Geometrical Size Detection on Key Contours of Safety Seat Base

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Abstract. According to the plastic base without clear benchmark, the contour features are extracted by the image processing method such as image matching and feature extraction. With the reference of the waist groove, the measuring coordinate system is established. The coordinate transformation relation is determined by the calibration of visual inspection system. Thus, the geometric relation of the arc groove with respect to the measuring coordinate system is obtained. The geometric dimensions of the safety seat base are measured. The experiment result shows that the relative error of measuring the waist-shaped groove’s width is 2.7%, the one of measuring the length is 2.1%. And the relative error of measuring the arc-shaped groove’s width is 0.7%.

Keywords: safety seats; image stitching; feature extraction; geometric dimensions; visual inspection

1. Introduction
With the popularity of family car, children's car safety has become increasingly prominent. Young parents pay more and more attention to children's car safety, which promotes the development of the domestic child safety seat market. The safety seat production enterprise mainly relies on the manual assembly and the wrong installment frequently occurs. According to the statistics, the number of parts that fail to assemble accounts for about 20% of the total. Therefore, it is of great practical significance to study the automatic measurement of geometric dimension parameters of safety seats.

According to the automatic measurement requirements of automobile safety seat manufacturers and combined with visual measurement technology, a visual detection method for spatial scale relationship of safety seat base is proposed in this paper. Firstly, the images of base’s arc-shaped groove and waist groove are captured by an industrial CCD camera, then image processing technology is utilized to extract the key size and geometric feature. Afterwards, the coordinate transformation relation is determined by calibrating camera parameters and visual inspection system and a measuring coordinate system with a benchmark of waist-shaped groove is established. Thus, the geometric relationship between the arc groove and the coordinate system is obtained. Finally, the measurement of geometric dimension relations of seat base’s profile is realized.

2. Overview of Method
The structure and feature definition of the safety seat base are shown in figure 1(a). There is no accurate positioning reference for the plastic base, and the waist groove and arc groove are distributed symmetrically on both sides. In order to simplify the measurement, only the geometric relationship
between the waist groove and arc groove on the same side is taken into consideration, and the measurement coordinate system is established with the waist groove as the reference. According to the above analysis, the measuring coordinate system takes the center of the waist groove #1-2 as the origin, the length direction as the X axis, the width direction as the Y axis, and the normal direction of the waist groove plane as the axis, as shown in figure 1(b). The detection process of critical contour geometry dimensions of seat base based on machine vision is shown in figure 2.

![Figure 1](image1.png)

(a) The safety seat base. (b) The measuring coordinate system.

**Figure 1.** Schematic diagram of the seat base and the measuring coordinate system.

![Figure 2](image2.png)

**Figure 2.** The detection process.

### 2.1. Visual System Calibration

For waist grooves and arc grooves with different spatial faces, the checkerboard is used to calibrate waist grooves and arc grooves respectively. The arc grooves and waist grooves are mapped to the focal plane parallel to the measuring plane by plane projection. In order to ensure the same accuracy of the projected image and the original image, the pixel point re-sampling of waist groove and arc groove images is carried out based on backward mapping [1-4].

As shown in figure 3, the measuring coordinate system is established with the waist groove as the feature. The coordinate (X, Y, 0) of the image point (u_o, v_o) measured on the projection plane of waist groove under the measuring coordinate system can be obtained through similar proportional relation and rotary translation transformation. The calculation formula 1 is as follows:

\[
\begin{bmatrix}
X \\
Y \\
0 \\
1 \\
\end{bmatrix} = \delta_1 \begin{bmatrix}
\cos \alpha & -\sin \alpha & v_o - v_A \\
\sin \alpha & \cos \alpha & u_A - u_o \\
0 & 0 & 0 \\
0 & 0 & 1 \\
\end{bmatrix} \begin{bmatrix}
\delta_u \\
\delta_v \\
\end{bmatrix}
\]

(1)

Where, \(\delta_1\) is the resolution of the waist-shaped groove projection plane; \(\alpha\) is the anti-clockwise rotation radian, \(\alpha = \theta - \pi/2\); \((u_o, v_o)\) is the projection plane image coordinate of the waist groove central point; \((u_A, v_A)\) is the projection plane image coordinate of the upper right vertex of checkerboard A.
Figure 3. Establish the measuring coordinate system.

