3Pb2-2

Basic Study on Vibration Measurement Using Digital Image Correlation Method with Projected Light Pattern

パターン投影型デジタル画像相関法を用いた振動分布計測に関する基礎検討

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1. Introduction

Ultrasonic testings (UT) for infrastructure have widely been studied.[1,2] This paper focuses on a vibration measurement method based on depth measurement techniques using a 2D image.

The depth measurement techniques usig fringe pattern projection have been sutdied for 3D mapping.[3] These depth measurement techniques usually need Plural 2D images for the 3D mapping, and thus are not suitable for vibration measuremet. In contrast, for displacement and distortion measurement, Digital Image Correlation (DIC) methods have been studied.[4] The DIC method needs to spread a random pattern on an ofject surface, for example, spray is used to paint the random pattern.

Applying pattern projection to the DIC method will be suitable for vibration mesurement and be easy-to-use. This paper reports a initial examination on the vibration measurement using the DIC method with projecting light pattern.

2. Method

2.1 Vibration measurement method

The vibration measurement consists of a depth measurement with a projected light pattern. Fig. 1 shows the schematic image of the depth measurement with a ray of light. The lay of light is captured at the pixel position corresponding to the target depth. The depth can be calculated form the pixel positions and reference range R_0 as follows

$$R_\mathrm{m} = \frac{P_0 - P_\mathrm{m}}{P_0 - P_1} R_0 \,. \qquad (1)$$

Where, R_m is the measured depth, P_0 and P_1 are the pixel positions with the reference measurement conditions and P_m is the pixel position with the object measurement condition.

The vibration (displacement of depth) at a pixel can be measured by measuring the depth continuously.

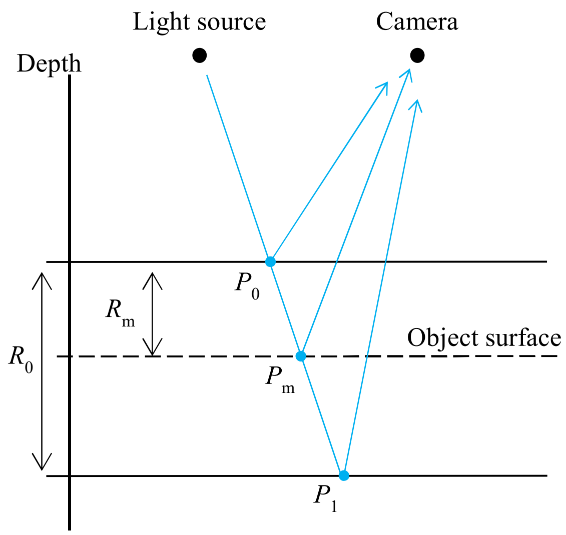

Fig. 1 Schematic image of the depth measurement

2.2 Digital image correlation for projecting light pattern

For the depth measurement, a correlation method is used. Normalized-Cross-Correlation (NCC) between the reference and the measured 2D images is used as follows

$$C = 1 - \frac{\sum_{i=-d}^{d}\sum_{j=-d}^{d} I_0(x_0+i, y_0+j) I_\mathrm{m}(x_\mathrm{m}+i, y_\mathrm{m}+j)}{\sqrt{\sum_{i=-d}^{d}\sum_{j=-d}^{d} I_0(x_0+i, y_0+j)^2 \sum_{i=-d}^{d}\sum_{j=-d}^{d} I_\mathrm{m}(x_\mathrm{m}+i, y_\mathrm{m}+j)^2}} \,. \qquad (2)$$

Where, I_0 and I_m are the brightness at the pixel position (x, y) on each images, d denotes the region of the correlation.

Moreover, for a sub-pixel estimation, Newton-Raphson (NR) method is used. For the NR method, a parameter vector $\boldsymbol{w}$ is used. The pixel position can be derived by the linear combination of $\boldsymbol{w}$ that assuming affine transformation. Then $\boldsymbol{w}$ is derived by the iterative calculation as follows

$$\boldsymbol{w}^{(\mathrm{new})} = \boldsymbol{w}^{(\mathrm{old})} - \nabla\nabla C(\boldsymbol{w})^{-1} \nabla C(\boldsymbol{w}) \,. \qquad (3)$$

Here, the brightness interpolation on the sub-pixel estimation is derived by bicubic interpolation.

