Automatic Detection of Pointer Automobile Instrument Based on Machine Vision

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Abstract. Automotive instrument detection is usually performed manually. Factors such as human subjectivity and external environment have a great influence and are prone to errors. This paper proposes a method for automatic detection of pointer automobile instruments based on machine vision. Firstly, the common part of multiple instrument images with different pointer angles is extracted as the background image; secondly, based on the frame difference method, binarization, morphological operation and other techniques the instrument pointer is identified, and then the intersections of the pointer extension lines are used to determine the center point; thirdly, we extract the image of the scale position and calculate the scale template array; finally, the pointer value of each input instrument image is calculated based on the scale template array. Experiments show that this method can effectively solve the shortcomings of poor applicability and poor intelligence of existing algorithms, and can identify the value of the pointer accurately.

1. Introduction

Automotive instrumentation is an important part of a car. Its quality is related to the overall performance of the car and to the safety of people's lives. At present, automotive instrument testing is usually performed manually, which is performed by observing the scale of the pointer with the human eye. Due to the existence of subjective factors and environmental influences, the detection results are prone to errors and thus affecting the safety of the car. Therefore, the introduction of efficient and accurate machine vision detection technology is inevitable. Visual inspection is based on image processing algorithms and powerful computing power of computers, which can detect pointers and screen qualified products more reliably, accurately and efficiently.

Instrument detection is an important step before the instrument is shipped from the production line. The overall process of automobile instrument detection is: firstly, the industrial computer sends different CAN commands under the control of the software; then, the industrial camera took an image after the instrument responds according to the CAN command; last of all, the industrial computer processes the image, automatically obtains the scale value and compares it with the expected value to judge whether the quality meets the requirements. Pointer scale intelligent detection based on instrument images is the key to the entire instrument detection.

At present, the problems of pointer instrument detection include: 1) Factors such as inconsistent styles, complex scale styles, and image noise effects caused by lighting, etc., cause the algorithm to
fail to accurately identify and detect; 2) Most of the existing automotive instrument detection algorithms are designed for specific models of instruments, with a single function and can only be used for basic detection tasks; 3) The existing algorithms need to manually set a series of configuration parameters. In actual detection, there are shortcomings such as poor applicability and low intelligence of the detection process.

This article focuses on the image characteristics of automobile instruments, researches on background modeling, pointer recognition, center point recognition, scale template calculation, pointer scale recognition and other issues. Based on computer vision technology, a new automotive instrument detection algorithm is proposed. The method proposed in this article can solve the various problems mentioned above efficiently.

2. Related work
Sablatnig et al. studied the automatic detection of circular water meters with uniform scale distribution and used Hough transform to obtain the rotation angle of the pointer [1]. Jaffery et al. researched on the real-time detection of the pointer of the fuel gauge, and used the second-order center moment to fit the position information of the pointer [2]. Belan proposed to read the numbers on the digital meter based on template matching, and use the radial projection and Bresenham algorithm to determine the pointer position of the analog meter [3]. Jiannan et al. Used the relative positions of the pointer line and the scale to identify the scale value of pointer [4]. Haoqiang et al. used CNN to determine the position of the instrument in a complex environment, and then used the Hough transform method for pointer detection [5]. Zheng et al. proposed a multi-scale homomorphic filtering algorithm, which has strong anti-interference performance for pointer recognition [6].

Most of the existing instrument detection algorithms detect a single type of instrument, and their versatility and intelligence are not good. It is necessary to design an automotive instrument detection algorithm with high detection accuracy, strong generalization ability, good stability and high intelligence.

3. Pointer automobile instrument recognition
The process of the pointer instrument detection and recognition method includes five parts: background modeling, pointer recognition, center point recognition, scale template calculation, and calculation of pointer scale values. Each algorithm is described in detail below.

3.1. Background modeling
The purpose of background modeling is to obtain the common background image, which will be used in the subsequent detection steps. The overall idea of background modeling is to obtain a common image from multiple images with different pointer angles as the background image. The entire algorithm flow is as follows:

1) At the same camera position, collect n instrument pictures (n ≥ 3) with different pointer angles as sample images;
2) Select the first picture as the reference picture;
3) Extract the difference parts between the reference picture and other n-1 pictures respectively to obtain n-1 difference images;
4) Obtain the common difference image P from the n-1 difference images;
5) Select a sample image outside the reference image, and then replace whose pixels in the common image area on the difference image P to the corresponding position of the reference image, and finally obtain the background image.

