Visual Measurement Method of Image Stitching Based on Homography Matrix and Image Quality Evaluation

XIN LI, LIMING WU, GUITANG WANG, YUJUN CHEN, JIANHAI LIN and KUAI RONG

ABSTRACT

Aiming at the problem of low precision of vision measurement technology for large size complex parts, a method that visual measurement method of image stitching based on homography matrix and image quality evaluation is proposed. Firstly, the normalization model between the world coordinate system to image coordinates is established to extract the simplest expression matrix H. Then the camera is calibrated to determine the pixel equivalent P, the field of view and obtain the focal length f. Images of component are obtained, and registration between the stitching images is obtained by the simplest expression matrix H to complete the stitching in many images. Result in this method is compared with the results of SURF and backward mapping model normalization, and the SSIM value of stitching images is calculated to evaluate the quality of stitching images, and the quality of stitching which meets the subjective feeling has been obtained, which meets the requirements of large size parts inspection.

KEYWORDS
Vision measurement, image normalization model, homography matrix, camera calibration, image mosaic, mass analysis.

INTRODUCTION

With the continuous development of visual inspection technology in the industry, a variety of means of measuring parts have appeared [1]. However, due to the current mainstream camera for low precision, small field of view of the CCD and most of the stitching technology based on the image feature points, the detection of the main focus on small parts, and the detection of large parts basically uses the laser scanning Volume system, joint coordinate measurement system and so on, rarely uses machine vision [2]. Or measurement means are very limited, the accuracy is not high[3-4]. Due to the shortcoming of above algorithm and different application occasion, in this paper, based on the analysis of the influence factors of the machining accuracy of large-sized parts, this paper introduces the analysis method of the covariance matrix coordinate transformation, combined with the homography matrix model, a method that visual measurement method of image stitching based on homography matrix and image

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Quality evaluation is proposed, which is used in automotive engine piston ring parts of the precision detection.

LARGE SIZE PARTS VISUAL MEASUREMENT SYSTEM COMPONENTS

System detection objects for the automotive engine core - piston ring, as shown in Figure 1. The detection accuracy of the opening part of piston ring will directly affect the engine efficiency, energy saving and life expectancy [5].

Automotive complex parts measurement system is consisted of three modules, namely, visual modules, motion control module, laser module, etc., as shown in Figure 2. The car engine parts are fixed in the middle of the experimental platform, the camera translates in the precision orbit. First, the camera collects parts of the local image in order in the horizontal axis and obtains a number of sub-images for image stitching.

Figure 1. Automobile engine piston ring.

Figure 2. Measurement system.
ALGORITHM MODEL

Project from 3D objects to 2D screens, the model used in this paper is: object coordinates → world coordinates → camera coordinates → projection coordinates → image coordinates (pixel coordinates), as shown in Figure 3. In order to ensure measurement accuracy, the camera plane must be perpendicular to the measuring plane.

Images Homography Matrix.

The H of satisfying is defined as homography matrix:

\[ q = sHQ \]  

Where the parameter s is a non-zero scale scaleconstant.

According to the camera imaging principle, the world coordinates and the coordinates of the image as shown in:

\[
\begin{bmatrix}
    x \\
    y \\
    1
\end{bmatrix} = sK \begin{bmatrix}
    R_\phi & R_\phi & T
\end{bmatrix} \begin{bmatrix}
    X \\
    Y \\
    1
\end{bmatrix}
\]  

Which R is a 3 * 3 rotation matrix, T is a three-dimensional translation vector, K is the camera calibration matrix.

\[
K = \begin{bmatrix}
    f & 0 & u_0 \\
    0 & f & v_0 \\
    0 & 0 & 1
\end{bmatrix}
\]
The plane Z is defined 0, so Rφ can be ignored. From (1)−(3), the homography matrix H is:

\[
H = \begin{bmatrix}
    f\Delta x & m & u_0 \\
    0 & f\Delta y & v_0 \\
    0 & 0 & 1
\end{bmatrix} [R_\theta, R_\varphi, T] \tag{4}
\]

In order to get the homography matrix H, it is only necessary to obtain the pixel equivalent Δx, Δy, the main point position (u0, v0), the rotation angle θ, φ, and the translation vector T on the coordinate axes.

