Recognition and Location of Solar Panels Based on Machine Vision

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***Abstract*—This paper mainly aims at the aerial image obtained by UAV, and proposes a new solar panel recognition method based on machine vision. In this paper, OpenCV and VS2013 are used to build the experimental platform. Firstly, the image is preprocessed, then the image is segmented in HSV color space, and then the morphological operation is carried out. Finally, according to the prior knowledge, the system can display the number of solar panels and the coordinates of each solar panel in the image in real time. It has a higher efficiency and success rate. The experimental results show that the algorithm is effective, and the model based on the algorithm design can realize real time and accuracy.**

Keywords-machine vision; solar panel recognition; OpenCV; digital image processing

I. INTRODUCTION

In order to obtain the best energy conversion efficiency, solar panels need periodic inspection and maintenance because its limitations. [1] Existing solar panels maintenance systems are mostly man-made mode of operation, which is a low degree of automation and has many other deficiencies. In order to realize the automation and intelligentization of the solar panel maintenance system, it is necessary to identify and locate the solar panel.

Therefore, the research of maintenance recognition and location system of solar panel based on machine vision has important theoretical value and practical engineering application value. However, the positioning of solar panels and the problem of anti-interference for the surrounding environment has been plagued by the two major problems.

The identification of solar panels is a pattern recognition technology based on machine vision. But there is no such related literature which use machine vision to identify the solar panels related literature. Solar panel recognition is a feature matching in image processing. The existing image feature detection includes three parts: key point detection, building feature descriptor and descriptor matching.

The key point detection is to find the point feature in the image and determine its position. Several commonly used detection algorithms are: FAST, STAR, SIFT, SURF, etc. [2] All of these methods are the characteristic corners of the first two graphs, construct the corresponding eigenvectors, and then calculate the similarity between the descriptors between the descriptor and the eigenvectors to achieve the matching of the features. [3]

In the aerial solar panel screen, if we use the existing mature SIFT, SURF, FAST feature matching algorithm for feature matching, will produce serious errors, resulting in matching failure or mis-match, due to the influence of solar panels and outdoor ambient light. Therefore, in this paper, contour matching method is used to identify solar panels.

In summary, the identification and positioning of existing solar panels are technically still blank. What`s more, because of the impact of the angle and the light, we can`t use the mature feature matching algorithm to identify. In order to solve these problems, this paper presents a method of solar panel recognition using contour and prior knowledge, which has high recognition rate and faster recognition speed.

The solar panel recognition area described in this article is a solar panel taken from a UAV aerial picture, and the shooting scene is an aerial scene of an industrial production area or a residential area. According to the solar panel color and shape of a priori knowledge, we can identify and locate, and then find the specific location of the solar panels together. As shown in Figure 1, firstly, convert the RGB color space of the digital image to HSV color space, to reduce the impact of the weather and light on the shooting screen. Secondly, in the HSV color space, color-based image segmentation is performed on the solar panels image. Finally, according to the solar panel color and shape of a priori knowledge, we identify it and display the position of the centroid in the image in real time.

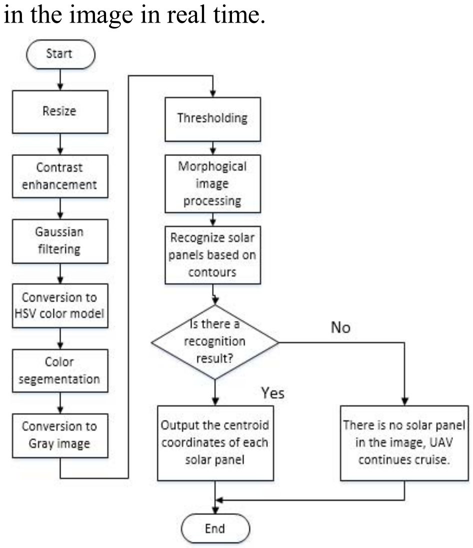

Figure 1. Solar panel recognition flow chart

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This paper uses OpenCV and Visual Studio 2013 to set up experimental test platform, and uses the console application framework to build the development system. At the beginning of the design, the system fully considered the overall requirements as a real-time solar panel identification system. So with the help of final design of the solar panel identification system, the time required for identification is shorter, and the recognition rate is higher. The impact of weather and light on the system is relatively small. The system is simple to operate, to the follow-up development of the system left the interface, taking full account of the system scalability. We left the system to follow the development of the interface, taking full account of the system scalability.

