Automatic Alignment System Based on Center Point Recognition of Analog Measuring Instruments Dial

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***Abstract* – This paper casts the problem of the automatic alignment in analog measuring instruments automatic calibration system via center point recognition of dial using total least squares. Random points on the dial contour are selected to establish set of equations, and the coordinate of center point of dial can be obtained by solving system of equations with total least squares. With the coordinate, the movable supporting point on the support frame can be automatically adjusted in vertical direction to the position where the optical axis of camera has same height with the center point. Then, by using the dial contours as a benchmark, the movable supporting point is automatically adjusted in anterior-posterior direction to make the image collected by camera be filled with the dial as possible. SCM (single-chip microcontroller) is used in the acceleration and deceleration of stepping motor discrete control. The experiment results show that the camera can be adjusted to the expected position by this approach accurately and quickly and the system can achieve a better image collection effect.**

Keywords- analog measuring instruments; automatic alignment; total least squares; center point recognition of dial; automatic calibration system

I. INTRODUCTION

In China, calibration of analog measuring instruments is still in the period of hand operated. It results in the low efficiency, and calibration accuracy is greatly reduced by human errors. To improve the existing situation, how to realize full-automatic pointer instrument calibration is the problem to be solved urgently for metrological service, since it is not sensitive to operator fatigue or lack of expertise, and cost reduction by decreasing the time and the operator skills that are required [1].

In the last years, many authors have proposed automatic calibration approaches using computer vision techniques [1–6]. F. Correa Alegria et al developed an automatic calibration system that can automatically determine the reading of the measuring instruments [2, 3]. Leo, S.L. et al summarized the application of an intelligent automatic calibration system for instruments without computer interface output which was designed to communicate with the high precision calibrator and connect to a camera to capture meter readings in image format and then convert to digital format for test data verification in computer automatically [4]. Guan Yudong et al used computer vision and image processing to realize automatic reading of pointer-type meter [5]. Wen He et al presented an intelligent precise reading method for analog meter based on computer vision and experiment results proved the validity and correctness of the proposed method [6].

Though computer-based automatic calibration system is not new, automatic calibration system which totally does not include manual operation has almost not been developed yet. In the existing automatic calibration system, alignment of camera before image acquisition is still done manually. In this paper, an automatic alignment system is proposed to make the calibration system more automatically.

II. ANALOG INSTRUMENTS CALIBRATION SYSTEM

Fig. 1 shows the structure diagram of analog measuring instruments calibration system. The work flow of this system is as follows: Image collected by a CCD camera is converted to a digital input, and the digital signal is processed by a computer to recognize the coordinate of center point of dial so as to provide a benchmark for the camera to be adjusted to the position where the optical axis of camera has same height with the center point. Using the dial contours as a benchmark, the camera is automatically adjusted in anterior-posterior direction to make the image collected by camera be filled with the dial as possible to ensure that the dial image has high resolution. Only when the series of operations mentioned above have been completed, the calibration will be started. The automatic alignment system researched in this paper is of vital importance to the effect of automatic reading in the calibration process.

In the calibration system, the support frame is used to support the image sensor and the auxiliary light. There is a movable supporting point on the support frame used to fix the camera which can be adjusted to aim the camera at the goal appropriately. The center point of the dial is in the same plane with axis of the adjustable support. Differ from the fixed instrument, the movable supporting point on the support frame can move in two dimensions, including vertical direction and anterior-posterior direction, which helps to achieve a satisfying image acquisition effect.

