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Research on the Visual Recognition Method of Pointer Water Meter Reading

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***Abstract*—For a long time, water companies have adopted manual meter reading methods when they settle water bills. Manual meter reading is inefficient, and there are often large subjective errors in it. Therefore, that water companies identify water meter readings automatically by computer technology and image processing technology is the future trend. This paper designed a kind of method to identify the water meter reading accurately. The method preprocessed collected water meter dial images by two-dimensional Gaussian filtering firstly. Then the pointer areas were separated from them by threshold and area growth method based on the difference of gray value. Finally, using Bresenham algorithm to calculate deflection angle between pointer center line and the zero scale which realizes the recognition of the reading. To enhance the algorithm's robustness to lighting, this method added the dynamic threshold mechanism and the pixel repair mechanism in the recognition process. This method was deployed on the Raspberry Pi 4B development board equipped with Raspbian GNU/Linux 10 "Buster" operating system, and the relationship between image resolution and reading accuracy was discussed.**

Keywords—instrument detection; multi-pointer water meter; image processing; embedded system

I. INTRODUCTION

Pointer instruments are often not very complex in structure, which is convenient for technicians to maintain. They are not easy to be electromagnetically interfered so their reliability is guaranteed. And they are low in price and have a greater cost advantage. At present, manual meter reading is still the most common method for reading pointer water meters. Manual meter reading mainly relies on professional skills and subjective judgments, which may lead to too large measurement errors, and have problems such as poor reliability, low efficiency, and susceptibility to environmental factors. The remote automatic meter reading technology is safe, reliable, convenient and fast. The efficiency is several times that of manual meter reading. It can be seen that remote automatic meter reading technology is the general trend.

Aiming at the problem of automatic reading of pointer instruments, domestic and foreign scholars have proposed a series of methods from different angles. Ricardo et al.[1] obtained the pointer information area directly by segmenting the region of interest in the image, and then the reading is recognized based on the shape of the pointer and other information. Although the accuracy is high, this method is not very versatile. S.L. Pang et al.[2] used The Hough transform algorithm to process the image, identify the pointer area in it, and then subtract any scale image from the zero-scale image obtained in advance to obtain a pointer-free image, and then identify the angle. This method needs to obtain a zero-scale image in advance and save it, which occupies a large storage space. Zheng et al.[3] proposed a multi-scale homomorphic filtering algorithm to repair pointer images of different brightness, and at the same time, perspective transformation is used to correct the image, which has strong anti-interference ability for pointer recognition. Xu et al.[4] proposed a faster method, which uses geometric transformation to correct the captured image, and then divides the image to extract the sub-dial, and finally recognizes the reading. This method requires uniform lighting and cannot eliminate the negative effects of reflections and shadows.

Aiming at the eight-pointer water meter, we proposed an automatic reading recognition method that can be deployed on the Raspberry Pi 4B embedded platform. This method determines the reading by positioning the pointer and the angle of the water meter image captured by the camera. It has good robustness and accuracy in low light environment, and overcomes the problem of reading errors caused by reflection on the dial surface. Fig.1 shows the algorithm flow chart.

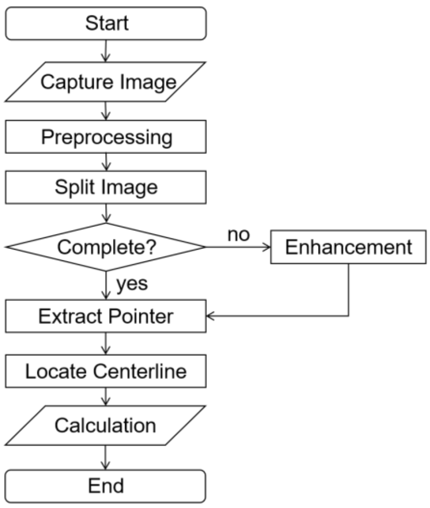

Fig. 1. The algorithm flow chart.

