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Vibration Measurement using Digital Image Correlation Method: A Depth Estimation with Linear Regression Models

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1. Introduction

Ultrasonic devices are widely used for measurements, imaging and detecting. Several applications have been also studied.[1,2] Here, the ultrasonic transducers usually need to contact on an object surface, and the applications also need multiple transducers for array. These may prevent the use of ultrasonic devices.

This paper discusses a non-contact vibration distribution measurement method by capturing a 2D image with a single camera. The vibration is measured from the depth data of an object surface. Depth measurement techniques using 2D images have been studied that named a Digital Image Correlation (DIC) method.[3,4] Author has applied the depth measurement techniques to a vibration distribution measurement that named a DIC with Projected-light-pattern (DICP) method.[5] For the vibration measurement, the depth data of an object surface is consecutively measured such as rapid shooting. A random dots pattern is projected and an image correlation method with a sub-pixel image correlation technique is used for the DICP method.

Here, at ideal measurement conditions, the depth can be calculated from a linear equation. However, the depth calculation has non-linearity on actual measurements.

Vibration measurements usually needs accurate depth measurement. Then, author applies A Linear Regression (LR) model to depth calculations. The depth is calculated by using a weight vector which is obtained from training depth data. The depth estimation will correspond to actual measurement conditions.

This paper reports a depth measurement and vibration measurement using the DICP method with the LR model depth estimation.

2. Method

2.1 Vibration measurement method

Vibration is measured from the depth data of an object surface which are consecutively measured, and the depth is measured with a projected light pattern.[5]

The depth is calculated from 2D image correlation techniques. A Normalized-Cross-Correlation (NCC) is used as follows

$$C = 1 - \frac{\sum_{i=-d}^{d}\sum_{j=-d}^{d} I_{\mathrm{r}}(x_{\mathrm{r}}+i, y_{\mathrm{r}}+j) I_{\mathrm{m}}(x_{\mathrm{m}}+i, y_{\mathrm{m}}+j)}{\sqrt{\sum_{i=-d}^{d}\sum_{j=-d}^{d} I_{\mathrm{r}}(x_{\mathrm{r}}+i, y_{\mathrm{r}}+j)^2 \sum_{i=-d}^{d}\sum_{j=-d}^{d} I_{\mathrm{m}}(x_{\mathrm{m}}+i, y_{\mathrm{m}}+j)^2}}. \quad (1)$$

Where, I_{r} and I_{m} are the brightness at the pixel coordinate (x, y) on each images, d denotes the region of the correlation. Seeking the least correlation value C denotes the reference image pixel coordinate (x_{r}, y_{r}) corresponding to the measured image pixel coordinate (x_{m}, y_{m}). Moreover, for a sub-pixel image correlation, a Newton-Raphson (NR) method is used. Affine transformation parameters $\boldsymbol{a}$, which are used for the 2D image at the NCC, are calculated the sequential process as follows

$$\boldsymbol{a}^{(\mathrm{new})} = \boldsymbol{a}^{(\mathrm{old})} - \nabla\nabla C(\boldsymbol{a})^{-1} \nabla C(\boldsymbol{a}). \quad (2)$$

At ideal measurement conditions, depths can be calculated from a linear equation, which consists of the reference image pixel coordinates corresponding to the measured image pixel coordinate. However, depth calculations have non-linearity on actual measurements.

2.2 Depth estimation method

A Linear Regression (LR) model is used for the depth estimation corresponding to non-linearity. The depth $d(z, \boldsymbol{w})$ is calculated from M parameters as follows

$$d(\boldsymbol{z}, \boldsymbol{w}) = \sum_{j=0}^{M-1} w_j \varphi_j(\boldsymbol{z}). \quad (3)$$

Where, $\boldsymbol{z}$ is the input vector, $\boldsymbol{w}$ is the weight vector, and $\varphi_{\mathrm{j}}(z)$ is a basis function.

The weight vector is optimized from the posterior probability of $\boldsymbol{w}$ as follows

$$p(\boldsymbol{w}|\boldsymbol{t}, \boldsymbol{Z}, \alpha, \beta) \propto p(\boldsymbol{t}|\boldsymbol{Z}, w, \beta) p(\boldsymbol{w}|\alpha). \quad (4)$$

Where, α and β are hyperparameters, and $\boldsymbol{t}$ is the training data vector of depths. The posterior probability is proportion to the multiplication of the likelihood function and the prior probability. The probabilities are assumed as a gaussian distribution.