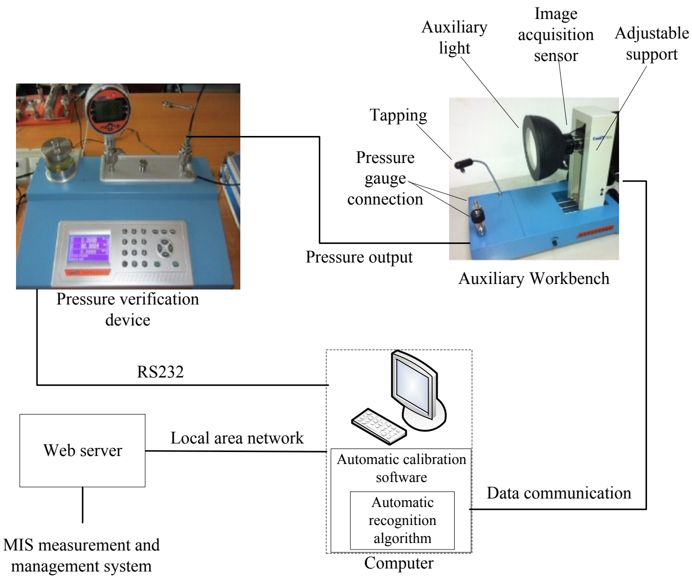

Fig.1 Automatic calibration system based on machine vision

III. RECOGNITION OF THE CENTER POINT OF DIAL

A. Image Preprocessing

The image collected by CCD camera is a color image. In order to reduce calculation time, binary [7] is used to process the dial image on the premise of not affecting the center point recognition. Then the dial contour can be extracted from the multi-value digital image directly. Fig. 2 shows an original image of dial, and Fig. 3 shows a dial image processed by binary. It can be seen that the dial contour is quite clear after binary processing.

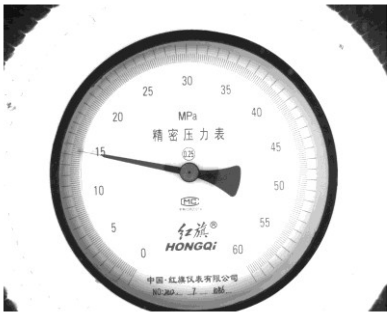

Fig.2 Original image of dial

Fig.3 Dial image after binary processing

B. Total Least Squares

Considering the perturbations of both coefficient matrix $\mathbf{A}$ and vector $\mathbf{b}$ simultaneously is the basic idea of total least squares [8] when solving the matrix equation $\mathbf{Ax} = \mathbf{b}$.

From the perspectives of geometric explanation, difference between total least squares and least squares has been illustrated intuitively as shown in Fig. 4. A more accurate result of dial center obtained by total least squares will be shown in the latter part of this paper.

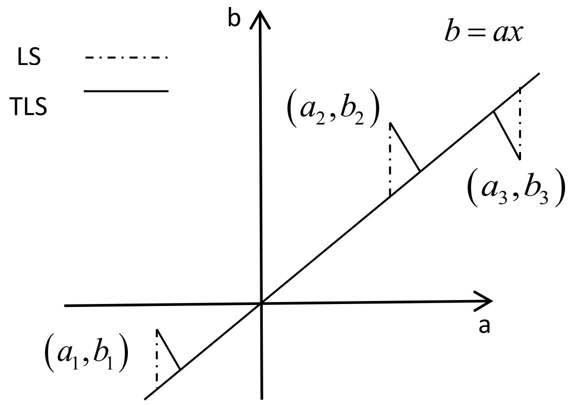

Fig.4 Geometric explanation of total least squares and least squares

C. Recognition Principle

The ternary linear equation using the coordinate of points in the circle as coefficients is shown in equation (1).

$$Mx + Ny + L = x^2 + y^2 \tag{1}$$

M, N, L can be obtained by solving the equation, that is to say the coordinates of both center point and radius of the circle can be obtained.