II. Recognition Method of Water Meter Reading Based on Embedded System

A. Experimental Platform Design

The overall plan is to install the meter reading terminal on the original traditional water meter, and realize the instant acquisition of the dial image through the image acquisition module. Fig. 2 shows the basic architecture of the experimental platform.

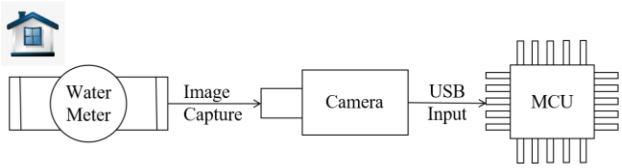

Fig. 2. The basic architecture of the experimental platform.

Raspberry Pi 4B uses 1.5GHz quad-core 64-bit ARM Cortex-A72 CPU to ensure the speed of processing image data. The identification object is an eight-pointer mechanical water meter with a diameter of 64mm, with a pointer sub-dial of 14mm in diameter. The image acquisition module uses a CMOS image sensor with a resolution of 640×480, whose power consumption is lower than 0.7W. Fig. 3 shows the physical map of the experimental device.

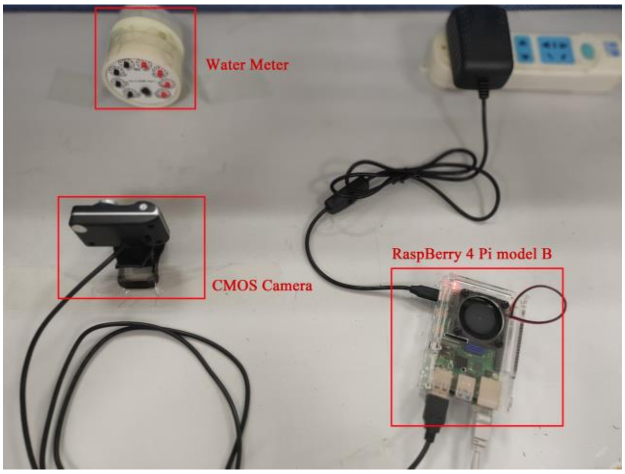

Fig. 3. The physical diagram of the experimental platform hardware.

B. Dial Image acquisition and Preprocessing

We use the camera to take images of the water meter directly. During the process, we keep the vertical distance between the front of the camera and the dial of the water meter constant. The front of the camera is facing the water meter, and its plane is always parallel to the surface of the water meter. The zero scale line of the water meter is vertically upward. Fig. 4 shows the shooting effect.

Fig. 4. The dial image collected by the camera.

In reality the billing rule for this type of water meter is to only charge for units above the ton level, that is, the reading of the black pointer in the picture is a valid reading and is included in the charge. Therefore, we only recognize the readings of the four black pointers.

The form of the two-dimensional Gaussian[5] function is shown in formula (1):

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

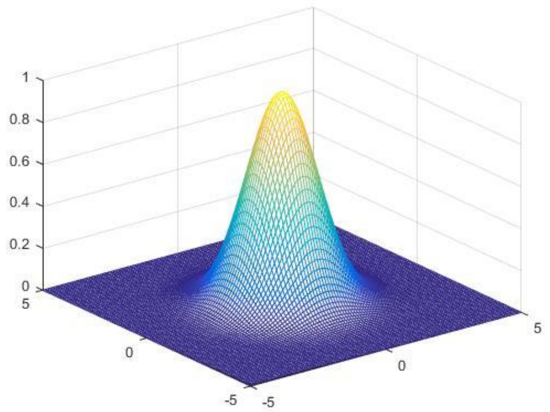

Fig. 5. Two-dimensional Gaussian distribution curve.

We use the Gaussian function with 7×7 kernel size, whose standard deviation is 1.5, to filter grayscale images. Fig. 6 shows the effect after treatment.

