A Method of Error Compensation for Multi-Linear Structured Light Probe

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Abstract. Aiming at the problem of un-equivalence and un-parallelism of light stripes in the measuring system based on multi-linear structured light, the method based on triangular standard piece is presented. When multiple light stripes are projected on the slant of a triangular standard piece, the information of un-equivalence and un-parallelism of light stripes can be converted into the light plane which can be captured by CCD and computed by trigonometry. According to the obtained error data, the appropriate scanning distance is selected to scan objects. After reconstructed, the 3D data are corrected and combined. An example is given to prove that presented method is effective.

1. Introduction

The measurement based on multi-linear structured light is a new measurement which uses more than one structured light to scan measured objects. The measuring speed of the measurement is faster than the measurement based on single-linear structured light. However, the complexity and difficulty of measurement are increased too. The forming of multi-linear structured light is one of the primary issues. Generally, the formed multi-linear structured light in the probe should strictly meet two conditions:

1. All light stripes must be parallel with each other;
2. The spaces of any two neighboring light stripes must be equivalent.

The two conditions are the guarantee of measuring objects accurately. Presently there are about three schemes available to form multi-linear structured light, and the scheme based on laser-set array is the most easy to be realized. Figure 1 illustrates the scheme based on laser-set array. However, due to fixing error and adjusting error are introduced by manual work, the two aforementioned conditions are difficult to be satisfied strictly. To solve the problem, a method of error compensating based on triangular standard piece is put forward.

Figure 1. Probe scheme based on laser-set array.
2. Error analysis

Above all, the formation of error is discussed here. According to two aforementioned conditions, it is divided two cases to be discussed respectively.

2.1. Case of unequal-space

In figure 2(a), some light stripes are drawn, \( d_j \) is the space of the \((j-1)\)-th light stripe and the \(j\)-th light stripe. Every \( d_j \) are not equal to each other, supposing \( d_{j-1} > d_j > d_{j+1} \). If a value, for instance \( d_j \), is selected as the scanning distance, there exist some un-scanned areas of measured objects’ surface as part A in figure 2(a). So it is necessary to select an appropriate scanning distance to scan.

![Figure 2. Error analysis of unequal-space and un-parallelism.](image)

2.2. Case of un-parallelism

In figure 2 (b), supposing that all spaces of any two neighboring light stripes are equal to each other, and that all light stripes but the \(j\)-th light stripe are parallel with each others. The angle between the \(j\)-th light stripe and other light stripes is \( \theta \). In the case, when scanning finished, there also exist two small parts of area C and D of measured objects’ surface are not scanned. So it is necessary to compensate for the error.

3. Principle of Compensating

Before compensate for the error, the spaces and un-parallelism degree among light stripes should be firstly measured accurately. However these values are difficult to be obtained by directly measuring. We propose the method which utilizes a triangular standard piece to realize measuring as shown in figure 3. When the light stripes projected vertically on the slant of the triangular standard piece, the position errors of light stripes in horizontal plane can be converted the vertical light plane. The converted errors can be captured by the CCD as shown in figure 4, and computed by image processing and trigonometry. Next, the method is explained in two cases respectively.

![Figure 3. Sketch of light-stripes projected on the a triangular standard piece.](image)

![Figure 4. Captured image of light-stripes projected on a triangular standard piece.](image)
3.1. Case of un-parallelism

In order to easily explain the principle, figure 5 are used and some hypothesizes are adopted:

1. All spaces between any two neighboring light stripes are equal to each other;
2. All light stripes are parallel with each other except the \( j \)-th light stripe;
3. The angle between the \( j \)-th light plane and other light stripes is \( \theta_j \).

In this case, when the \( j \)-th light stripe is projected on the slant of the triangular standard piece, it intersects with two side of the slant at point C and point D. The vertical distance between the two points is \( r_j \) which can be computed by image processing. From figure 5, it is obtained that the relationship of the angle \( \theta_j \) and the vertical distance \( r_j \):

\[
\tan(\theta_j) = \frac{D'E'}{C'E'} = \frac{EF \cdot \cot(\alpha)}{w} = \frac{r_j \cdot \cot(\alpha)}{w}
\]

\[
(1)
\]

(a) Side view \hspace{2cm} (b) Right-top view

**Figure 5.** Principle of Compensating for un-parallelism.

Where \( \alpha \) is the angle between the slant and horizontal plane of the triangular standard piece, and \( w \) is the width of the slant of the triangular standard piece.