II. PRE-PROCESSING OF IMAGE

A. Histogram Equalization

In general, the gray scale of the image is concentrated in a narrow range, so the details of the image are not clear enough with low contrast. In order to make the gray scale distribution, and the image detail more clear, the processing method usually has two methods: histogram equalization and histogram specification. [4] Histogram equalization method is used in this paper. The histogram of the image is a graphic representation of the intensity distribution of the image, and it counts the number of pixels per intensity value. First of all, the original three channels (Red channel, Blue channel, Green channel) separately; then, for each single channel, the statistics of each point intensity values are calculated for each pixel intensity value number corresponding to the channel; finally draw the histogram, as shown in Figure 2.

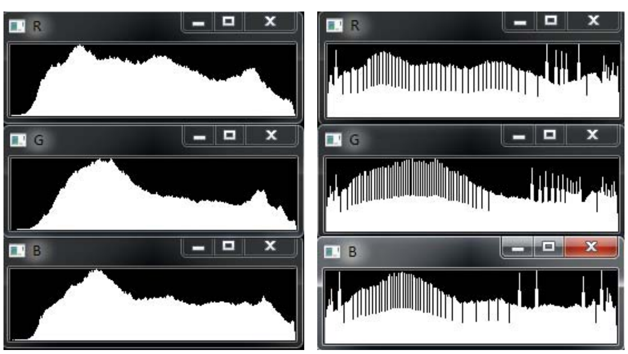

Figure 2. Histogram of the original image and the processed image

If a pixel of an image occupies a lot of gray levels and is evenly distributed, then such images tend to have high contrast and variable gradation tones. Histogram equalization is a transform function that automatically achieves this effect by simply entering the image histogram information. The basic idea is to broaden the number of pixels in the image, and to reduce the gray scale of the pixels in the image, so as to extend the dynamic range of the original value, improve the contrast and gray tint Changes make the image clearer. To the above histogram, for example, we can see the pixels are mainly concentrated in the middle of some strength values. Histogram equalization is stretching this range. After the application is equalized, the histogram shown in Fig. 2 is obtained. The balanced image is shown in Fig. 3.

Figure 3. Image enhanced after contrast

The specific method is as follows:

Mathematically, the normalized histogram is defined as the relative frequency P_r (k) of the gray level, which is

$$P_r(k) = \frac{n_k}{N}$$

where N is the total number of pixels, n_k represents the number of pixels whose gray level is k. We use r and s to represent the values of the original pixel and the value of the equalized pixel. Any one of the original value in the [0,1] interval through the transformation function T(r) will produce a new value. And the new value is obtained by

$$\mathrm{s} = \mathrm{T}(\mathrm{r})$$

Assuming that the distribution function of the random variable s is represented by $F_s(s)$, according to the definition of the distribution function

$$\mathrm{F}_S(s) = \int_{-\infty}^{S} P_S(s)\,ds = \int_{-\infty}^{r} P_r(r)\,dr$$

The equation on both sides of the s for the guide

$$P_s(s) = \frac{d}{ds}\left[\int_{-\infty}^{r} P_r(r)\,dr\right] = P_r(r)\frac{dr}{ds} = P_r(r)\frac{d}{ds}\left[T^{-1}(s)\right]$$

Because of the normalized assumption

$$P_s(s) = 1$$

It can be get that

$$\mathrm{ds} = P_s(s)\,dr$$

Equivalence of both sides of the equation

$$\mathrm{s} = \mathrm{T}(\mathrm{r}) = \int_0^r P_r(r)\,dr$$

It is just the requested transformation function. For discrete digital images, the frequency is used instead of the probability that the discrete form of the transform function $T(r_k)$ can be expressed as

$$s_k = \mathrm{T}(r_k) = \sum_{i=0}^{k} P_r(r_i) = \sum_{i=0}^{k} \frac{n_i}{n}$$

where $0 \leqslant r\_k \leqslant 1$, k=0,1,2,⋯.,L-1. The gray value s_k of each pixel after equalization can be calculated from the histogram of the original image.