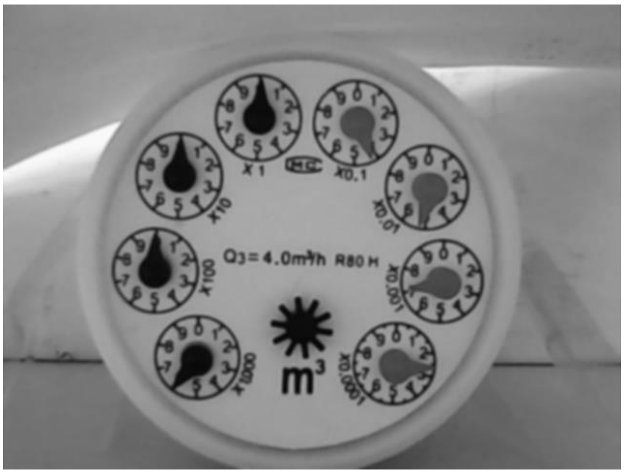

Fig. 6. The dial image after preprocessing.

C. Adaptive Threshold Segmentation Based on Gray Difference and Pointer Area

It is easy to observe that the pixels with the lowest gray value in the image are concentrated in two areas: One is the pointer area, and the other is the wheel and m³ logo located at the bottom of the dial. Assuming that the image pixel point set is $\mathbf{S}$, for $\forall(x,y)\in\mathbf{S}$, setting a static gray level threshold T, then the low gray value point set $\mathbf{S_1}$ satisfies the formula (2):

$$\left(x,y\right)\in\mathbf{S_1}, Gray(x,y)\le T \tag{2}$$

The high gray value point set $\mathbf{S_2}$ satisfies formula (3):

$$\left(x,y\right)\in\mathbf{S}_2, Gray(x,y) > T \tag{3}$$

We use an image segmentation method based on position information to erase the redundant information area. Fig. 7 shows $\mathbf{S_1}$ that contains only the pointer area.

Fig. 7. Image with pointer information only.

The static threshold segmentation method has very poor robustness to illumination[6]. When the ambient light is too strong, the image segmentation is excessive and the pointer area is severely damaged. On the contrary the image segmentation is incomplete, and a large number of redundant areas are left, which interferes with the recognition of the pointer. But under the condition that the camera and the water meter are relatively static, the number of pixels A contained in the pointer area is basically unchanged.

Therefore, we use a dynamic threshold t, and set the set of gray values contained in the image as $\mathbf{G}$:

$$\mathbf{G}=\{g_i \mid i=0,1,2,\ldots,l\} \tag{4}$$

The number of pixels with gray value g_i is $n(g_i)$, then the sum of the number of pixels with gray value less than or equal to g_i is $N(g_i)$:

$$N(g_i)=\sum_{g_k\le g_i} n(g_k) \tag{5}$$

The set of all satisfied $N(g_i)\ge A$ gray values is $\mathbf{G_A}$:

$$\mathbf{G_A}=\{g_m \mid N(g_m)\ge A\}, g_m\in\mathbf{G} \tag{6}$$

In general $\exists t\in[0,255]$, it $N(t)$ is just met $N(t)\ge A$, and t at this time is the best threshold for image segmentation in the current environment. which is:

$$t=\min(g_m), g_m\in\mathbf{G_A} \tag{7}$$

We have done tests under the conditions of strong and weak ambient light respectively, as shown in Fig. 8 and Fig. 9. The adaptive threshold method greatly improves the algorithm's robustness to illumination.

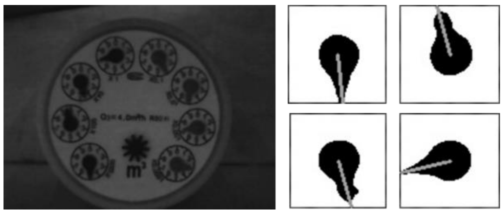

Fig. 8. The dynamic threshold is robust to weak light.

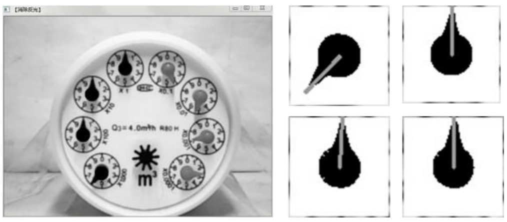

Fig. 9. The dynamic threshold is robust to strong light.

