Measuring Runout Value of Sliding Door Using Combination Method of Laser and Machine Vision

Qi Chen[1], Liming Wu[1], Ya'nan Zhao[1], Chao Xu[2] and Yonggen Xu[2]
1School of Electromechanical Engineering,Guangdong University of Technology, Guangzhou, China
2Zhongshan OPK Hardware products Co., Ltd, Zhongshan Xiaolan, China

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Abstract: In order to solve the problem of low automation in the original measurement of sliding door run out value, a method of using a servo motor to replace the manual sliding door is proposed at first, then give an analysis about the error source of laser measurement when the run out value is large, and a measurement method of the run out value of the sliding door based on machine vision is designed. The method estimate the ROI of every frame by calculating of the motor speed at first, then use image processing to process the run out video, and the position of the marker is finally gotten. The measurement results of the laser displacement sensor are used to optimize the visual measurement results, and Gauss-Newton is used to solve the nonlinear least squares problem. Experimental results show that this method can effectively improve the overall accuracy in visual measurement.

1 INTRODUCTION

The damping system of the pulley is an important part of the sliding door. Because the ordinary sliding door does not have a damping system installed, the door will have a strong collision with the door frame at the moment of closing, which not only destroys the structure of the door frame, but also creates environmental noise and affects people's quality of life. Instead, elegant sliding doors are installed with the damping system on the door rail, which can effectively avoid this problem. The door will experience a buffering time of 2-5s before fully closing. However, the performance of the damping system will also directly affect the user's sliding door experience. When the sliding door contacts with the damping system, it will be affected by the force which make it generate a run out in the vertical direction, and the value of run out is not only affected by the installation quality of the sliding door fittings but also the speed of door movement and the structure of the damper pulley system. If the value of jump is too large, not only will it reduce the comfort when using the sliding door and increase the noise of the sliding door, but it will also cause the door to fall off from the track.

Obviously, the measurement of the run out value of the sliding door has become a key step in the testing of the damping system. Analysis of the run out curve can not only verify the product's conformity, but also can reflect the defects in the structural design of the damping system. In this paper, according to the existing test methods, the servo motor is used instead of the manual sliding door, after analysing the inevitable error of the laser measurement method in the test process , a vision-based runout measurement method is proposed, and the laser sensor is used for correcting the result which can reduces the overall measurement error.

2 SLIDING DOOR TEST FRAME

The sliding door run out test is tested on the test frame. The traditional test frame consists of a door frame, a track, a sliding door, and a damping system. After being installed with the matching damping system, when the sliding door is closed to a certain distance, it will be subject to a buffering effect of damping, so that the sliding door will automatically and slowly close in the closing direction. Due to the different mechanical structures of the dampers, some dampers will cause the door to jump slightly in the vertical direction while allowing the sliding door to close slowly. The value of run out is also related to the weight of the door itself. The smaller the weight, the greater the run out value.

The traditional testing framework itself does not have the power to move the door. It requires people to push the door manually. The manual method of sliding the door is closer to the actual use, but the long-time test can easily cause fatigue to the operator (Xu Xianzhe, 2015). That will cause the intensity and speed of pushing the door cannot be accurately grasped. And the manual push door test method has uncertainty in the direction of the push door. If the force of the push door is not horizontal, it will generate extra displacement in the vertical direction.

In order to solve this problem, the sliding door frame was reconstructed and servo motor with conveyor belt was used to control the movement of the door. In this method, the position, speed, acceleration and test times of the door movement could be set to achieve automatic testing, which greatly reduced the workload of testers. Use this method to push the sliding door can only produce a horizontal speed and ensuring that the moving door is in the horizontal direction before the run out occurs.