B. Gaussian Filte

For images with severe noise interference, the noise points are mapped to high frequency components in the frequency domain. So the noise can be filtered out through a low-pass filter and the low-frequency component can be enhanced. In the spatial domain, the common filtering methods are as follows: mean filtering, median filtering, Gaussian filtering, bilateral filtering and so on. In this paper, the image is smoothed by Gaussian filter. [5]

The principle of filtering noise reduction is to use a core in the image on the convolution operation. The core will slide on the image until the end. In this way, the color of the new image pixel is determined not only by itself, but also by the pixels around it. Objectively speaking, such a setting satisfies the Gaussian law that the closer the distance from the center, the greater the weight is. The distribution of these weights satisfies the Gaussian distribution:

$$\mathrm{G}(\mathrm{x},\mathrm{y})=\frac{1}{2\pi\sigma^2}e^{-\frac{x^2+y^2}{2\sigma^2}}$$

In this paper, Gaussian 3*3 core is used to reduce image smoothing noise, that is

$$\frac{1}{16}\times\begin{bmatrix}1&2&1\\2&4&2\\1&2&1\end{bmatrix}$$

The image after filtering operation is shown in Figure 4.

Figure 4. Gauss filtered image

III. SEGMENTATION AND RECOGNITIO

A. Image Segmentation Based on HSV Color Space

In machine vision image processing, the most commonly used color space is RGB model, which is often used in color display and image processing. The RGB model is in the form of three-dimensional coordinates, which is very easy to understand. However, in the outdoor environment, the impact of light on the RGB color space is large, which is difficult to find the corresponding color of the solar panel. So we need to convert the RGB color space to HSV (Hue, Saturation, Value) color space. It is a color space according to the visual characteristics of color by A. R. Smith was founded in 1978, the color parameters in this model are: hue saturation (H), (S), brightness (V), with a cone to express the color space, as shown in Figure 5.

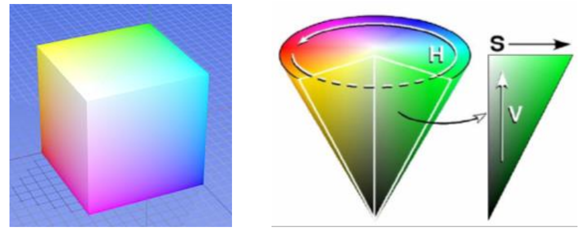

Figure 5. RGB color space model and HSV color space model

The formula for converting the RGB color space to the HSV color space is as follows:

$$H=\begin{cases}60\times\dfrac{G-B}{\max-\min} & if\ \max=R\ and\ G>B\\[2mm] 60\times\dfrac{G-B}{\max-\min}+360 & if\ \max=R\ and\ G<B\\[2mm] 60\times\dfrac{B-G}{\max-\min}+120 & if\ \max=G\\[2mm] 60\times\dfrac{G-B}{\max-\min}+240 & if\ \max=B\end{cases}$$

$$S=\begin{cases}0 & \max=0\\ \dfrac{\max-\min}{\max} & \max\neq 0\end{cases}$$

$$V=\max(R+G+B)$$

In the HSV color space, for the image segmentation, we set the threshold for the corresponding color of the solar panel as follows:

H	S	V
[100, 129]	[31, 255]	[80, 255]

The pixel value of the image is within the threshold, preserving the original image; not within the threshold, converting it to white. The processed image is shown in Figure 6, which completes the segmentation of the image based on the HSV color space.