3.2. Case of unequal-space

Similarly, figure 6 is used to assist explanation and it is divided into two cases:

1. All light stripes are parallel with each other, as shown in figure 6(a);
2. The \( j \)-th light stripes is not parallel other light stripes, as shown in figure 6(b).

\[
d_j = h_j \cdot \cot(\alpha)
\]

\[
(2)
\]

Where \( \alpha \) is the angle between the slant and horizontal plane of the triangular standard piece.
In the second case, the \( j \)-th light stripe intersects with the slant at point C and point D. The distances between two points and the \((j-1)\)-th light-stripe are \( p_j \) and \( q_j \), and their according vertical distances in light plane are \( s_j \) and \( t_j \) respectively as shown in figure 6(b). It can be obtained the following equation:

\[
d_j = 0.5 \cdot \left| p_j + q_j \right| = 0.5 \cdot \left| s_j + t_j \right| \cdot \cotg(\alpha)
\]

4. Compensation

During explaining the method, it is supposed that the number of light stripes in the probe is 8.

Firstly, it is necessary to select the appropriate scanning distance. From above analysis, it is concluded that the case of omitting-scan can be avoided if the maximum of all \( d_j \), \( p_j \) and \( q_j \) is selected as the scanning distance. It can be proved by figure 7.

Secondly, the obtained error data are used to compensate the 3D data which are collected by all light stripes and reconstructed. Supposing that the 3D data set obtained by the \( j \)-th light stripe is \( A_j \) (\( j=0\sim7 \)):

\[
A_j = \{(x,y,z)\}_j
\]

Supposing that the scanning direction is y, the coordinate \( y \) of points in dataset \( A_j \) are revised as (5):

\[
B_j = \{(x_B,y_B,z_B)\}_j = \left\{ x, y + \sum_{i=0}^{j} d_i, z \right\}_j
\]

In the equation, \( d_0 \) is considered as zero.

Thirdly, from figure 2(b), it is concluded that the coordinate \( y \) also must be revised as (6) in order to compensating the error introduced by un-parallelism:

\[
C_j = \{(x_C,y_C,z_C)\}_j = \left\{ x_B, y_B + x_B \cdot \tan\theta_j, z_B \right\}_j
\]

At last, all datasets \( C_j \) are combined to form an integral compensated 3D dataset \( D \):

\[
D = \bigcup_{j=0}^{7} C_j
\]

5. Example

In order to illustrate the performance of the method, it is applied to the multi-linear structured light measurement system in our laboratory. The triangular standard piece whose angle is 30° and width \( w \) is 35mm. The experiment results are listed in Table.1. According to these error data and the above
method, the 3D data of a toy-car scanned by the probe are compensated. The final point-cloud data is shown in figure 11.

Table 1. Experiment results ($j=0\sim7$, $\alpha=30^\circ$, $w=35\text{mm}$).

| $j$   | 1    | 2    | 3    | 4    | 5    | 6    | 7    |
|-------|------|------|------|------|------|------|------|
| $\Delta h_j$ (mm) | 11.84 | 11.37 | 11.76 | 11.54 | 11.88 | 11.62 | 11.35 |
| $\Delta d_j$ (mm) | 20.51 | 19.70 | 20.37 | 19.99 | 20.58 | 20.13 | 19.66 |
| $\Delta r_j$ (mm) | 0.32  | -0.67 | 0.14  | 0.22  | -0.45 | 0.26  | -0.03 |
| $\theta_j$ (degree) | 0.9   | -1.9  | 0.4   | 0.6   | -1.3  | 0.7   | 0.1   |

6. Conclusion

The presented method of error compensating for the multi-linear structured light probe eliminates the errors introduced by the un-equivalence and un-parallelism of light stripes. Due to the method is only based on a triangular standard piece, it is easy to be realized reliably, and the compensated 3D data are accurate.

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