Analog Gauge Reader based on Image Recognition

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Abstract. Analog dial are widely used in modern production and life. In the fields of meter detection and meter scale value recording, the demand for automatic reading of analog dial is increasing. This paper proposes an improved method of fast reading of images, which refines the scale circle and uses the branch point extraction algorithm to extract the intersection of the scale line and the scale circle to express the scale line indirectly. Finally, the pointer reading is calculated based on the ratio of the deflection angle of the pointer to the total angle of the range.

Keywords: Pointer meter, meter detection, automatic reading.

1. Introduction

Analog dial are widely used in modern production and life, such as voltmeters, ammeters, water temperature meters, and water pressure meters. In the power, petroleum, chemical and other industries, the use of analog dial is particularly huge. With the development of society, the need for automated reading of this type of instrument in the process of testing and use is stronger than ever before, because the work performed by technicians in the process of instrument testing is highly repetitive and tiring tedious labor. The results are susceptible to both human factors and the external environment, such as weather, environment, and human health (such as vision and visual fatigue). These subjective and objective factors will inevitably bring unpredictable negative effects on the test results, that is, detection. The degree of uncertainty increases. In the use of the meter, many times rely on the field readings of personnel to record a specific working state, but in some specific working environments (such as high noise, high temperature, humidity, toxic, odor), it is not suitable or even unsuitable allowing personnel to enter, there is a need for a system that can replace meter readings by artificial characters.

Image recognition is a combination of computer, image processing technology and other optical equipment, and is an extension of the development of modern computer technology [1]. The biggest advantage of image recognition is that the color and grayscale range processed is much wider than that of human vision, and the recognition accuracy is also a range beyond the reach of the human eye. The method of pointer reading based on image recognition is to replace the manual reading and realize the automatic reading function as the goal in order to achieve the purpose of accurate and efficient pointer reading.

2. Principle

Hough Transform. Hough transform is one of the basic methods for identifying geometric shapes from images in image processing [2]. The basic principle of the Hough transform is to use the duality of points
and lines to change a given curve in the original image space into a point in the parameter space through a curve representation. In this way, the problem of detecting a given curve in the original image is converted into a problem of finding peaks in the parameter space, that is, the overall characteristics of the detection are detected into local characteristics, such as straight lines, ellipses, circles, arcs, and so on.

Hough transform is a circle detection algorithm proposed by Paul Hough in 1962. Its basic idea is to transform the image from the original image space to the parameter space [3]. In the parameter space, some parameters that most boundary points meet form a description of the curve in the image. It accumulates parameters by setting an accumulator, and the point corresponding to its peak is the required information. The biggest advantage of Hough transform is that it is insensitive to noise.

For a point \((x_0, y_0)\) that satisfies the straight line equation \(y = ax + b\), it corresponds to a straight line \(b = y_0 - ax_0\) on the parameter plane \((a, b)\), and other data points from this straight line also correspond to a straight line on the parametric plane \((a, b)\) and intersect at a specific parametric point \((a, b)\).

In practical applications, in order to avoid the problem of infinite slope of vertical straight lines, the equation of linear polar coordinates \(r = x \cos \theta + y \sin \theta\) is usually used. Obviously, the parameter plane becomes \((r, \theta)\) plane.

The straight line is defined by two points \(A(x_1, y_1)\) and \(B(x_2, y_2)\) (as shown in Fig. 1, left). All straight lines passing through point \(A\) can be expressed by the equation \(y_1 = k x_1 + q\), where \(k\) and \(q\) are certain values representing slope and intercept. If we consider \(k\) and \(q\) as parameter spaces, then all straight lines passing through point \(A\) can be expressed as \(q = -x_1 k + y_1\) (as shown in Fig. 1, right).

Similarly, all straight lines passing through point \(B\) can be represented by the equation \(y_2 = k x_2 + q\). In the parameter spaces \(k\) and \(q\), all straight lines passing through point \(B\) can be represented as \(q = -x_2 k + y_2\). At this time, the only common intersection point of the two straight lines in Fig. 1, right represents the straight line connecting the two points \(A\) and \(B\) in Fig. 1, left.

In this way, each point on the straight line in the original image space can be mapped to a straight line in the parameter space \(k\) and \(q\). We accumulate the points in the parameter space, and the peak value corresponds to the straight line to be determined in the image space.

Therefore, for the Hough transform, there are the following correspondences:
- A straight line in image space is mapped as a point in parameter space.
- A point in image space is mapped to a sine curve in the parameter space.
- Multiple collinear points on a straight line in the image space are mapped into multiple sinusoids where the parameter space intersects at one point.