One row selected randomly in Fig. 3 is scanned from left to right. If there exists one point which values 1, it is defined as a contour point and its coordinate should be recorded. Then, the row just selected will be scanned from right to left again. So the symmetry point in contour can be found and its coordinate should be recorded as well. If there doesn't exist one point which values 1, another row should be selected randomly to be scanned as the steps mentioned above until finding the point valued 1. Scanning steps are taken successively until 20 sets of symmetric points in contour are obtained, and the coordinates of these points should be recorded. The coordinates of these points are label as (x, y). [x, y, 1] is the coefficient matrix of equation (1), and $x^T x + y^T y$ is the vector **b**. The coordinates of center point of dial can be obtained by solving the equation with total least squares.

D. Simulation

Q. Cheng et al [9] used least squares to fit the center point of dial. H. Zhang et al [10] scanned in horizontal and vertical direction, and the coordinates of midpoint of horizontal chord and vertical chord equaled the coordinates of the center point of dial respectively. In this paper, total least squares is applied to fit 20 sets of points obtained in last section, to find the corresponding points in contour in the vertical direction, and to record the coordinates of the center point recognized by the method in [9]. The center point results recognized by three methods respectively are shown in Fig. 5.

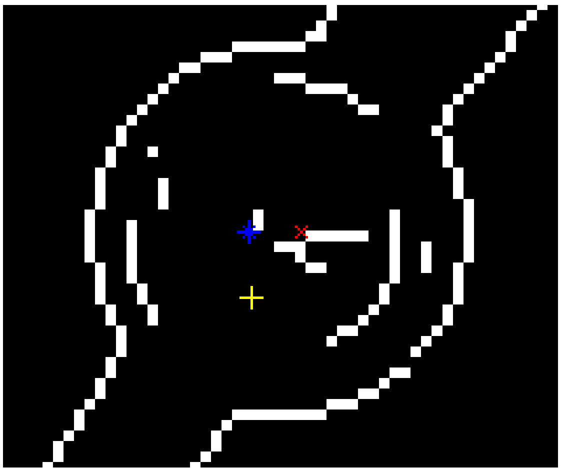

Fig.5 Enlarge figure of dial center

The coordinate of dial center recognized by least squares labeled yellow point "+" is (419.2985, 297.7768) .The coordinate of blue star is (419, 219.5) which is recognized by the method in reference [9]. The red cross is recognized by total least squares and its coordinates is (424, 219.4934). It can be seen intuitively that the result recognized by total least squares is the most accurate one. On this basis, the camera on the adjustable support can be automatically controlled to be aligned with the dial center.

IV. Automatic Alignment System

A. The principle of alignment control

The visible area of image acquisition system is much larger than the whole dial. The accuracy of automatic reading can be improved by adjusting the camera to the optimal location. To achieve this goal, there are two stepping motors in the automatic alignment system for adjusting the camera in vertical direction and anterior-posterior direction. For convenience, the vertical direction is defined as the z-direction, and the anterior-posterior direction is defined as y-direction.

Image collected by CCD camera is composed of 1280 * 1024 pixels. Adjusting the dial center to the view center can be accomplished by the following steps. Firstly, recognize the center point of dial and record its coordinate. Secondly, calculate the distance in image between the dial center and view center (640,512). Thirdly, drive the stepping motor to adjust the movable point according to the distance calculated in second step. It will meet the requirement if the coordinate of the dial center is in the permissible range (640 ± 5,512 ± 5). Because step-size of stepping motor is constant and a small deviation does not affect automatic reading much. This can be realized by adjusting the stepping motor in z-direction.

According to the design parameters of the support frame, the moving range of the camera is 140mm * 200mm. The steps of stepping motor required to move while image moves each pixel in vertical direction can be obtained by experiments. Then, the steps of stepping motor required to move in z-direction can be calculated from the distance between the dial center point and the view center. Based on that, the camera can be automatically adjusted to the front of the center point. Similarly, the steps of stepping motor required to move while the dial contour image expands or narrows one circle of pixel can be obtained by experiments. Then calculate the steps of stepping motor required to move in y-direction depends on the distance from the dial contour to the lower edge of the image. Control the stepping motor in y-direction so that the dial occupies the entire image. The flow chart is shown as Fig. 6.

