A structured light image quality evaluation method based on no-reference quality assessment

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Abstract. Affected by noise, color, and light blocking, there are some large error data contained in the results of structured light 3D measurement. In the absence of effective criterion, the data can only be recognized artificially. In this paper, a criterion based on Human Vision System (HVS), which can be applied to recognize the large error data by evaluating the noise variance level of the stripe images, and a method used to improve the level of measurement accuracy are proposed. According to the proposed method, the no-reference quality assessment is used to evaluate the quality of stripe images. With the noise evaluation coefficient, the large error data can be identified automatically. The experimental results show that this method is efficient in detecting large error data in the stripe images.

1. Introduction
Structured light has been applied in the 3D measurement of object surface [1]. At present, the line structured light with Gaussian distribution, sinusoidal distribution and rectangular distribution are applied in measurement [2-4]. Compared with the traditional contact measurement method, the stripes are more efficiency and reliability [5]. However, the image quality of the stripes will be deteriorated if the stripes were disturbed by the random noise, curvature and reflectivity of object deformation [6]. The degradation leads to a certain number of large error parts, which will reduce the measurement accuracy [7].

Some studies have been conducted on improve the accuracy in measuring. Steger et al. proposed a high-precision method purposed to extract the stripe edge. The profile of the stripe was analyzed using the explicit model of the strips [8]. Zhou proposed an algorithm based on hybrid image processing method for the stripe, which reduced the redundant calculation of stripe extraction and achieved high-precision extraction [9]. Although the above method improves the accuracy of stripe measurement, there are still large error data in the measurement result. Moreover, these methods do not adopt appropriate objective discriminant methods, so the large error data cannot be identified or eliminated from the result. In this paper, a method based on no-reference quality assessment [10] is proposed to identify large error data in stripe images.
This paper is organized as follows. In Section 2, an introduction is made of the no-reference image quality assessment method. In Section 3, the simulation results and the experimental results in the actual measurement scene are listed to validate the method. The conclusion is indicated in Section 4.

2. No-reference image quality assessment

In structured light measurement, the random noise results the deformation and blur of the stripe, which lead to image quality degradation and reduce the stripe measurement accuracy. This paper proposes a method for the evaluation of the stripe images.

2.1. Noise evaluation coefficient

Most methods evaluate the image quality by comparing the original image with the processed image. There is no original image or the efficiency of obtaining the original image is very low for reference [10]. Considering this, the evaluation of noise level must be incorporated into the standard of image quality evaluation. Based on the Human Visual System (HVS), this paper proposed an image block of interest to replace the whole image with local variance [11] to identify the large error data and evaluate the quality of the stripe image. The flow chart is shown in Figure 2.

\begin{align}
\sigma(b) &= \sum_{(i,j)} \sigma(i, j) \\
\end{align}

Set threshold $T = \lambda \times \sigma(b)_{\text{max}}$. $\lambda$ is the sensitive parameter of HVS, and $\lambda \in (0, 1)$. $\sigma(b)_{\text{max}}$ denotes the maximum value of the sum of variances of all areas. Let $f_k = \{ f_k \mid \sigma(b) > T, k < B \}$.
where \( f_k \) represents the selected image block areas. \( k \) is referred to as the number of the selected areas.

A characteristic shown by the HVS is that the number of selected areas is in inverse proportion to the size of sensitivity coefficient. The selected block areas have to be blurred by a low-pass filter. With an image block area \( f_k \) exemplified, the process is detailed as follows.

Put the area \( f_k \) in filter vertically and horizontally to obtain the corresponding blurred image block \( b_v \) and \( b_h \). \( h_v \) and \( h_h \) is the vertical and horizontal model of the filter. The vertical filter \( h_v \) is \( \frac{1}{9} \times [111111111] \), and the horizontal one is \( h_h = (h_v)^T = h_v \).