The Hough transform transforms the circle on the X-Y plane into the (a,b,r) parameter space and re-expresses it.

$$\begin{aligned} a &= x - r\cos\theta \\ b &= y - r\sin\theta \end{aligned} \tag{8}$$

Each group (a,b,r) represents a circle. At the same time, every zero-value pixel on the image may be a point on a potential circle. The four circles with the top four votes are selected through the voting mechanism, and the coordinate positions of the four pointers are determined.

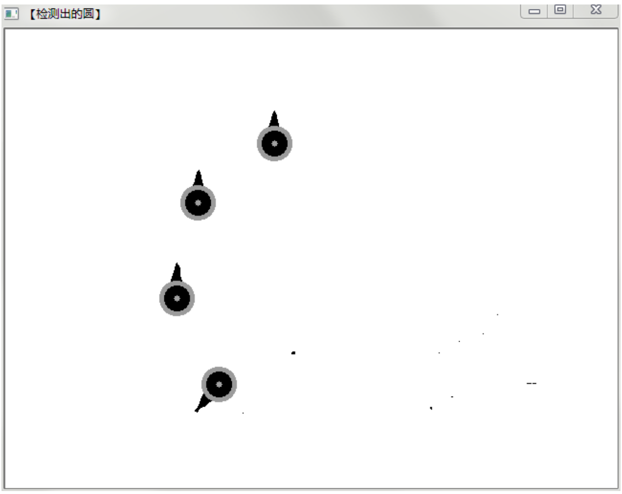

Fig. 10. Get pointer center coordinates and radius.

D. Water Meter Reading Recognition Method

Since the pointer area has a fixed shape and a closed boundary, we use the area growing method to enhance the gray value of the pointer area once in order to retain the pointer information to the greatest extent.

Take the circle center coordinates (x_0, y_0) obtained by the Hough transform as the seed point of the first iteration. The similarity of all pixels in the eight neighborhoods of the point (x, y) is measured[7]. This measurement is based on the formula (9).

$$|Gray(x,y) - Gray(x_0,y_0)| \le 10 \tag{9}$$

If the gray value of the point (x, y) satisfies the formula (9), then it will be used as a new seed point for the next iteration until no new seed point is born[8]. The resulting enhanced pointer image is as follows.

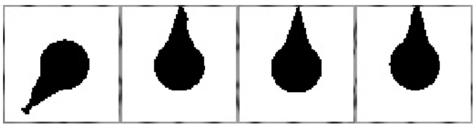

Fig. 11. The pointer information area is enhanced.

Because the surface material of the pointer is easy to reflect light, too strong ambient light will cause growth failure and large faults, as shown in Fig. 12.

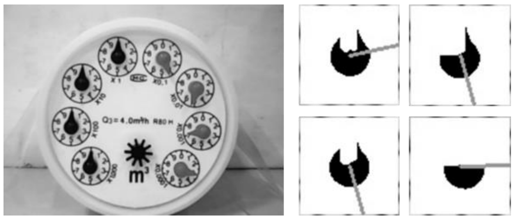

Fig. 12. Some pointer reflective area information is missing.

However, the structure of the pointer makes the reflective part only appear in the circular needle seat part. We can set the gray value of all points in the circular needle seat area to zero.

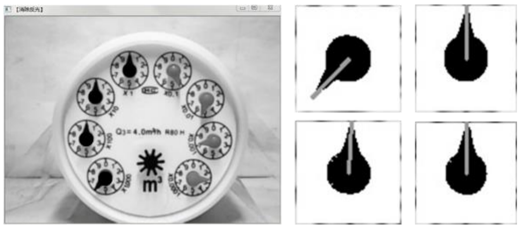

Fig. 13. Repair the pixel value of the reflective area.