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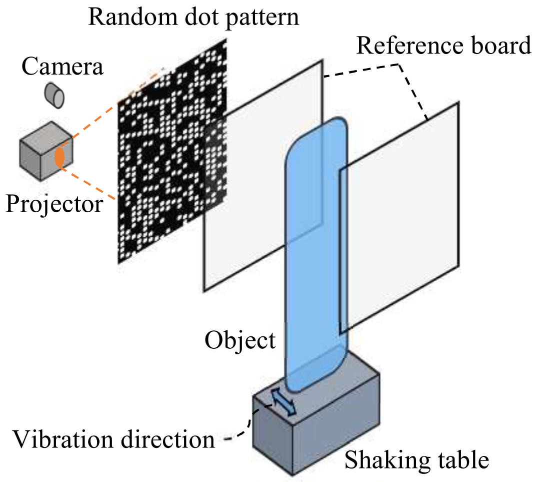
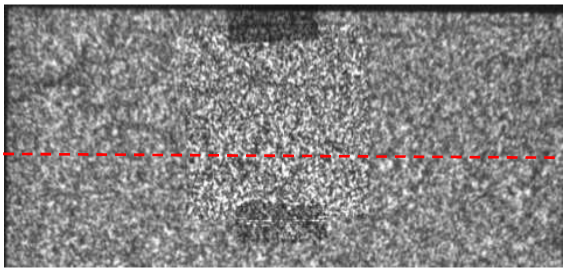
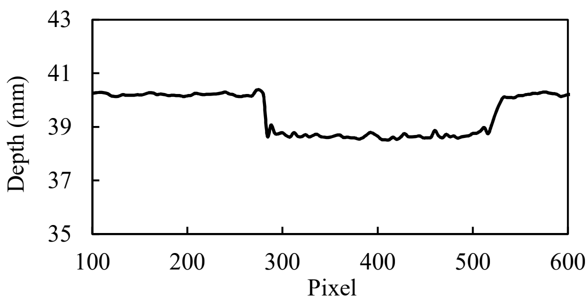


Fig. 2 Arrangement for the measurement



(a) Captured 2D image for depth measurement



(b) Depth at the dashed line

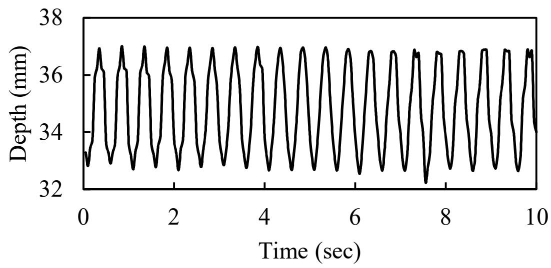
Fig. 3 depth measurement example

3. Experimental condition

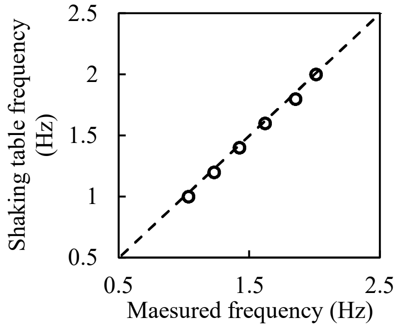
Fig. 2 shows the arrangement for the measurement. The projector illuminates an object with a random light pattern to obtain higher correlation images. Two reference images are captured for the depth measurement. A flat board is located for each reference image capturing. Here, the depth between the flat board locations is 50 mm.

As the example of a depth measurement, an unevenness object is measured. The object has a depth difference with 1 mm.

For the vibration measurement, the shaking table vibrates the object (flat board) and controls the vibration width (4.0 mm) and the frequency (1.0 to 2.0 Hz).



(a) Time domain depth variation example



(b) Relation between measured frequencies and shaking table frequencies

Fig. 4 Vibration measurement

4. Results

Fig. 3 shows the example of the depth measurement. For the captured image, the object is illuminated with the random pattern. The captured image is correlated with the reference image. The depth measurement example shows the depth difference clearly.

Fig. 4 shows the vibration measurement. The example of the measured depth on time domain shows the depth variation corresponding to the time domain. The principal frequency derived from the spectrum is 2.01 Hz. This result agrees well with the shaking table frequency (2.0 Hz). The relation between the measured frequencies and the shaking table frequencies is also suitable.

5. Conclusion

In this study, the vibration measurement using the Digital Image Correlation method with projected light pattern were conducted. Then the vibration was successfully measured. Using this method for Ultrasonic testing on infrastructure will be expected.

References

1. K. Sugimoto, T. Sugimoto, N. Utagawa and C. Kuroda: Jpn. J. Appl. Phys., **58** (2019) SGGB15.
2. Y. Ohara, H. Nakajima, S. Haupert, T. Tsuji and T. Mihara: Jpn. J. Appl. Phys., **59** (2020) SKKB01.
3. L. Yong, H. Dingfa and J. Yong: Appl. Opt., **51** (2012) p. 4945.
4. M. Malesa and M. Kujawinska: Appl. Opt., **52** (2013) p. 4681.