Hough transform is not only suitable for straight line detection, but also for any form of \(f(x, a) = 0\), where \(x\) is the coordinate vector and \(a\) is the coefficient vector. Below we briefly introduce the principle of detecting circles by Hough transform.
For a circle with radius $r$ and center $(a, b)$, we denote it as

$$(x-a)^2+(y-b)^2=r^2$$  \hspace{1cm} (1)$$

At this time, $x = [x, y]^T$, $a = [a, b, r]^T$, and its parameter space is three-dimensional. Obviously, a point $(x, y)$ on the image space corresponds to a cone in the parameter space, as shown in the Fig. 2 below.

![Figure 2. Hough transform in three-dimensional space.](image1)

A circle in the image space corresponds to a point where the cluster of cones intersect. This particular point has a constant three-dimensional parameter in the parameter space, which means a circle in the image space with a certain radius and a certain center point. The above method is the principle of the classic Hough circle detection method, which has the advantages of high accuracy and strong anti-interference ability.

**Gaussian Blur.** The so-called "blur" can be understood as each pixel takes the average value of the surrounding pixels. As shown in Fig. 3, 2 is the middle point, and the surrounding points are all 1. Take the average of the surrounding points at the middle point and it will become 1. Numerically, this is a "smoothing". On the graphics, it is equivalent to produce a "blur" effect, and the "middle point" loses details. Obviously, when calculating the average value, the larger the value range, the stronger the "blurring effect" [4].

![Figure 3. The relationship between a pixel and the surrounding 8 pixels.](image2)

If you use simple averaging, it is obviously not very reasonable, because the images are continuous, the closer the points are, the closer the relationship is, and the further away the points are, the more distant the relationship is. Therefore, the weighted average is more reasonable, the closer the point is, the greater the weight is, and the farther the point is, the smaller the weight is. Gaussian blur determines
the weights of surrounding points according to the normal distribution. The standard normal distribution is shown in Fig. 4.

![Figure 4. Normal curve standard deviation.](image)

The normal distribution is a bell-shaped curve. The closer to the center, the larger the value, and the farther away from the center, the smaller the value.

When calculating the average value, we only need to use the "center point" as the origin, and assign other weights according to their positions on the normal curve to get a weighted average.

The one-dimensional formula for the normal distribution is:

\[ f(x) = \frac{1}{\sqrt{2\pi}\sigma^2} e^{-\frac{(x-\mu)^2}{2\sigma^2}} \] (2)

Since each calculation uses the middle point as the origin, \( \mu \) is the standard deviation, which is 0. So the formula evolves further:

\[ f(x) = \frac{1}{\sqrt{2\pi}\sigma^2} e^{-\frac{x^2}{2\sigma^2}} \] (3)

Since the image is two-dimensional, the weight value needs to be calculated according to the two-dimensional normal distribution function. Its formula is as follows and the curve is shown in Fig. 5

\[ G(x,y) = \frac{1}{2\pi\sigma^2} e^{-\frac{(x^2+y^2)}{2\sigma^2}} \] (4)

![Figure 5. Graph of two-dimensional normal distribution function.](image)
However, for the sake of code efficiency, the calculation method of two-dimensional normal distribution will not be adopted, but the Gaussian blur of the X-axis and Y-axis will be achieved twice, which can also achieve the effect (that is, the weight is calculated by the one-dimensional normal distribution).

3. Experiment

The dial reading recognition process mainly includes several steps such as circular dial positioning, tick positioning and fitting, pointer positioning, and counting calculation.

1. Circular dial positioning
   For circular instruments, the common method for dial positioning is Hough circle detection. In OpenCV, the traditional Hough is improved. The speed is improved by at least several orders of magnitude. It uses gradient-based Hough circle detection. The basic idea is as follows:
   a) Calculate the gradient vector in each direction of each non-zero pixel.
   b) If some pixels are on the same circle, the gradient vectors of these points eventually intersect at one point.
   c) Vote on the intersections of these gradient vectors, and select the point with the highest number of votes as the center of the circle.
   d) After the center of the circle is determined, the radius is scaled. When the radius is scaled to a certain value and there are enough points on the circle, it can be determined that the current circle is the circle that is being sought.

   The gradient-based Hough circle detection first calculates the gradient of the pixel point, and then performs the zoom radius to find the circle, so that the three-dimensional parameter space is converted into two dimensions (the center and radius of the circle are calculated), and the efficiency is greatly improved.

![Figure 6. (Left) Original dashboard image. (Right) Instrument panel after Hough transformation.](image)

2. Tick positioning and fitting
   The scale is not used as the basis for calculation in the automatic reading of the meter (except for the start and stop scales). The final reading depends only on the pointer, dial position and range. Therefore, a small amount of error can be allowed when calculating the scale of the meter. Make an impact.