3 ANALYSIS THE ERROR OF LASER MEASUREMENT

The run out value of the sliding door refers to the moving distance of the door in the vertical direction during the movement. The jumping usually occurs at the moment of contact with the damping system, and the whole process is about 200 ms. The traditional method is to use the laser sensor to measure the displacement in real time. The laser sensor has the advantages of high precision, fast response and non-contact measurement, and the measurement frequency can reach 50-100 Hz(Sun Bin,2015). The method is to install the laser sensor on the sliding door when the door is not moving, and record the distance from the sensor to the door frame at this time. This distance is defined as the base reference value. In the test process, the actual run out value is equal to the measured value minus the base reference value:

$$S_1 = Y_1 - C_1 \quad (1)$$

Note that the sensor observation value is , C1 is the base reference value of the sensor before the start of the test, and is the theoretical jump distance.

This measurement method can accurately measure the run out value of the moving door without considering the tilt angle of the jump. However, when the door is jumping, it must be one end jumping and the other end is in the original posture. This will cause the tilt angle is not equal to 0 at the jumping moment, as shown in the figure:

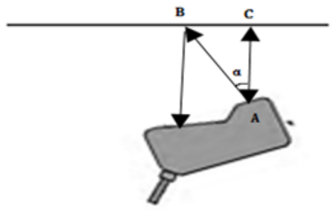

Figure 1: Tilted laser sensor.

When there is a certain tilt angle between the sensor and the test frame, the observation value of the laser sensor is no longer the shortest distance AC from the test frame. Instead, the result is tilted by . Obviously, the actual run out value should be:

$$S_1' = Y_1 \cos\alpha - C_1 \quad (2)$$

is the actual run-out distance. Since the laser sensor cannot measure the tilt angle , the measurement error of the laser method is:

$$e_1 = Y_1 - Y_1 \cos\alpha \quad (3)$$

As can be seen from equation, the measurement error of the laser measurement method is affected by the run out observation value and the magnitude of the tilt angle, and when the run out value and the tilt angle are small, high-precision measurement results can be obtained. With the increase of the tilt angle, the error will be gradually enlarged. In this regard, there is an urgent need to design a measurement method capable of observing from a global perspective so that the accuracy of the observation results will not be affected by the position of the sliding door.

4 DETECTION BASED ON MACHINE VISION

The advantage of machine vision-based run out detection is that the camera sensor can observe the run out value from a global perspective. The position of the sensor during the observation process is not affected by the movement of the sliding door.

The camera is mounted on the top right of the test frame where the jump occurs. A square red marker with a side of 10 mm is pasted on the sliding door and let the edge of the marker is parallel to the sliding door frame.

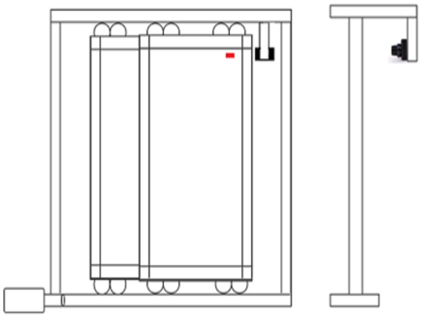

Figure2: Test Frame with Camera and Marker.

4.1 Camera Calibration

Camera calibration is a key step in the process of obtaining three-dimensional information using the two-dimensional plane image information of the object (Xu Chao,2017). The camera calibration is to obtain the camera's own structural parameters and camera pose. In the visual inspection system, the accuracy of the calibration directly affects the accuracy of the measurement results. Different inspection requirements require different calibration methods.

Realizing the three-dimensional point in the real world and the two-dimensional transformation in the image requires the use of four coordinate systems: world coordinate system, camera coordinate system, image coordinate system and pixel coordinate system (Li Xin,2017). The world coordinates are the reference coordinates of the spatial position. The camera coordinates are based on the lens optical center and the optical axis direction is the z-axis. The formula from the world coordinate to the camera coordinate is:

$$\begin{bmatrix} x_c \\ y_c \\ z_c \\ 1 \end{bmatrix} = \begin{bmatrix} R & t \\ 0 & 1 \end{bmatrix} \begin{bmatrix} x_w \\ y_w \\ z_w \\ 1 \end{bmatrix} \tag{4}$$

R is a 3x3 rotation matrix, which represents the rotation of the camera coordinates to world coordinates, and t is a 3x1 translation vector.