B. Adjustment system

Adjustment system controlled by stepping motors is a critical part in auxiliary workbench. Compared with conventional servo system, the complexity of the step-by-step control is significantly reduced, and the cost is effectively saved. Compared with a general step-by-step control system which is open-loop, the adjustment system includes images collected in real time which forms feedback-loop. The controlled quantity is exactly calculated from the error signal in the image. The structure diagram is shown as Fig. 7.

Stepping motor has many advantages, such as fast start-stop, high precision and is easy to be controlled. But in the actual operation, if improperly controlled, the stepping motor will jitter when starting or overshoot when stopping, which affects the performance of system. In this paper, acceleration and deceleration of stepping motors are controlled by SCM with discrete control method. Acceleration and deceleration curves are shown in Fig. 9. Take inertia effect of stepping motor into account, its response would not keep up with the changes if the change rate is too high during acceleration and that will result in out-of-step. Therefore, once the frequency makes a change, the stepping motor continues to run a certain number of steps to make it adapt to the changes. As shown in Fig. 10, the acceleration and deceleration curve is discretized. Once the frequency increased, the rate should be maintained for a period of time in order to overcome the lag caused by rotor inertia of the stepping motor.

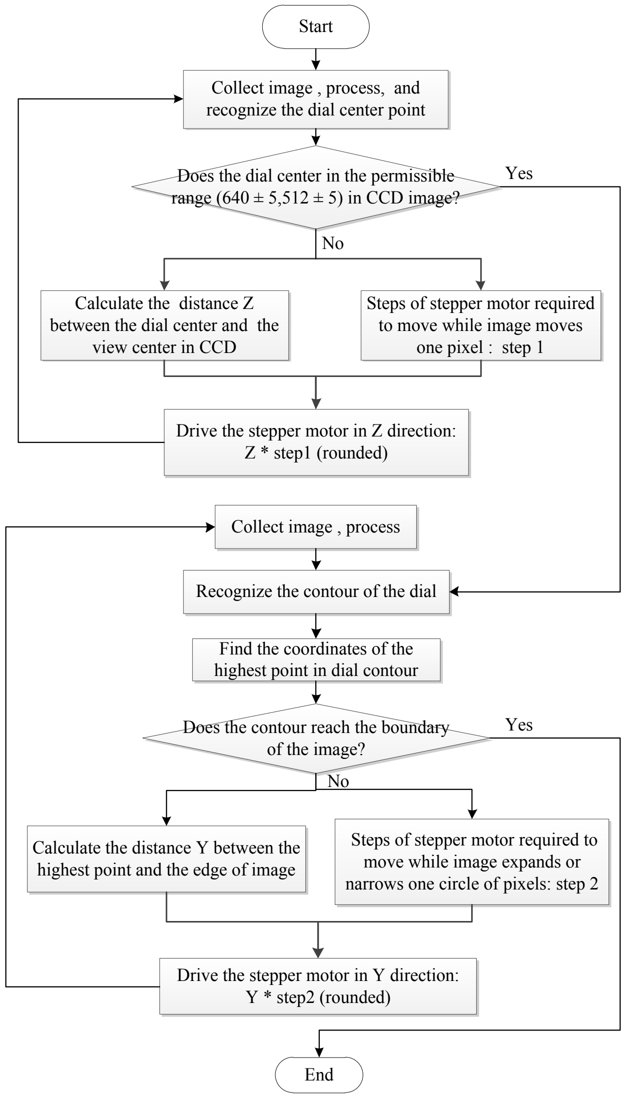

Fig.6 Flow chart of alignment control

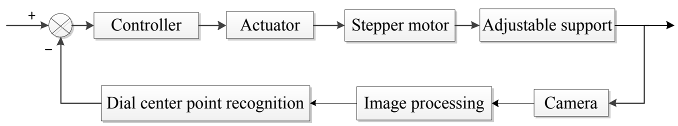

Fig.7 The structure diagram of support regulating system

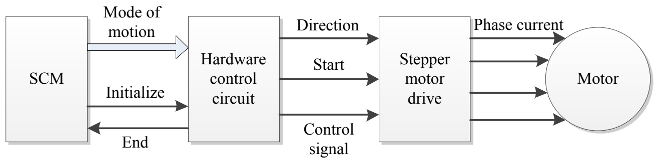

Fig.8 Stepping motor control system