   For the fitting of tick marks, it is essentially the fitting of straight lines, so the commonly used methods include least square method and Hough transform fitting. We have selected the contours several times, and then calculated the center of the rectangle surrounding the contour as the scale point, and the line connecting the scale point with the center of the dial as the scale line.

   According to the characteristics of tick marks, contour filtering includes filtering the shape, size, position, and angle of contours. Contours that meet the following conditions will be retained, otherwise they will be rejected:
a) The number of contour points \( n \) (or area) is within the set range. By judging the number (or area) of contour points, a large area of non-scale areas can be filtered out initially.

b) The ratio of the minimum circumscribed rectangle width \( w \) and height \( h \) of the contour point is within the set range. According to the characteristics of the scale line, the aspect ratio \( M \) of the scale line is generally between 1:2 and 1:5. According to the aspect ratio, non-scale contours of the same area can be filtered out.

c) The position of the contour is near the circumference of the dial. After positioning to the dial through circle detection, determine the distance \( d \) between the center of the contour \( (x_0, y_0) \) and the center of the dial circle \( O(a, b, r) \) to filter out contours with similar areas and aspect ratios.

d) The direction of the smallest circumscribed rectangle points to the center of the circle. According to the characteristics of the scale line, the scale line always points to the center of the dial. Therefore, according to the inclination angle \( \alpha \) of its smallest circumscribed rectangle, it is judged whether it is pointing to the center of the dial to achieve the final filtering purpose.

Figure 7. Dashboard scale fitting effect diagram.

3. Pointer positioning, and counting calculation

This paper uses the Hough straight line detection method to find the pointer in the pointer dial, and marks it with a green line, as shown in Fig. 8

Figure 8. Dashboard pointer positioning effect chart.

The final reading of the meter depends on the center of the dial, the angle at which the pointer is offset from the actual scale, and the range. After determining the center of the dial, the direction of the
pointer, and the range, the indicator can be calculated by the offset of the pointer. The important thing here is to calculate the position of the start or end scale.

To determine the start / end scale, you can use the scale fitting method to find the scale, and then determine the start / end scale according to the position relationship of the scale. However, due to the effects of rotation, noise, etc., the positioning results are often unsatisfactory, and the final reading is closely related to the starting coordinates, so to ensure its accuracy, I use manual positioning to mark the starting and ending scales. Of course, make a magnifying glass to zoom in on the local image first, so it is more accurate.

With the starting scale, range, center, and pointer, you can calculate the reading.

Calculated as follows:

\[
data = \frac{R}{\alpha} \times \beta
\]

(5)

Where \( \alpha \) is the angle between the start and end of the scale and the center of the circle, \( \beta \) is the angle at which the pointer is offset from the start of the scale, and \( R \) is the range. The calculation method of \( \alpha \) and \( \beta \) is as follows:

Let the detected center of the circle be \( O(a, b, r) \), the two endpoints of the pointer \( L \) be \( P_1(x_1, y_1) \) and \( P_2(x_2, y_2) \), and the starting and ending scale positions are \( P_s(x_s, y_s) \), \( P_e(x_e, y_e) \), then:

\[
\alpha = \tan^{-1} \left( \frac{b-y_2-b-y_3}{a-x_2-a-x_3} \right)
\]

(6)

\[
\beta = \tan^{-1} \left( \frac{y_2-y_1}{x_2-x_1} \right)
\]

(7)

In order to reduce the error in the straight line detection leading to inaccurate calculation of the pointer offset angle, the line segment of the detected pointer line segment that is far from the center of the circle (P2) and the center of the circle is used as the pointer, so \( \beta \) is calculated as:

\[
\beta = \tan^{-1} \left( \frac{b-y_2-b-y_3}{a-x_2-a-x_3} \right)
\]

(8)

The final reading effect is shown in Fig. 9.

4. Summary
With the continuous development of computer technology and image processing technology, the automatic reading technology of pointer mechanical watches came into being. This technology improves the degree of automation of dial identification and will be widely used instead of the traditional industrial dial reading method. The dial automatic reading system refers to a system that analyzes the pointer dial collected by the camera through image processing methods such as machine vision and automatically recognizes the dial indication. Its main purpose is to replace manual readings, reduce workload, improve work efficiency, and at the same time be able to implement the working state of the reaction equipment to keep it in the best operating state.
Acknowledgments
This work was financially supported by fund project, that is, Guangzhou Institute of industry and commerce college level research project in 2019"Research and design of S bandradio frequency front-end" KA201937 and KA201939.

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