The number of zero pixels in the direction of the pointer centerline is the largest[9], so we use the Bresenham method to determine the direction of the centerline. Take the center of the pointer (x_0, y_0) as the starting point of the line segment and the length of the pointer is r, then the end point of the line segment is expressed as:

$$\begin{aligned} x_1 &= x_0 + r\cos\theta, \theta \in [0, 2\pi) \\ y_1 &= y_0 + r\sin\theta, \theta \in [0, 2\pi) \end{aligned} \tag{10}$$

Assuming that the line segment is in the first quadrant, the slope is positive. Count the number of pixels on the raster path from the starting point (x_0, y_0). Increase the abscissa by one. If the end point is reached, the count ends. Otherwise, it will iterate to find the next point. The next point is either the right adjacent point of (x_0, y_0) or the upper right adjacent point of (x_0, y_0).

The next point of the point $(x, y+\varepsilon)$ is $(x, y+\varepsilon+m)$, ε is the cumulative error. From Fig. 14 when $\varepsilon + m < 0.5$, the point $(x+1, y)$ is selected, otherwise the point $(x+1, y+1)$ is selected. After each iteration, ε will update itself:

$$\begin{aligned} &\varepsilon = \varepsilon + m \quad && \text{if } 2(\varepsilon + m) < 0.5 \\ &\varepsilon = \varepsilon + m - 1 && \text{others} \end{aligned} \tag{11}$$

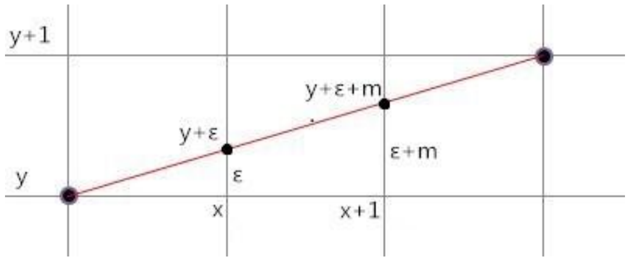

Fig. 14. Principle of Bresenham algorithm.

Multiply both sides of formula (12) by dx, and use ξ to represent εdx. We can get:

$$\begin{aligned} &\xi = \xi + dy \qquad \text{if } 2(\xi + dy) < dx \\ &\xi = \xi + dy - dx \quad \text{others} \end{aligned} \tag{12}$$

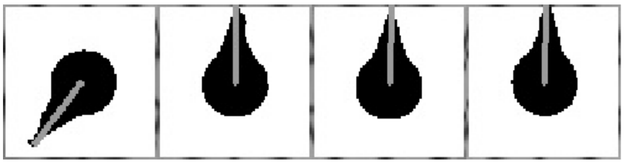

Fig. 15. Determine the direction of the center line of the pointer.

The pointer indication is obtained by calculating the angle that the center line has turned clockwise compared to the zero scale line. The corresponding relationship between the two is shown in Table 1.

TABLE I. CORRESPONDENCE BETWEEN ANGLE AND READING

Angle	Reading
$[0^\circ \sim 36^\circ)$	0
$[36^\circ \sim 72^\circ)$	1
$[72^\circ \sim 108^\circ)$	2
$[108^\circ \sim 144^\circ)$	3
$[144^\circ \sim 180^\circ)$	4
$[180^\circ \sim 216^\circ)$	5
$[216^\circ \sim 252^\circ)$	6
$[252^\circ \sim 288^\circ)$	7
$[288^\circ \sim 324^\circ)$	8
$[324^\circ \sim 360^\circ)$	9

Fig. 16 shows the reading results, proving the effectiveness of this method.

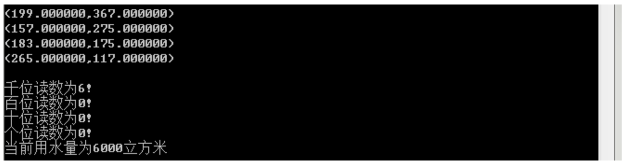

Fig. 16. Reading results returned by the program.

III. RESULT

A. Water Meter Reading Recognition Experiment

We changed the indicator of the water meter many times and used different readings to prove the effectiveness of the algorithm. Part of the experimental results are shown in Fig. 17 to Fig. 19.