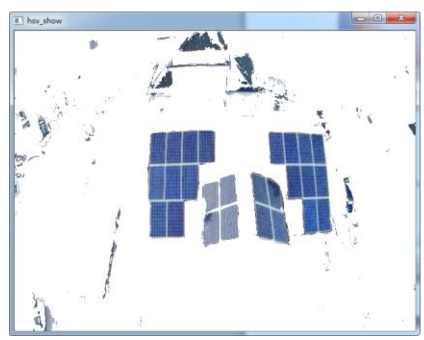

Figure 6. The image segmentation results based on the HSV color space

B. Thresholding

After obtaining the gray image, the image needs to be binarized. That is, set a threshold, if the pixel gray value is greater than the threshold, its value is assigned to 255 (white), otherwise assigned to 0 (black). In this paper, the threshold is set to 180, the resulting binarized image shown in Figure 7.

Figure 7. Threshold Processing Results Image

C. Morphological Image Processing

Mathematical morphology is based on the morphological elements of the image analysis of the mathematical tools. The basic idea is to use a certain form of structural elements to measure and extract the corresponding shape in the image to achieve the purpose of image analysis and identification. The application of mathematical morphology can simplify the image data, maintain their basic shape features, and remove the irrelevant structure. Mathematical morphology of the basic operation of four: Erosion, Dilation, Opening and Closing. [6]

The basic morphological operations are Dilation and Erosion. The Dilation and Erosion of the binary image is to move a small binary, which is a structural element, on a large binary plot and to compare it, and to process it according to the result of the comparison.

When the image is eroded, if all the black dots in the structural element are exactly the same as the corresponding large image, the point is black, otherwise it is white, as shown in Figure 8. The operator of the erosion is $\ominus$, and A uses B to erode is writing with A $\ominus$ B, which is defined as

$$A \ominus B\{x \mid \left[(B)_x \cap A\right] \subseteq A\}$$

When the image is dilate, if the structural elements as long as one or more black dot and its corresponding original image of the same point, the point is black, otherwise it is white. The operator of the dilation is $\oplus$, and A uses B to dilate is writing with A $\oplus$ B, which is defined as

$$A \oplus B\{x \mid \left[(B)_x \cap A\right] \subseteq A\}$$

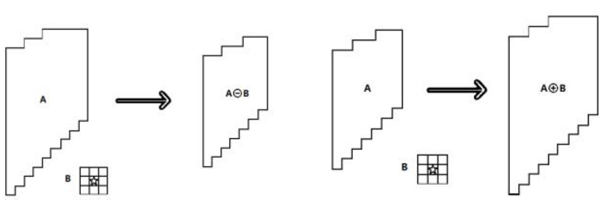

Figure 8. image Erosion and image Dilation

The Opening is to erode the image and then dilate the result. It has the effect of eliminating small objects, separating objects from slender and smoothing larger objects. The Closing is to dilate the image and then erode the result. It has the effect of eliminating fine voids in the filling body, connecting adjacent objects and smoothing larger objects.

To identify the solar panels, the parallelogram features of the solar panels should be as obvious as possible. In this paper, a 3 * 3 structure element is used to open the binarized graph, to remove the solar panels around the small interference. The result is shown in Figure 9, the small object in the image is corroded, and the edge of the solar panel contour is very clear.

Figure 9. the image after opening

D. Recognize Solar Panels Based on Contours

After the treatment of mathematical morphology, the contour and position of the solar panels have been very clear, but there are a lot of disturbing objects on the image. In order to accurately identify the location of solar panels, according to the perimeter of the solar panel, shape, etc., we remove the pixels that do not meet the requirements.

This article uses the cvFindContours function in the OpenCV library, [7] and finds all the outer contours in the image as shown in Figure 10.