**IMAGE STITCHING**

In the case of ensuring that the optical axis of the camera is perpendicular to the measuring plane, the path of the mechanical axis of the test platform is arbitrary. Obtaining the vehicle complex large size parts adjacent sequence diagram for stitching arbitrarily.

N pairs (g1 ～ gn) images are collected. The homography matrix H between adjacent images is found. According to the above formula, cause the image obtained is that the camera is perpendicular to the experimental platform in this experiment. Therefore, the rotation angle θ = φ = 0. Since the coordinates of the obtained image are fixed, so there is no misalignment, that is the skew parameter m = 0, focal length f fixation. In the image coordinate system, the position of the main point is (1296, 972), the unit is pixel. It’s easy to obtain the homography matrix H12 of two images g1, g2, but the homography matrix of g12 and g3 should be calculated through the calculation, the key is to find adjacent images (such as g12 and g3) between the amount of translation T (x, y).

**Image Translation.**

The homography matrix is transitive, ie:

\[
H_{12} = H_{13}H_{32} \tag{5}
\]

So the homography matrix H12,3 of g1, g2 mosaic images g12 and g3 as follows:

\[
H_{12,3} = H_{23}H_{12,2} \tag{6}
\]

The translation matrix is expressed as:

\[
x = x_{12} - x_2, y = y_{12} - y_2 \tag{7}
\]

By parity of reasoning, the amount of translation of the image to be spliced is:

\[
x = x_{mm+1} - x_{m+1}; y = y_{mm+1} - y_{m+1} \tag{8}
\]

Thus, the transformation matrix H (mm+1, m+1) is calculated, and then H (mm+1,m+2)is further obtained. Finally, the image is spliced.
Evaluation and Analysis of Stitching Image Quality.

According to the calculation of similarity (SSIM) value judgment stitching image quality subjective evaluation criteria in CCIR500-1 [6] levels, the subjective criteria are shown in Table 1.

SSIM obtains the information of structure and brightness from the stitching images and acknowledge the measure of information as the approximate of perceptual quality of images. SSIM that is combined with the characteristics [7] of human visual system that can feel image has a good adaptability, which is consistent with the subjective criterion, the calculation formula is as follows:

\[
SSIM(x,y) = \frac{(2\mu_x\mu_y + C_1)(2\sigma_{xy} + C_2)}{\left(\mu_x^2 + \mu_y^2 + C_1\right)\left(\sigma_x^2 + \sigma_y^2 + C_2\right)}
\] (9)

Which \(\mu_x, \mu_y\) are the average intensity of 2 stitching images respectively; \(\sigma_x, \sigma_y\) are the standard deviation; \(\sigma_{xy}\) is the cross-correlation function between two images.

<table>
<thead>
<tr>
<th>level</th>
<th>maxim quality</th>
<th>effect criterion</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>very good</td>
<td>The image is in good condition.</td>
</tr>
<tr>
<td>4</td>
<td>good</td>
<td>Image is damaged a little, but not be affected to see.</td>
</tr>
<tr>
<td>3</td>
<td>so so</td>
<td>The details of image can be seen only.</td>
</tr>
<tr>
<td>2</td>
<td>bad</td>
<td>Half of the image is damaged.</td>
</tr>
<tr>
<td>1</td>
<td>terrible</td>
<td>The image is damaged terribly.</td>
</tr>
</tbody>
</table>

Table 1. CCIR500-1 subjective evaluation standard level 5.

Figure 4. Quartz glass pixel equivalent calibration plate.

Figure 5. Calibration results for three different circles.
DATA ACQUISITION AND ANALYSIS

Calibration of Camera Pixel Equivalents.

In the machine vision measurement, the measured data obtained by the image processing is the amount of pixels. The accurate calibration of the pixel equivalent is critical to the accuracy of the measurement. In this paper, the accuracy of 1um of quartz glass calibration plate is used, as shown in Figure 4. In the field of view, the diameter of each circle is measured, and the number of pixels on the D is N, and the pixel equivalent P is obtained by the following formula:

\[ p = \frac{D}{N} \]  \hspace{1cm} (10)

In order to improve the measurement accuracy, taking pictures of the three round (D=16.0mm, D=10.16mm, group D=5.0mm) in the different position of the field, each round were taken 15 times, each pixel equivalent round average mi (i=1, 2, 3), then calculate the average m of average value of the three round. The calibration method is adopted[8]. Three different diameter circle calibration is shown in Figure 5. It can be seen from Fig. 5 that the maximum difference between the calibration results is 0.003um and the calibration is basically 9.0050. And the calibration matrix of the camera is:

\[
K = \begin{bmatrix}
4739.648 & 0 & 11.671 \\
0 & 4739.648 & 8.753 \\
0 & 0 & 1
\end{bmatrix}
\]

Stitching Images and Data Analysis.