Then, the absolute errors of the vertical and horizontal directions of the area are calculated and recorded as \( Df_v \), \( Df_h \), \( Db_v \) and \( Db_h \). Absolute error is the absolute of the pixel difference in the vertical (or horizontal) direction of the area. \( V_v \) and \( V_h \) are the difference before and after the area filtering, which are shown in equation (2) and equation (3).

\[
V_v = \max(0, Df_v(i, j) - Db_v(i, j)) \quad (2)
\]
\[
V_h = \max(0, Df_h(i, j) - Db_h(i, j)) \quad (3)
\]

In order to reflect the overall difference content of the area, the absolute errors \( Df_v \), \( Df_h \), \( Db_v \) and \( Db_h \) of the area are added respectively to obtain the regional differences of the whole area, corresponding to \( sf_v \), \( sf_h \), \( sV_v \) and \( sV_h \).

For comparing the noise level, the results are normalized to \([0,1]\): \( bf_v = \frac{sf_v - sV_v}{sf_v} \) \( (4) \)

\[
bf_h = \frac{sf_h - sV_h}{sf_h} \quad (5)
\]

Finally, every selected block area is processed by the method, and the average values of \( bf_v \) and \( bf_h \) are \( \overline{bf_v} \) and \( \overline{bf_h} \). The greater values in horizontal and vertical directions are treated as \( H \):

\[
H = \max(\overline{bf_v}, \overline{bf_h}) \quad (6)
\]

Where \( H \in [0,1] \). The larger the noise variance, the higher the image quality evaluation coefficient.

3. The result and analysis of simulation experiment

A series of simulations and experiments were carried out to verify the method. The simulation of the improved algorithm is on a computer with Windows 10 operating system, and the simulation software is Matlab 2009a. The \( H \) in simulation and experiment are the average value of \( H \) after processing the image 30 times.

3.1. Simulation Results

Figure 3 shows that the images adding Gaussian noise with different variance. And the images are respectively evaluated by the method. (The size of each block area is 24x24) The noise situation and the evaluation coefficient of Figure 3 (a), (b), (c) and (d) are shown in Table 1.
Figure 3. Simulation stripe images with Gaussian white noise.

Table 1. Influence of different degrees of random noise on image quality evaluation parameters.

| Images in Figure 3 | (a) | (b) | (c) | (d) |
|-------------------|-----|-----|-----|-----|
| Variance of noise | 0   | 0.01| 0.05| 0.1 |
| Image quality evaluation coefficient H | 0.3452 | 0.5495 | 0.5977 | 0.6341 |

It can be seen from above that the feedback of large noisy error image is obvious when the variance of noise increases falls into a certain range. The larger the noise variance, the higher the image quality evaluation coefficient.

3.2. Experimental results and analysis

Figure 4 shows the experimental environment and instruments used in the experiment.

Figure 4. The experimental environment

Figure 5 shows the experimental measurement images with the brightness decreasing areas of the stripe image projected on the bearing steel ball. Table 2 shows the evaluation coefficients of (b), (c) and (d). It can be seen from the Figure 5 that the change in evaluation coefficient is relatively notable when the stripe feature undergoes degradation.
Figure 5. Measurement of steel ball by projected stripes.

Table 2. Influence of stripes deterioration on H.

| Images in Figure 5 | (b) | (c) | (d) |
|--------------------|-----|-----|-----|
| Image quality evaluation coefficient H | 0.3686 | 0.5196 | 0.7316 |

4. Conclusions
In order to improve the accuracy of structured light three-dimensional measurement system, this paper proposes a high-efficiency and relatively stable large error data identification method. It depends on the no-reference quality evaluation coefficient to evaluate the quality of the stripe image. Firstly, the image is isolated into blocks. Secondly, the sensitivity coefficient of HVS is set to select some areas from the image. Then the noise variances of the selected regions are estimated. Finally, the image quality is evaluated according to the estimation results. According to the evaluation coefficient given by the algorithm, the quality of stripe images is determined. The large error data can be effectively identified by this method. It can be seen from the experimental results that the method is capable to meet the design expectation, and it is effective in identifying and screening large error images through the estimate of noise variance level. In the future, the large error data selected will be corrected to meet the expected accuracy requirements.

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