High Resolution Measurement of Luminous Marker Position by Image Processing

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Abstract
We have been developing the three-dimensional measurement system using the camera image. This system is used a similar technique of the motion capture. In this measurement, the several markers are attached at the measured object and the luminous points in camera image are traced. The advantage of this measurement system is that the non-contact measurement and three-dimensional measurement is possible. In our three-dimensional measurement system, the measured target is the high brightness LED marker. The 3D position of the LED marker is calculated with the 2D positions in the camera screen coordinate. The LED marker in the camera image exists on some pixels, the position of the LED marker in the camera image is given by the luminance distribution of them. The position of the luminous point is obtained as the gravity center of light intensity, and the sub-pixel resolution is achieved. In this study, the influences of luminous marker conditions and calculation conditions on the measurement precision are investigated.

Key words: Three-dimensional Measurement, LED Marker, Center of Gravity, Luminous Distribution, Light Intensity, Sub-pixel Resolution

1. Introduction

In order to evaluate the earthquake protection on the structural object, the experiment such as the vibration testing of the small-scale model and the simulated on the computer is conducted. But only these experiments, the researcher can’t get enough data on vibration behavior of the structure. Thus, the vibration testing of the real-scale structure was attracted attention. Because of this factor, the 3-D full-scale earthquake testing facility nicknamed "E-defense" has built in Kobe. We have been developing the three-dimensional measurement system, and a target of it is to measure the vibration behavior of the structure from full-scale vibration testing (1)(2)(3)(4). In measuring the full-scale testing, it is expected to be designed as non-contact measurement system, and be able to measure the displacement of three-direction of many points. One of the measurement methods that fulfill these needs is stereo image measurement. Stereo image measurement by triangulation method is used extensively for measurement using image processing. However, this measurement method has the problem that it is difficult to determine the target position on each camera image. Therefore, our measurement system is used the LED marker for measured target. The accuracy of measurement on the image by this method is above the pixel resolution. In this paper, the influences of luminous marker conditions(size, light-intensity, background) and calculation conditions(thresh level, noise-reduction method) on the measurement precision are investigated in detail.
2. Theory of Three-Dimensional Measurement

Three-dimensional measurement by stereo images is used more than two cameras, and the three-dimensional position of measured target is determined from the target position on each camera image. Figure 1 shows the relationship between the position of measured target in the global coordinate and it in the camera screen. The notation p(x,y,z) indicates the position of measured target in the three-dimensional coordinate, and P(X,Y) indicates the position in the two-dimensional camera image coordinate. In case of i-th camera, the relationship of p(x,y,z) and P_i(X_i,Y_i) is expressed, as followings,

\[
\begin{align*}
C_{i11}x + C_{i12}y + C_{i13}z &= X \\
C_{i21}x + C_{i22}y + C_{i23}z &= Y
\end{align*}
\]

(1)

Here, \(C_{ijk}\) describe the camera parameters of i-th camera. The linear parameters \(C_{ijk}\) denote the camera position, viewing direction, focal length and the aspect ratio of pixel. After the camera parameter is determined by camera calibration, the target position p(x,y,z) in the three-dimensional coordinate can be derived from target position P_i(X_i,Y_i) in the two-dimensional coordinate by equation (1). p(x,y,z) is each camera’s extension of the line between the projection center and P_i(X_i,Y_i). It means p(x,y,z) is obtained by intersection of these lines.

![Fig.1 Relationship between global coordinate and camera coordinate](image)

3. Method of Sub-Pixel displacement Measurement

In order to determine the measured target position and camera parameter, the exact measurement of P(X,Y) in the camera image is necessary. However, there is a limit in the pixel resolution of camera image. Therefore, the determination of P(X,Y) with the sub-pixel order is required. In our research, the target is LED light because of the easy detection in camera image. The position of target P(X,Y) is determined by the gravity center calculation of partial image and obtained the sub-pixel resolution. The size of the partial image (w, and h) is larger than target light size. The distributions of vertical and horizontal light intensity are expressed as followings,

\[
\begin{align*}
f_x(i) &= \sum_{p=1}^{w} f(i,p) \\
f_y(j) &= \sum_{p=1}^{h} f(p,j)
\end{align*}
\]

(2)

Where f(i,j) indicate the light intensity of pixel at (i, j) position in partial image. Figure 2 shows a partial image and its distributions of vertical and horizontal light intensity. However, \(f_x(i)\) and \(f_y(j)\) means total summation of light intensity of pixel, and they include
the background image and noise. To get the target light position and reduce the influence of background and noise, the noise reduction process is adopted as followings,

\[ \tilde{f}_i(i) = \sum_{p=1}^{n} f(i, p) \cdot \delta(f(i, p) - \text{threshold}) \]

\[ \tilde{f}_j(j) = \sum_{p=1}^{n} f(p, j) \cdot \delta(f(p, j) - \text{threshold}) \]

\[ \delta(u) = \begin{cases} 1 & (\text{if } u \geq 0) \\ 0 & \text{(otherwise)} \end{cases} \]

Where \( \tilde{f}_i(i) \) and \( \tilde{f}_j(j) \) indicate vertical and horizontal light intensity without noise. The notation of \( \text{threshold} \) means boundary between the signal and noise values. The gravity center \( G(X, Y) \) of the target light is calculated by the following relations,

\[ X = \frac{\sum_{i=1}^{n} i \cdot f_i(i)}{\sum_{i=1}^{n} f_i(i)} \]
\[ Y = \frac{\sum_{j=1}^{n} j \cdot f_j(j)}{\sum_{j=1}^{n} f_j(j)} \]

The gravity center \( G(X, Y) \) corresponds the target position \( P(X, Y) \).