Figure 6 is to collect 4 pairs of engine piston ring sequence diagram, and each map has a partial overlap.

The coordinates of the center of projection are collected, grating coordinates (pulse number) obtained in this system as shown in Table 2

Table 2. Image sequence coordinates (mm).

<table>
<thead>
<tr>
<th>Numbering</th>
<th>Grating coordinates</th>
</tr>
</thead>
<tbody>
<tr>
<td>(a)</td>
<td>(93.575,77.530)</td>
</tr>
<tr>
<td>(b)</td>
<td>(228.015,77.530)</td>
</tr>
<tr>
<td>(c)</td>
<td>(186.105,135.545)</td>
</tr>
<tr>
<td>(d)</td>
<td>(93.575,135.545)</td>
</tr>
</tbody>
</table>
Table 3. Shape transformation matrix.

<table>
<thead>
<tr>
<th>No.</th>
<th>Homogeneity matrix/H</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$H_{12} = \begin{bmatrix} 0.6309 &amp; 0 &amp; 0 \ 0.1177 &amp; 0.4740 &amp; 0 \ 0.0134 &amp; 0 &amp; 0 \end{bmatrix}$</td>
</tr>
<tr>
<td>2</td>
<td>$H_{12,3} = \begin{bmatrix} 0.4251 &amp; 0.0677 &amp; -45.0237 \ -0.0367 &amp; 0.5247 &amp; -37.2508 \ -0.0042 &amp; 0.0058 &amp; -0.0576 \end{bmatrix}$</td>
</tr>
<tr>
<td>3</td>
<td>$H_{23,4} = \begin{bmatrix} 0.3660 &amp; 0 &amp; -83.4473 \ 0.0810 &amp; 0.4740 &amp; -18.2792 \ 0.0093 &amp; 0 &amp; 2.1098 \end{bmatrix}$</td>
</tr>
</tbody>
</table>

Analysis and Evaluation of Image Quality of Stitching.

SURF feature point method is unstable from the general point of view, and as the image becomes more and more, the error of the splicing error increases, and the error is more and more. In the backward mapping method, the stitching error tends to be steady with the increase of the mosaic images, but the average error is larger. In this paper, the error is much smaller than the SURF method and the backward mapping method, which is 50.95% and 25.08% respectively, on the whole, and the splicing error is basically stable, which provides the basis for further reducing the splicing error as shown in Figure 8.

SURF feature point method and backward mapping method for increasing image stitching, more and more time,

While the method in this paper, basic splicing time increased with the increasing of image stitching, basically stable, compared to the SURF feature point mapping method and after splicing with decreased to 86.55% and 67.30% as shown in Figure 9.

Two stitching images are chosen randomly. The brightness mutation rate will be 10%, the changing value is from -80% to +80%, and there are two groups of pictures, each of which has 17 pictures. The SSIM value of the image in different brightness is calculated, and the image quality is evaluated, as shown in Figure 10.
The evaluation results show that. The result scores of the SSIM brightness of the two groups of different brightness images are almost 0.85, which is in the grade 4-5 level of subjective criteria. There is no obvious effect on the visual effect, which basically conforms to the subjective evaluation trend, which further indicates that the stitching image obtained by the algorithm has many good quality effects.

CONCLUSION

The problem of low accuracy of on-line detection of large parts of automobile by machine vision is presented. A method that visual measurement method of image stitching based on homography matrix and image quality evaluation is proposed. The problem of coordinate normalization simplification model of multiple sequence graphs is studied, and the homography matrix H between adjacent images is obtained to realize image stitching. And then the impact, which the accuracy of the camera calibration affects the accuracy of the measurement, is analyzed. Finally, this method is compared with the SURF feature point method and the back mapping method. The quality of image stitching is evaluated by calculating the SSIM value of image stitching. The results show that this method not only can reduced the stitching time greatly, and the stitching accuracy is higher than the SURF method and backward mapping method, but
also the quality of stitching which meets the subjective feeling has been obtained, which meets the requirements of large size parts inspection.

REFERENCES