Figure 1 shows the entire process of creating background image. figure 1(a), 1(b), and 1(c) are the three collected sample images. Figure 1(d) and 1(e) are the extracted two difference images, and figure 1(f) is the final background image.
3.2. Pointer recognition

The extraction of automobile instrument pointers is a key step in instrument detection. Only after the pointer position is accurately identified, the accuracy of subsequent processing may be able to meet the requirements. The specific implementation algorithm for extracting pointers is as follows.

1. Obtain the instrument image, in which the pointer will be extracted;
2. Extract the difference image by detecting the frame difference between the instrument image to be detected and the background image;
3. Binarize the difference images and perform morphological operations to denoise. The resulting connected domain is the approximate area of the pointer.
4. If there are discontinuities in the connected domain, the foreground pixels after binarization processing need to be filled to complete the break repair.
5. Obtain the smallest circumscribed rectangle of the connected domain, and set the four corner points of the rectangle as pt_near1, pt_near2, pt_far1, pt_far2;
6. Calculate near-end point pt_near as the center point of corner points pt_near1 and pt_near2, and pt_far as the center point of corner points pt_far1 and pt_far2.

Figure 2 shows the entire process of the pointer recognition algorithm. Figure 2(a) is the instrument image to be detected, figure 2(b) is the background image, and figure 2(c) is the difference after removing the background image. Figure 2(d) is the image after denoising operation. Figure 2(e) shows the discontinuity of the pointer image area, and figure 2(f) shows the pointer image obtained after repairing the discontinuity.

3.3. Center point recognition

Before calculating the pointer scale, the center position of the automobile instrument needs to be determined. The accuracy of this position directly affects the accuracy of pointer scale recognition. It is necessary to find the instrument center point automatically, accurately and efficiently with less information. The detailed process of the center point recognition algorithm is as follows.

1. At the same camera position, collect n instrument pictures (n ≥ 4) with different pointer angles as sample images.
2. Based on the above-mentioned pointer recognition algorithm, obtain the coordinates of the near-end point and the far-end point of the pointer in each sample image;
3. Calculate the minimum abscissa $X_{\text{MIN}}$, the largest abscissa $X_{\text{MAX}}$, the smallest ordinate $Y_{\text{MIN}}$, and the largest ordinate $Y_{\text{MAX}}$ based on the coordinates of the near-end pointers calculated above.
4. The four corner points $(X_{\text{MIN}}, Y_{\text{MIN}})$, $(X_{\text{MIN}}, Y_{\text{MAX}})$, $(X_{\text{MAX}}, Y_{\text{MIN}})$, $(X_{\text{MAX}}, Y_{\text{MAX}})$ are used to determine a rectangular area that can contain all the near endpoints, that is, the ROI (region of interest) of the instrument center point;
(5) Find all the intersection positions of the straight lines formed by the near-end and far-end points of each the sample image, filter out all the intersections in the ROI region and define them as the candidate center points;

(6) For each candidate center point coordinate \((x, y)\), calculate the vertical distance from the point to the straight line formed by the near-end and far-end points. Use formula (1) to calculate the distance, where the coordinates of the near-end point are \((x_1, y_1)\) and the coordinates of the far-end point are \((x_2, y_2)\):

\[
dist = \frac{(x-x_1)(y_2-y_1)-(x_2-x_1)(y-y_1)}{\sqrt{(x_2-x_1)^2 + (y_2-y_1)^2}} \tag{1}
\]

(7) For each candidate center point coordinate, calculate the sum of the vertical distance between the point and all the \(n\) straight lines. The candidate center point with the smallest sum of all distances, can be determined as the instrument center point.

Figure 3 shows the execution process of the center point recognition algorithm, where figure 3 (a), (b), (c), (d) are four instrument images with different pointer angles, figure 3(e) is the region of interest obtained from the four near-end points, and figure 3(f) shows the final determined instrument center point position.

![Figure 3. The process of the center point recognition algorithm.](image)

3.4. Scale template calculation

The scale template includes 2 arrays, which store the corresponding scale values and pointer angles in the instrument. The accurate scale template is a powerful guarantee for the calculation of pointer scale values. Considering the different shapes of instruments, a small amount of manual intervention is required at this stage to improve the accuracy of the algorithm. Calculation method of instrument scale template, including the following steps.