The image coordinate system refers to the two-dimensional coordinate system established on the image with the camera optical center as the origin, and the unit of the coordinate axis is the physical size of the actual pixel. The pixel coordinates are the coordinate system established with the upper left corner of the image as the origin of coordinates. The unit of the pixel coordinate axis is the pixel. The conversion from the image coordinate system to the pixel coordinate system can be expressed as:

$$\begin{bmatrix} u \\ v \\ 1 \end{bmatrix} = \begin{bmatrix} 1/dx & 0 & u_0 \\ 0 & 1/dy & v_0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_c \\ y_c \\ 1 \end{bmatrix} \tag{5}$$

To detect the amount of run out value, we only need to calculate the proportional relationship between the unit pixel and the actual length. This paper selects the checkerboard calibration board as the reference object, first determines the physical dimension d (unit: mm)of the calibration board, and calculates the number of pixels n(unit: pixel) of the checker boxin the image is acquired, then the proportional coefficient (Gong Cong,2014):

$$k = d/n \ (\text{unit:mm/pixel}) \tag{6}$$

In order to improve the camera calibration accuracy and eliminate the impact of the camera lens distortion, the calibration board needs to be photographed at different angles, and then take the average of these calibration results as the final calibration result. In this paper, the resolution of the camera is 1024*960, 9*9, checkerboard calibration board with 4mm grid length is used for calibration, and 9 pictures of different angles are taken on the calibration board. The measurement results are as follows:

Table 1:Camera calibration results.

times	Pixel number
1	128.0212
2	129.0043
3	128
4	129
5	128.0089
6	129.0012
7	129.0318
8	128.0724
9	128.0416

The average value is 128.4646 and the proportional coefficient k=0.0311 mm/pixel.

4.2 Runout Displacement Measurement

After the test video is recorded, images are extracted frame by frame for processing. The first is the image preprocessing. In order to reduce the image processing time, the image needs to be extracted from the region of interest (Qiu Zhicheng, 2012). Because the servo motor is used to control the sliding door, the approximate position of the marker at a certain moment can be calculated according to the speed, and then converts it to image coordinates and intercepts the image. As shown in the figure, the color of the marker and the color of the door are significantly different. After the grayscale transformation and binarization of the image, the background is filtered from the image, and use the canny edge detection to extract the edges of the marker.

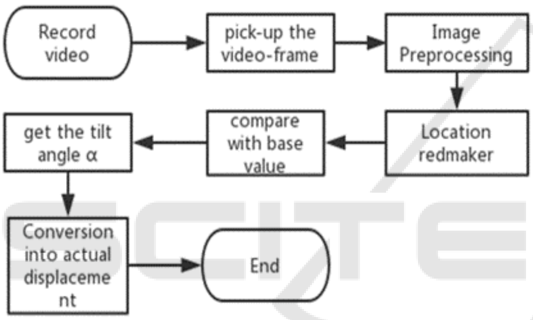

Figure 3: Visual Measurement Process.

Then use the Hough transformation to detect line segment to locate the coordinates of the four edges of the marker, and note that the endpoint in the upper right corner is $A(x_a,$ and the endpoint in the upper left corner is $B(x_b,$. Before the start of the test, the reference value $A_1(x_{a1},)$ is measured using this method. In the following frames, - can be used to obtain the vertical pixel of the jumping gate, and and coordinates can be used to find the runout tilt angle α. As we can see from the formula:

$$s_C = k(A_n - A_1) \quad (7)$$

You can calculate the actual runout value of the sliding door.

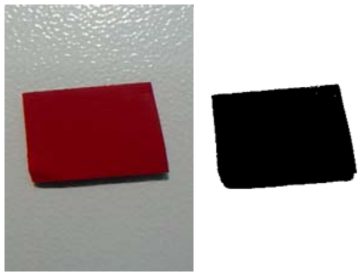

Figure 4: ROI and Binary image.