4. Computer Simulation and Experiment for Evaluation of Sub-pixel Displacement Measurement

4.1 Preparation of target and image detection

Five kinds of target markers with LED light are prepared as shown in Fig. 3. These targets are put on the plate and it is moved with the linear actuator. The image of the moved targets is captured by a high speed digital camera. Figure 4 shows the linear actuator with targets and high speed digital camera. The several cases of image capture are carried out for the different distance between the targets and camera, 2.0m, 3.0m, 4.0m, 5.0m 6.0m, and 7.0m. Figure 5 shows the partial image of the targets. The resolution of image is mega-pixel (1024 x 992) and each pixel is 8 bits resolution monochrome data. The capture speed is 100 frames per second and the experiments are carried out for about 30 second. The movement of the linear actuator is controlled precisely as shown in Fig. 6. The targets are given the small displacements after large displacement. At first, the targets are transferred 100mm. After that, the targets are given the small displacements, 0.1mm, 0.2mm, 0.4mm, 0.6mm, 0.8mm and 1.6mm.
4.2 Computer simulation

The partial image including the LED marker is used to this simulation. The size of partial image is 16 x 16 pixels. The image that moved to sub-pixel is created by the linear interpolation method. The luminance value of each pixel by interpolation is calculated according to the following equation,

\[ f'(i) = f(i) \cdot (1 - d) + f(i-1) \cdot d \]  

(5)

Here, \( f(i) \) indicates the luminance value of i-th pixel for interpolation. The notation of \( d \) indicates the value of displacement within 1-pixel. Figure 7 shows the partial image that is moved by linear interpolation.

In this simulation, the image is moved twenty times within 1-pixel. Therefore, the ideal displacement by calculation of one time is 0.05 pixels. Figure 8 show the displacement of LED marker by gravity center calculation method and the ideal displacement. These Figures are simulated from same LED marker as (e) in Fig.3. The differences of these Figures are the threshold calculating the gravity center of LED marker and the distance from camera. The error value of the center gravity calculation method is increased by using a smaller LED marker for the calculation target.
4.3 Experimental results

The results of experiment are shown in Figure 9. In these figures, the points of each denote the mean position of the LED marker while the linear actuator is not controlled and moved. The line denotes the theoretical value which is calculated from the ratio of actual movement and displacement in the image. The 0 start position of displacement in the image is normalized after the actuator is moved at 100.0mm. The different types of marker indicate the distance between the target LED marker and camera. Threshold is 50 among these figures. The table 1, 2, 3 and 4 show the error value of measurement in each different condition. The highest error is occurred by marker (a) in table 3. This marker is one of the smallest markers on camera image. And, the lowest error is marker (d) in table 2. This marker is one of the largest markers on camera image, too.
Fig. 9 Displacement on the image and actual movement of linear actuator for each maker

<table>
<thead>
<tr>
<th>Table 1</th>
<th>The error value (Distance : 2m threshold : 50)</th>
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</thead>
<tbody>
<tr>
<td>Marker (a)</td>
<td>Marker (b)</td>
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<tr>
<td>Max. Error</td>
<td>0.0694</td>
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<tr>
<td>Ave. Error</td>
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<tr>
<td>RMS Error</td>
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<th>The error value (Distance : 2m threshold : 60)</th>
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<tr>
<td>Marker (a)</td>
<td>Marker (b)</td>
</tr>
<tr>
<td>Max. Error</td>
<td>0.0793</td>
</tr>
<tr>
<td>Ave. Error</td>
<td>0.0446</td>
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<tr>
<td>RMS Error</td>
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<tr>
<th>Table 3</th>
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<td>Marker (a)</td>
<td>Marker (b)</td>
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<tr>
<td>Max. Error</td>
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<td>Ave. Error</td>
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<td>RMS Error</td>
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<th>Table 4</th>
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<td>Marker (a)</td>
<td>Marker (b)</td>
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<td>Max. Error</td>
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<td>Ave. Error</td>
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<tr>
<td>RMS Error</td>
<td>0.0364</td>
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5. Conclusion

This study has been carried out the research and development of the three-dimensional measurement system using image processing. This paper describes results of the computer simulation and the experiment for the accuracy evaluation of the measurement using LED marker. In this experiment, the effect of the marker conditions such as size and light intensity on the accuracy and resolution power of measurement is investigated.

As a result of this experiment, it is confirmed that the size of LED marker in the camera image influences the accuracy of the measurement. When the diameter of image of LED marker is a few pixels, the error of measurement is largest. The larger marker size leads the better accuracy of measurement. These results are confirmed in experiments as well as computer simulations. In the case that LED light intensity is strong enough and image of LED has halation, also noticeable error of measurement is appeared.

References