3. Experimental condition

A projector illuminates an object with a random dots pattern to obtain higher correlation images, and a camera captures the 2D images. **Figure 1** shows an arrangement for the range estimation process. The flat board is used for depth

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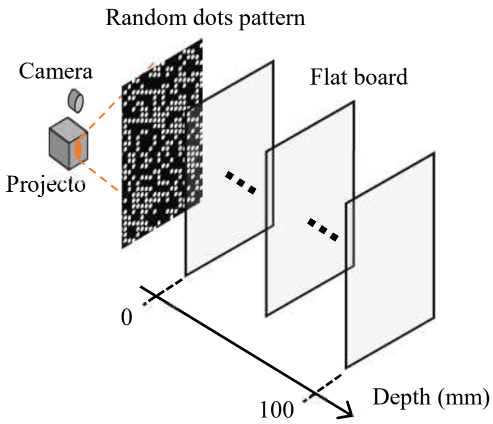

Fig.1 An arrangement for the range estimation process.

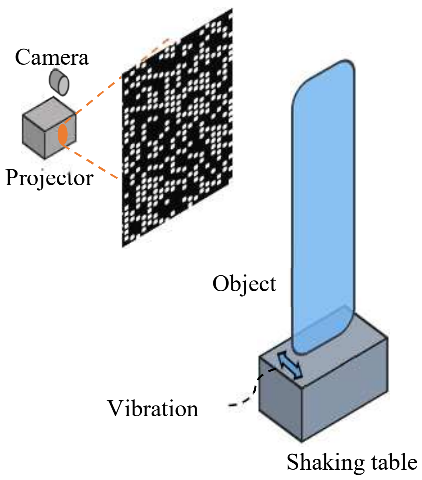

Fig. 2 A vibration measurement arrangement

training data measurements and is located at 0 to 100 mm with 20mm intervals. **Figure 2** shows an arrangement for vibration measurements. The shaking table vibrates the object (flat board) and controls the vibration width (20 mm) and the frequency (1.0 Hz).

The range estimation method is compared with a linear equation method. The depth using the linear equation is calculated from the reference images which are captured when the flat board is located at 0 and 100 mm.

4. Results

Figure 3 shows the range estimation results. The depths using the linear equation had more than 3.5 mm errors at the conditions when the depths were distant from the reference images location. In contrast, the depth estimation reduced the depth errors which were 1.2 mm at most.

Figure 4 shows the vibration measurement result. The depth estimation led to more accurate vibration width.

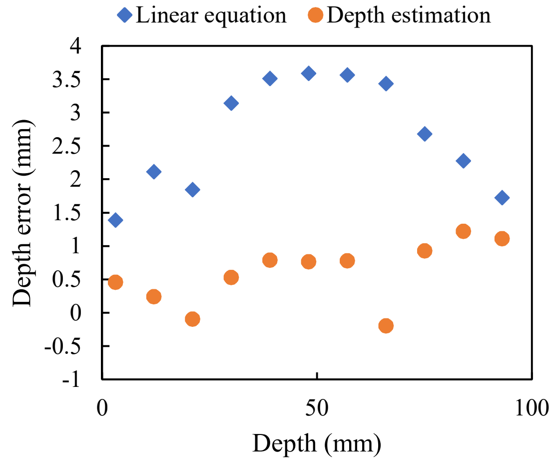

Fig. 3 Depth measurement examples

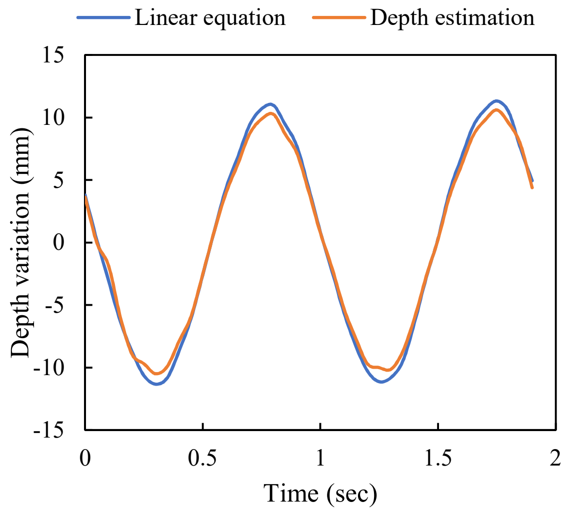

Fig. 4 A vibration measurement example

5. Conclusion

This paper reported an image correlation technique with a depth estimation method for an accurate vibration measurement. The depth estimation using an LR model reduced the depth measurement errors and led to more accurate vibration measurements.

References

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