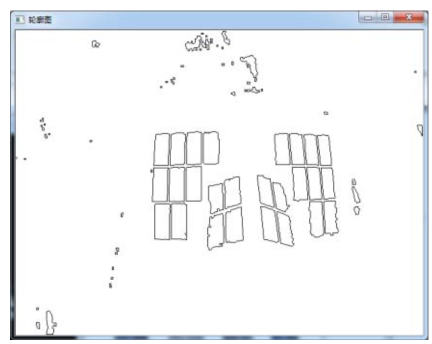

Figure 10. the contour image

According to the prior knowledge, the circumference of the contour is limited, and the upper and lower thresholds l_{min} and l_{max} are set to remove the contours that are not in the range of [l_{min}, l_{max}]. In this article, the threshold is given by

$$l_{min} = \frac{1}{10}\left(\text{height} + \text{width}\right)$$

$$l_{max} = \frac{1}{2}\left(\text{height} + \text{width}\right)$$

where height is the height of the image and width is the width of the image. The results obtained are shown in Figure 11.

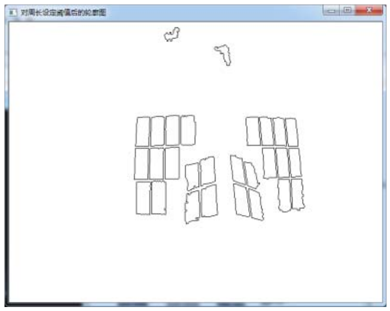

Figure 11. The contour image after setting the threshold for the perimeter

We use the shape of the solar panel to judge. Since the solar panels are rectangular, according to the principle of perspective, the solar panels in the image can be regarded as parallelogram. So it is necessary to extract the four corners of the contours to be saved to the sequence, to judge all the contours stored in the sequence one by one, to keep the matching corners in the sequence, and the rest to get the final result. The method of extracting four corners and determining whether the connection of the four corners is a parallelogram is as follows.

Traverse each point in the contour, according to its coordinates (x, y), find x + y, x-y to obtain the maximum and minimum points, the four points that the corners of the contour. In the four corners, the upper left corner of the method to find the flow chart shown in Figure 12, the same token can be left, right, bottom right corner coordinates.

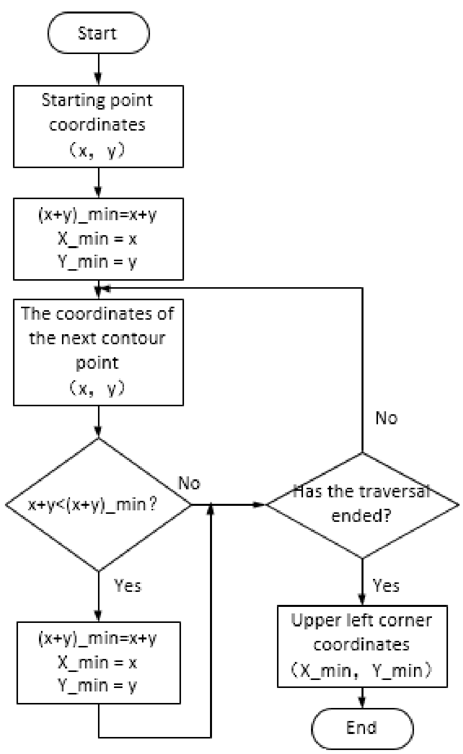

Figure 12. The flow chart of the method at the top left corner of the contour

The four corners are connected in turn, that is, a quadrilateral, the angle of each of the two adjacent angles are added, and the result is compared with 180°. If the difference between the four summation is less than ± 5%, the quadrilateral is a parallelogram; otherwise, that is not parallel to the quadrilateral, removed from the contour. The formula for finding the contours is as follows: [8]

The zero moment of the image:

$$\mathrm{M}_{00} = \sum_{I}\sum_{J} V(i,j)$$

The first moment of image:

$$\begin{cases} \mathrm{M}_{10} = \sum_{I}\sum_{J} i * V(i,j) \\ M_{01} = \sum_{I}\sum_{J} j * V(i,j) \end{cases}$$

The heart coordinates:

$$\begin{cases} x_c = \dfrac{M_{10}}{M_{00}} \\ y_c = \dfrac{M_{01}}{M_{00}} \end{cases}$$

The final recognition result and coordinates are shown in Fig. 13, Fig. 14, and Fig. 15. In the recognition result graph, the four corners of the contour of the solar panel identified by the straight line are connected in sequence, and rounded with the centroid coordinates of the contour to be identified.