(1) Mark the key points manually on the outer frame and the inner frame of the instrument, and then the outer ellipse and the inner ellipse are respectively fitted, based on these points;

(2) Find the difference between the outer ellipse and the inner ellipse to obtain the scale region;

(3) Extract the connected fields of all scales by binarization, and get the position of each scale;

(4) Calculate the angle between each scale and the center point to get the array \(angleTemplate\), which is the array of angle templates;

(5) Get the start and end scale values of the instrument manually, and then automatically calculate the scale value of each angle according to the length of the \(angleTemplate\) array to obtain the corresponding scale value template array \(Nums\).

Figure 4 shows the calculation process of the scale template, where figure 4(a) is the instrument image to be detected, figure 4(b) is the fitted inner and outer ellipses, and figure 4(c) is the scale region. Figure 4(d) shows each scale angle and the corresponding scale value.
3.5. Calculation of pointer scale values

Based on the obtained background image, center point coordinates, scale template and other information, the instrument image in any state can be automatically identified and detected. The specific calculation method of the pointer scale value includes the following steps.

1. Collect an instrument image to be detected;
2. Identify the pointer position in the image based on the pointer recognition method;
3. Calculate the angle of the straight line formed by the far-end point and the center point of the instrument, which is the target pointer angle called as $dAngle$;
4. Match the template angle value, which is closest to $dAngle$ in the angle template array $angleTemplate$, and the index of this value in $angleTemplate$ is recorded as $dstIndex$;
5. Use the scale template array $angleTemplate$ and $Nums$ to calculate the actual scale of the pointer. The calculation formula is shown in formula (2), where $speed$ is the final scale value.

$$speed = \frac{dAngle}{angleTemplate[dstIndex]} \times Nums[dstIndex]$$  \hspace{1cm} (2)

4. Experimental results and analysis

4.1. Experiment platform

The experimental platform for automatic detection of automobile instrument used in this paper is shown in figure 5. The entire detection system consists of instrument control, image acquisition, and image processing. The instrument control management unit is responsible for parsing the received CAN commands and sending them to the instrument; the image acquisition unit is responsible for taking sufficient clear images for the instruments at various pointer angles; the image processing unit is responsible for identifying the pointer value of the automobile instrument under the current CAN command and comparing it with the expected value.
detection system is developed using C++, and the image processing part is based on the OpenCV open source library.

4.2. Automatic detection process

Figure 6 shows the entire process of automatic instrument detection. Figure 6 (a) is the input instrument image to be detected, figure 6 (b) is the result image after pointer recognition, and the two red dots in the figure are the far-end point and near-end point, figure 6 (c) shows the position of the instrument center point. Finally, figure 6 (d) shows the scale template, and the calculated result of the pointer scale value of this image is 60.23. This scale value will be compared with the expected value to judge the quality of this instrument.

![Figure 6. Automatic detection process.](image)

4.3. Analysis of detection results

In order to test the accuracy, applicability and stability of the algorithm, the instrument detection method proposed in this paper is used to test 100 collected instrument samples. Table 1 shows the test results of 5 samples. From the test results in table 1, it can be known that the average accuracy of the instrument detection system implemented in this paper is higher than 99.5%, and the average of the absolute error value of the automatic detection system is less than 0.320. The automatic detection system is more accurate than the result obtained by manual reading, which meet the practical needs of quality inspection of automobile instrument factory.

| The actual angle | Manual detection value | Automatic detection value | Manual absolute error | Automatic absolute error | Manual relative error | Automatic relative error |
|------------------|------------------------|---------------------------|-----------------------|-------------------------|----------------------|-------------------------|
| 19.50            | 19                     | 19.51                     | 0.50                  | 0.01                    | 2.56%                | 0.05%                   |
| 78.71            | 78                     | 78.98                     | 0.71                  | 0.27                    | 0.90%                | 0.34%                   |
| 106.6            | 106                    | 107.01                    | 0.60                  | 0.41                    | 0.56%                | 0.38%                   |
| 118.6            | 118                    | 118.12                    | 0.60                  | 0.48                    | 0.51%                | 0.40%                   |
| 124.0            | 123                    | 124.39                    | 1.00                  | 0.39                    | 0.81%                | 0.31%                   |

5. Conclusion

Aiming at the image characteristics of automobile instruments, based on the actual needs of industrial production, this paper proposes a pointer scale detection calculation algorithm based on image processing technology. The algorithm automatically detects the pointer scale value of the automobile instrument through a series of processes such as background modeling, pointer recognition, center point recognition, scale template calculation, and pointer scale calculation. This method has fast processing speed and is suitable for real-time detection of automobile instrument. The experiment proves that this method has strong adaptability, small error, and has certain application value. At present, the algorithm has been successfully applied to the visual detection system of automotive instruments in actual industrial production.
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