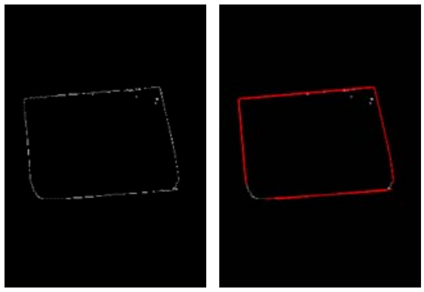

Figure 5: Canny and Hough Change.

5 OPTIMIZE MEASUREMENT RESULTS

Among the above two measurement methods, the displacement measurement accuracy of the laser displacement sensor is higher, reaching 0.01mm, repeatability 15um, and the error mainly comes from the tilt angle α in the test process, and the laser sensor tilt angle αcannot be measured by itself. In the detection of runout using machine vision, we can get both the runout value and the tilt angle by using the points $A(x_a,$ and $B(x_b,$ and the reference coordinates $A_1(x_{a1},)$. However, because of camera noise in the actual measurement process, our measurement results will inevitably have errors, that is, the coordinates of A and B may actually have a certain offset:

$$A'(x_a', y_a') = A(x_a + a, y_a + b) \quad (8)$$

$$B'(x_b', y_b') = B(x_b + c, y_b + d) \quad (9)$$

Here, a, b, c, d are the offsets of the new coordinate point on the original coordinate point. The angle and the new runout value calculated from the new coordinate are:

$$\alpha' = \arctan\left(\frac{y_a - y_b + b - d}{x_a - x_b + a - c}\right) \quad (10)$$

$$s_C^f = s_C + b * k \quad (11)$$

Substituting the obtained into Equation 1：

$$S_l^f = S_l \cos\alpha' \quad (12)$$

It is not difficult to know that both S_l and S_C indicate the actual run out value. Ideally there are：

$$s_l^f = s_C^f \quad (13)$$

$$S_l \cos\alpha' = s_C + b * k \quad (14)$$

$$S_l = \frac{s_C + b * k}{\cos\alpha'} \quad (15)$$

Due to the presence of noise, a, b, c, d are not always equal to zero. The above formula cannot be established, defining the error function：

$$f(x) = S_l - \frac{s_C + b * k}{\cos\alpha'} \quad (16)$$

$$e = \frac{1}{2}\sum_{i}^{N} ||S_{li} - \frac{s_{Ci} + b * k}{\cos\alpha'}||^2 \quad (17)$$

Here N is the total number of video frames. It can be seen that this is a non-linear optimization problem that can be linearized by performing a first-order Taylor expansion:

$$f(x + \Delta x) \approx f(x) + J(x)\Delta x \quad (18)$$

Substitute the linearized f(x) into (17).Then calculates the derivative of and let it equals to zero.

$$J(x)^T J(x)\Delta x = -J(x)^T f(x) \quad (19)$$

x is a 4x1 vector [a,b,c,d]T, the Gauss-Newton method is used to find the optimal offset. The solution is(Li Bo,2015):

(1) Given a preliminary test value

(2) Calculate iteration step size

(3) Update iterative value = x +

(4) The result of the calculation. If e is small enough, is output, otherwise, step 2 is returned.

This article uses a small weight sliding door to test, the purpose is to make the tilt angle and runout value more obvious. After testing 10 times, 50 sets of laser sensor data synchronized with time stamp and 50 frames were obtained. After using Google ceres library for optimization, after 8 iterations, the value of the error function was decreased from 0.1118 to 0.0421. The optimal values of a, b, c, and d are 1.2622, -3.6903, -1.2622, and -3.9108.

6 CONCLUSIONS

Aiming at the problem that the method of laser measurement has obvious errors when the runout value and tilt angle are large, a detection method based on machine vision is proposed. The measurement result of the laser sensor is used to correct the visual measurement result and a nonlinear optimization problemis constructed, then use Gaussian Newton method to solve the optimization variables. The experimental results show that, given the initial value of 0,0,0,0, the Gauss Newton method can iterate the optimal offset with fewer iterations, and the optimization error decreases from 0.1118 to 0.0421, which effectively improve the overall accuracy in visual measurement.

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