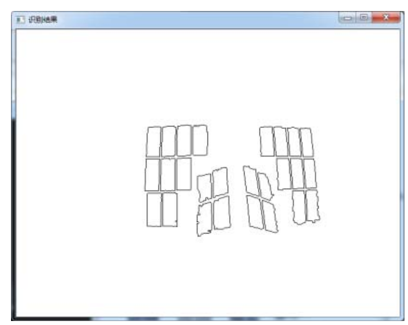

Figure 13. Contour recognition results

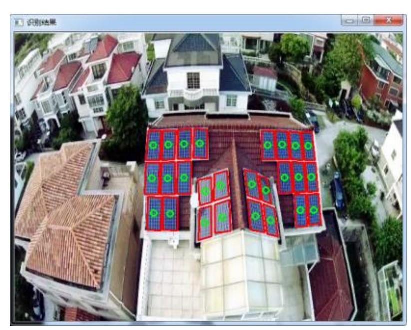

Figure 14. Solar panel recognition results

```
C:\Windows\system32\cmd.exe
The number of solar panels in the image:26
Number:1        Coordinate:(313,316)
Number:2        Coordinate:(422,312)
Number:3        Coordinate:(342,307)
Number:4        Coordinate:(397,305)
Number:5        Coordinate:(229,300)
Number:6        Coordinate:(256,301)
Number:7        Coordinate:(471,295)
Number:8        Coordinate:(493,295)
Number:9        Coordinate:(314,264)
Number:10       Coordinate:(414,262)
Number:11       Coordinate:(339,254)
Number:12       Coordinate:(391,252)
Number:13       Coordinate:(489,240)
Number:14       Coordinate:(226,242)
Number:15       Coordinate:(468,240)
Number:16       Coordinate:(445,241)
Number:17       Coordinate:(252,242)
Number:18       Coordinate:(279,241)
Number:19       Coordinate:(484,188)
Number:20       Coordinate:(463,188)
Number:21       Coordinate:(441,186)
Number:22       Coordinate:(417,187)
Number:23       Coordinate:(228,187)
Number:24       Coordinate:(253,186)
Number:25       Coordinate:(305,184)
Number:26       Coordinate:(279,185)
```

Figure 15. Solar plate shape coordinate recognition results

IV. CONCLUSIONS

This paper is based on the current mainstream image processing technology, the UAV aerial picture in the solar panel identification in-depth analysis and research. The general idea is based on the prior knowledge of the solar panels, through its color and shape, and using the relevant algorithm to get the recognition results, the solar panels in the heart of the real-time position in the screen for the maintenance of solar panels automation, intelligent Provide conditions.

The design of the system is based on VS 2013 as the development tool, with C ++ as the development language, with OpenCV 3.0.0 as the support library function to develop. For each frame, the advanced image preprocessing, and then transformed into HSV space color, image segmentation, through mathematical morphology, according to a priori knowledge, successfully identify and locate the solar panels in the picture.

The advantages of the image processing method used in this paper are:

1) Image segmentation in HSV color space overcomes the influence of illumination in the outdoor environment on the color of the identified object;

2) The use of external contour identification, even if the solar panel surface fouling, spots, etc., can also accurately identify the solar panels, the recognition rate is high, robustness is better;

3) Compared with the use of feature point matching algorithm, recognition speed greatly improved.

The shortcomings of this paper:

1) There is a certain possibility of matching errors in feature recognition. In the case of multiple solar panels connected to the case, the white border between them may be due to the angle, light and other reasons is not so obvious, and as a solar panel, resulting in the number of matching errors.

2) There is the possibility of misidentification. In the complex aerial picture, the interference factor is very much, this paper because of the HSV space color in the color of the screen segmentation, if the screen exists with the solar panel color similar to the roof, and happens in the image parallelogram, and then will also be included in the scope of solar panels. The solution is to increase whether the solar panel to determine the conditions, such as setting the threshold for the contour area, combined with the feature point matching method.

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