurately and quickly. Li et al.\cite{35} proposed an improved watershed algorithm to segment water droplet images. First, the gradient operator was used to obtain the image boundary. And then the image was reconstructed by mathematical morphology. Then they used the Maximum between-Cluster Variance algorithm to segment the threshold of the image and marked the foreground and background targets respectively. Finally, they did the watershed segmentation. This method solves the problem of over-segmentation in traditional watershed segmentation. TAN et al.\cite{36} proposed to transform the original image into HSV color model and used the obvious contrast between the water drop and the dry area in the s component to fill in the missing part of the water drop image. Then, the pre-processed image was processed by two different marked watershed transforms. The experimental results showed that the algorithm can effectively segmented the water droplet image, and the detected water droplet image area error was less than 5%.

Although the water droplet image segmentation algorithm based on watershed algorithm has the advantages of fast calculation speed and accurate positioning of the target contour and obtaining the closed contour, it is easy to cause the problem of excessive segmentation and still needs further improvement in practical application.

5. Recognition method based on clustering and special model

A clustering method is the process of dividing a collection of objects into classes made up of similar method objects. The idea of clustering is to cluster similar pixels in an image into the same region or image block, and to modify the result of clustering until it converges to form the result of image segmentation, its essence is to transform the problem of image segmentation into the problem of pattern recognition cluster analysis\cite{37}. The fuzzy C-means algorithm is a kind of FCM proposed by Bezdek in 1981, referred to as FCM, which uses the initialization method to determine the clustering center and the number of clusters, and adjusts and optimizes the clustering center through continuous iteration loops, and finally minimizes the intra-class variance to achieve clustering\cite{38}. WANG et al.\cite{39} applied the fuzzy clustering segmentation algorithm to the segmentation of fabric watering images in 1997, and realized the evaluation of fabric watering grade. Zhang\cite{40} proposed an improved FCM method based on information measure for water droplet image segmentation, and compared the segmentation results with those based on Otsu Algorithm, which improved the accuracy of the
subsequent classification of hydrophobicity of insulators. Yang et al.\cite{41} used the K-means clustering algorithm combined with the open-close alternating filtering operation in morphology to segment the fluorescence image of cucumber leaf water droplets. Experimental results show that this method is superior to the segmentation algorithm based on H component histogram and C_V model in segmentation effect and time complexity of the algorithm.

Active Contour model is an important method of image segmentation, which has a unified and open description form, and provides an ideal framework for the research and innovation of image segmentation technology. Kass et al. put forward the classic parametric active contour model, which is called “Snake” model\cite{42}. The Snake model makes up the defect of ignoring the high-level information in the traditional target extraction method, and combines the low-level knowledge with the high-level information, the problem of uncertainty in object contour extraction is overcome effectively. Considering the particularity of hydrophobic images and the shortcomings of Snake model such as sensitivity to initial contour and poor topological variability of curves, YU et al.\cite{43} adjusted the parameters of S-L model according to the prior knowledge of water droplets, and then extracted the shape of water droplets from hydrophobic images using the improved S-L model. This method can effectively extract the contour of water droplet. On the basis of GAC\cite{44} model and CV\cite{45} model, AN\cite{46} proposed an image segmentation algorithm based on improved GAC-CV model according to the edge and regional characteristics of water droplets. This method uses the respective advantages of the two models, and the segmentation effect is better than the single model.

6. Existing problems and technological innovation direction

The background of the water droplet image is complex and changeable, mainly reflected in the different types and materials of the object where the water droplet is located and the different environment. The current algorithm research does not particularly consider complex backgrounds and changeable environments, which weakens the applicability of the algorithm. Therefore, further research and improvement of the image preprocessing algorithm and segmentation algorithm are still needed to solve the impact of the complex background, So as to optimize the water bead extraction effect.

At present, researchers have proposed many different algorithms for water droplets recognition. Different algorithms have their own advantages and need to be applied according to different scenes. However, the selection of algorithms at present mostly depends on people's subjective experience, and the intelligence and self-adaptation of algorithms are insufficient.

At present, there are many researches on the recognition and segmentation of water droplets, but there are few researches on the extraction of water droplet shape features, such as the perimeter, area and texture of water droplets.

The rapid development of machine learning and artificial intelligence has brought new methods to computer image recognition. After Hinton et al.\cite{47} proposed deep belief network in 2006, deep learning has attracted the attention of researchers again. Since then, classic networks such as VGG\cite{48}, GoogleNet\cite{49}, and ResNet\cite{50} have appeared, and have achieved great success in the fields of image recognition and scene segmentation. Depth learning is different from traditional manual feature extraction method. It can automatically extract useful features from images by means of iterative updating of weights through back propagation and error optimization. At present, researches on water bead recognition based on depth learning are relatively few, which is a direction worthy of attention in the future.

7. Conclusion

Recognition and extraction of water droplets on the surface of objects have important practical application value. This paper focuses on summarizing different water droplet recognition and segmentation algorithms, then compares and analyzes the advantages and disadvantages of different algorithms. Finally, the future research direction is prospected. With the development of information technology, people have higher requirements for the effect of image recognition in practical
applications. Future water droplets recognition algorithms should be developed in the direction of higher accuracy, stronger adaptive ability and higher degree of automation.

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