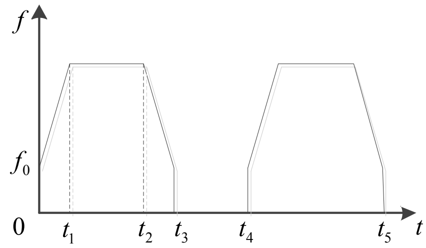

Fig.9 Time-frequency curve of acceleration and deceleration

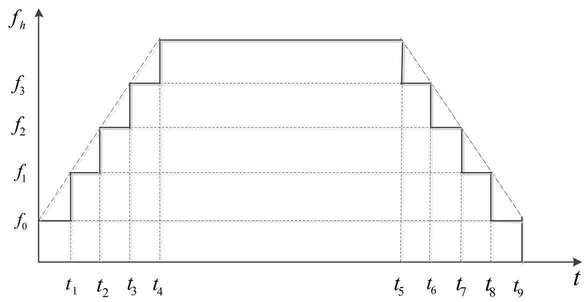

Fig.10 Discretized time-frequency curve

V. REALIZATION BASED ON CONST700A

ConST700A is an auto-acquisition device. An auto-alignment system is added on the device to improve its automation performance. The system contains stepping motor typed 57BYG250-56 which is two-phase and four-wire and stepping motor drive typed ZD-6560-V3 which is two-phase. The movement of the stepping motors is controlled by SCM.

Fig. 11 shows the dial image collected by the camera in the initial position. Fig. 12 shows the dial image collected by the camera after automatically aligned. It can be seen that when the camera is automatically aligned, the dial center is located in the center of view and the dial image is maximized to occupy the entire view on the premise of not affecting the reading. It provides an optimal position for image acquisition in order to do the automatic reading in the next step. The whole process of adjustment does not exceed 2s.

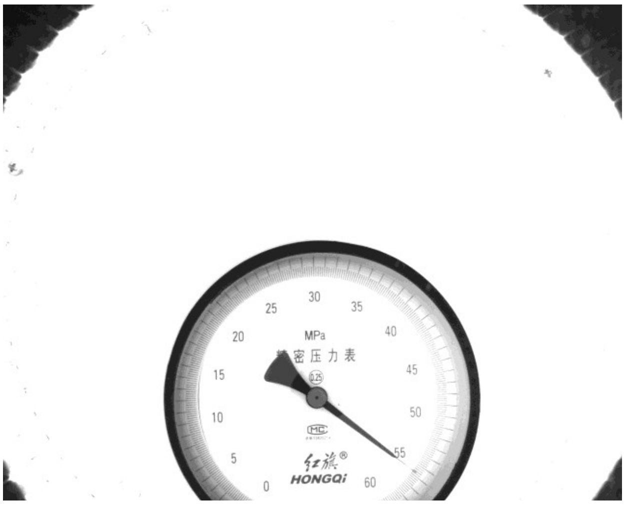

Fig.11 Image collected by the camera in the initial position

Fig.12 Image collected by the camera after adjustment

VI. Conclusion

To summarize, in order to improve the automation of the instrument calibration, a support frame is reformed so that the camera can move along with the collected image in vertical and anterior-posterior directions. The research transforms dial alignment operations from manual to automatic in order to shorten aiming time, reduces artificial error and improves efficiency of calibration. To some extent, it reaches a real sense of the automatic calibration system.

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