Since the image positions of the two checkerboard on the calibration plate are fixed, and the moving distance of the calibration plate when the waist groove plane and arc groove plane are calibrated is 20 mm, The coordinate (X, Y, 20) under the measuring coordinate system with the waist groove as benchmark of the image coordinate (u_b, v_b) of the arc groove projection plane can be obtained through similar proportional relation and rotary translation transformation. The calculation formula 2 is as follows

\[
\begin{bmatrix}
X \\
Y \\
20 \\
1
\end{bmatrix}
= \delta_2
\begin{bmatrix}
\cos \alpha & -\sin \alpha & \Delta H - v_b \delta_2 + (v_o - v_A) \delta_1 \\
\sin \alpha & \cos \alpha & \Delta W - u_b \delta_2 - (u_A - u_o) \delta_1 \\
0 & 0 & 20 \\
0 & 0 & 1
\end{bmatrix}
\begin{bmatrix}
v_b \\
u_b \\
1
\end{bmatrix}
\]

Where, \( \delta_2 \) is the projection plane resolution of arc groove, \( \Delta W \) is the horizontal offset of two checkerboards, \( \Delta H \) is the vertical offset of two checkerboards, \((u_b, v_b)\) is the image coordinate of the upper left vertex of chessboard B on the projection plane of left camera image.

2.2. Contour Feature Extraction

As shown in figure 4, the key geometric dimensions of the seat base are mainly the contour dimensions of waist groove and arc groove and the geometric relationship between them. Although we have realized the measurement of all the key dimensions, due to length limitations, we mainly describe the visual measurement process of the length and width of waist groove and the width of arc groove [5-10].

Figure 4. Measuring parameters of contour dimension of safety seat base.

The contour feature extraction process of waist groove is shown in figure 5.
2.3. Calculation of Geometric Dimension Parameter

As shown in figure 7(a), through PCA, the geometric center of waist groove contour, the direction of length and width are extracted. Based on the Maximum projection variance, the sample set input of PCA is the sequence point vector \( \{x_1, x_2, \ldots, x_n\} \) of waist groove contour and the output is \( k \) principal components of the sample set, each of which is represented by eigenvalue \( \lambda_i \) and eigenvector \( v_i \). For waist groove contour, its geometric center is corresponding with the mean value \( \mu \) of sample set, the length direction corresponds to the zeroth principal component and the width direction is linked with the first principal component [11-14].

The contour sequence points of each arc segment of arc groove are segmented by corner points acquired through feature extraction. Then the equidistant sampling is carried out for each arc segment.
of the upper arc groove. Small arcs determined by three adjacent sampling points are used to approximately replace the arc groove contour, thus the groove width at the sampling point can be calculate out. As shown in figure 7(b), the sampling interval is set to 20 pixel, and the contour of arc groove is sampled at equal intervals for 51 points. The average slot width of sampling points is taken as the width of arc groove [15-19].

3. Analysis of Experimental Results

As shown in figure 8(a), a visual inspection system for geometric dimensions of safety seat base is built under laboratory conditions. As shown in figure 8(b), the checkerboard A and B are used to calibrate the relative position relationship between waist groove and arc groove, and the calibration parameters of geometric dimension vision detection system are shown in table 1.

![Visual inspection system](image-a)

(a) Visual inspection system for key geometry dimensions of seat base.

![Calibration plate](image-b)

(b) Calibration plate.

**Figure 8.** Experimental facilities.

| Item                                         | Parameter                  |
|----------------------------------------------|----------------------------|
| The projection plane resolution of waist groove \( \delta_1 \) (mm/pixel) | 0.110                      |
| The projection plane resolution of arc groove \( \delta_2 \) (mm/pixel)   | 0.166                      |
| Horizontal offset between checkerboard A and B \( \Delta W \) (mm)       | 193                        |
| Vertical offset between checkerboard A and B \( \Delta H \) (mm)         | 310                        |
| The waist groove center \( (u_o, v_o) \)                                | (577,504)                  |
| The upper right vertex of checkerboard A \( (u_A, v_A) \)               | (276,346)                  |
| The upper left vertex of checkerboard B \( (u_B, v_B) \)                | (760,432)                  |
| Rotation angle of coordinate system \( \alpha \) (rad)                  | 0.388                      |

The Minimum Enclosing Rectangle method is used to calculate the waist groove contour size. The contour length of measured waist groove is 731.00 pixel and the width is 110.56 pixel. According to the image resolution to calculate the actual size, the measured waist groove width is 12.16 mm, the length is 80.41 mm, the relative error of width measurement is 2.7%, and the relative error of length measurement is 2.1%. As shown in figure 9, the measured average width value of 51 sampling points in arc groove is 14.398 mm, the actual value is 14.50 mm, and the relative error is 0.7%.
4. Conclusion
In this paper, the geometric dimension detection method based on machine vision is studied, and the visual detection platform of safety seat base is built. According to the characteristics that the plastic base has no clear benchmark, a measurement coordinate system with the waist groove as the reference is established. The contour features are extracted through image processing and the position relation of arc groove with respect to measuring-coordinate system is obtained by coordinate transformation. Then, the contour geometrical sizes of safety seat base are measured.

Acknowledgments
This work was supported by the National Natural Science Foundation of China (No.51975293), Aeronautical Science Foundation of China (No. 2019ZD052010) and Open Foundation of Graduate Laboratory (No.kfjj20190512).

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