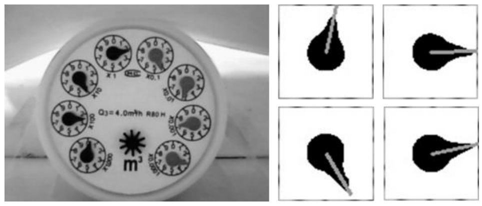

Fig. 17. The reading is 242.

Fig. 18. The reading is 5999.

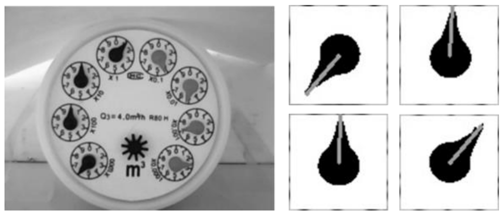

Fig. 19. The reading is 6000.

The test results show that the algorithm is very accurate in positioning the pointer direction, the angle calculation is accurate, and the reading is completely correct. During the test, we deliberately pointed the pointer to an angle that is prone to misinterpretation, such as the direction facing the integer scale and the direction slightly deviating from the integer scale. From the results, the algorithm recognizes these angles accurately and is not affected by the scale line. interference.

B. Analyze the Relationship between Image Resolution and Reading Recognition Accuracy

The straight lines in computer images are simulated by pixels[10], so the algorithm has a problem of pointer recognition accuracy. This section discusses the relationship between pointer image resolution and pointer recognition accuracy. Assume that the smallest pointer rotation angle that the algorithm can distinguish is α .

Because the straight line segments drawn by Bresenham algorithm start from the center of the pointer circle, as long as the end point coordinates of the line segments are different, they are regarded as different straight line segments. Suppose the end point coordinates of one of the line segments is $B_1(x_{b1}, y_{b1})$, and the end point coordinates of the line segment obtained after α rotation is $B_2(x_{b2}, y_{b2})$. Then the difference between the horizontal and vertical coordinates of the two end points is:

$$\begin{aligned} x_{b2} - x_{b1} &= r \times [\cos(\theta + \alpha) - \cos\theta] = 2r \times \sin\frac{\alpha}{2} \times \sin(\theta + \frac{\alpha}{2}) \\ y_{b2} - y_{b1} &= r \times [\sin(\theta + \alpha) - \sin\theta] = 2r \times \sin\frac{\alpha}{2} \times \cos(\theta + \frac{\alpha}{2}) \end{aligned} \quad (13)$$

Because the coordinates must be integers, only one of the two differences is greater than or equal to 1. According to formula (13), the relationship between pointer recognition accuracy and pointer image resolution can be obtained.

The resolution of the pointer image in this paper is 76*76, and the pointer length is 38 pixels. From Table 2, it can be seen that the recognition accuracy of the method in this paper is about 2°. The water meter is a non-precision instrument, and there are only ten scale values on the sub-dial, that is to say, theoretically, it can be recognized with an accuracy exceeding 36°. Considering both the recognition accuracy and the space occupied by the pointer image in the computer, we believe that the recognition accuracy is most appropriate between 2° and 4°.

TABLE II. THE RELATIONSHIP BETWEEN POINTER RECOGNITION ACCURACY AND RESOLUTION

Pointer recognition accuracy α	Pointer length	Pointer image resolution	Pointer image size
1°	≥ 81	162*162	9.48KB
2°	≥ 40	80*80	2.48KB
3°	≥ 27	54*54	1.67KB
4°	≥ 20	40*40	1.29KB
5°	≥ 16	32*32	947B

IV. CONCLUSIONS

The realization of eight-pointer water meter reading recognition in the embedded system is the core work of this paper. We adopted the relevant digital image processing method, combined with the structural characteristics and optical characteristics of the water meter, designed a method that can automatically recognize the reading, and implemented it in the embedded system. We also discussed the impact of image resolution on recognition accuracy. From the experimental results, the pointer water meter reading recognition method designed in this paper is successful.

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