Vibration measurement of large-scale mechanical structures using phase-locked loop imaging and marker tracking

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Vibration testing is an effective method for studying structural dynamics; it is an important step in the product development cycle. To evaluate vibration characteristics, discrete measurement points should be specified in a space where the vibration shape of the target mechanical structure can be defined. For large-scale structures in particular, an increase in the number of measurement points requires time-consuming experimental preparation for the sensors, wiring, and other elements. In this regard, a non-contact system capable of simultaneously measuring multiple points reduces the number of work-hours required for experiments and obviating changes in the vibration characteristics of the structure; such a system is expected to contribute to more efficient machine design and development. A high-speed camera is a non-contact type of sensor that can measure multiple points simultaneously, but it is difficult to achieve both the required sampling frequency (related to frame rate (fps)) and measurement resolution (related to the number of pixels). Furthermore, its installation cost is high.

In this study, we propose a digital image vibration measurement method for capturing vibration of large-scale structures, coupled with a filming system based on phase-locked loop (PLL), and marker tracking method for sub-pixel resolution. The proposed system consists of a digital single-lens camera, strobe, hydraulic shaker, and function generator, all controlled by a signal-processing device, as shown in Fig. 1. The hydraulic shaker is used to apply steady-state vibration to the construction machinery under test. The response is a sine wave with a phase delay relative to the input wave; the input and response are time-invariant and periodic. When this assumption is satisfied, the strobe effect and PLL methods that are used in fluid engineering may be utilized as measurement methods using a low-frame-rate camera. This system can perform measurements for periodic phenomena at high spatial and temporal resolutions.

The position-adjusted subset tracking analysis (PASTA) method was used as the sub-pixel processing method. The PASTA method calculates displacement by using the edges of circular markers as tracking targets, and requires only the application of stickers to a test structure. Displacement is based on the change in luminance of a subset of the edges. Therefore, PASTA is a low-cost and highly accurate method to calculate displacements from images, provided that the requirements for stability of the light source and other conditions are met.

Tests were conducted on a hydraulic excavator to verify validity. We confirmed that a displacement of approximately 0.2 mm could be measured, as shown in Fig. 2, within an imaging area of approximately 1.4 m × 2.2 m.

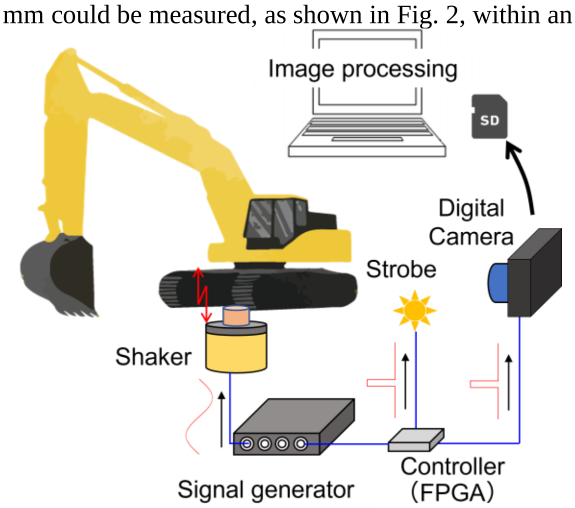

Fig.1 Illustration of filming using phase-locked loop

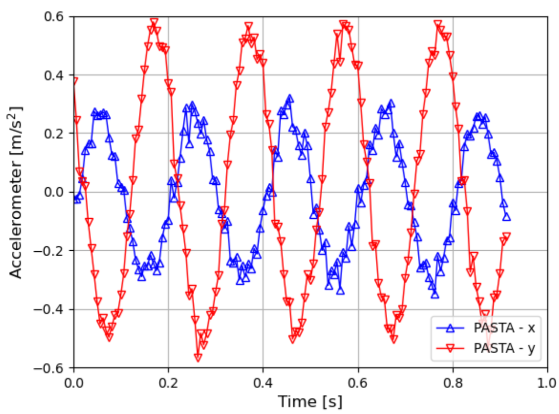

Fig.2 Acceleration data at 5 Hz using the proposed method