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Original Article

VIBRATION DISPLACEMENT MEASUREMENT TECHNOLOGY FOR CYLINDRICAL STRUCTURES USING CAMERA IMAGES

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ABSTRACT

Acceleration sensors are usually used to measure the vibration of a structure. Although this is the most accurate method, it cannot be used remotely because these are contact-type sensors. This makes measurement difficult in areas that cannot be easily approached by surveyors, such as structures located in high or dangerous areas. Therefore, a method that can measure the structural vibration without installing sensors is required for the vibration measurement of structures located in these areas. Many conventional studies have been carried out on non–contact-type vibration measurement methods using cameras. However, they have been applied to structures with relatively large vibration displacements such as buildings or bridges, and since most of them use targets, people still have to approach the structure to install the targets. Therefore, a new method is required to supplement the weaknesses of the conventional methods. In this paper, a method is proposed to measure vibration displacements remotely using a camera without having to approach the structure. Furthermore, an estimation method for the measurement resolution and measurement error is proposed for the vibration displacement of a cylindrical structure measured using the proposed measurement method. The proposed methods are described, along with experimental results that verify their accuracy.

1. Introduction

Contact-type acceleration sensors are usually used for vibration measurement of structures. However, because contact-type sensors need to be directly attached to the structure, approaching the structure is necessary, and consequently, much time and expense are required when measuring a structure that is difficult to approach or located in a dangerous area such as a high-temperature/high-pressure structure and high radiation area in nuclear power plants. Therefore, a remote measurement method is required for measuring the vibration of structures in areas that are difficult to approach.

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Accordingly, along with the rapid advancement of camera hardware, many studies have been carried out on vibration measurement using cameras in recent years [1–6]. Although the measurement resolutions and sampling speeds of methods using cameras are lower than those of sensor measurement methods, they have the great advantage that remote and simultaneous multipoint measurements are possible. Therefore, many studies have been conducted on relatively large structures that have low frequencies and large vibration displacements such as bridges and buildings. However, most of the conventional methods use targets, and in general, the measurement resolution is constrained by the camera resolution. Furthermore, these methods have a disadvantage, where measurement is impossible, when the structure is difficult to approach by surveyors because these methods require the installation of targets such as contact sensors on the object being measured. Recently, a vibration measurement method using the edges of a structure was proposed, but the error range of the measurement signals and the measurement resolutions could not be accurately determined, and the measurement environment had an influence on the image noise [6].

In this paper, a remote vibration displacement measurement method is proposed that uses an improved edge detection method and a camera. The proposed method uses the second derivative of an image and has a measurement resolution equal to the pixel resolution, or higher. This method has the advantage that multipoint measurement is possible. In addition, we propose a method for estimating the measurement resolution and error range when measuring the vibration displacement of a cylindrical structure.

2. Vibration displacement measurement method using cameras

The single pixel value of a grayscale image is determined by the brightness value (0~255), which depends on the amount of light received by the image sensor. This value can be defined as the brightness value of a two-dimensional area transmitted from the photographed area of the subject to the image sensor through the optical lens. Measuring the vibration displacement of a subject begins with the movement detection of a specific point on the subject. The measurement point can be a mark specified by a user or an edge of the subject. Conventional image processing methods for edge detection include Laplacian, Sobel, and Canny edge detectors [7]. These methods determine the edge pixel as the pixel having a strong edge component in the image using the first or second derivatives. Conventional vibration measurement methods using cameras detect the edge and monitor its variation rate using one of these image processing methods. However, the edge coordinates determined through the image processing technique introduced earlier are approximated integer-type pixel coordinate values. Therefore, if a regular image processing technique is used to measure the vibration displacement, a large error will be inherent. To obtain the coordinates of the actual edges of the vibration-displacement measurement subject, they should be expressed as real number-type coordinate values instead of approximated integer-type coordinate values. Therefore, instead of conventional image processing techniques, an improved real-number-type edge detection method is required.

2.1. Basic theory

In an image, the boundary between the subject and background is not perfectly distinguished, as in reality. In most cases, the brightness value of the edge area, which is the boundary between the subject and background in the image, does not change radically, but changes gradually. This is because of image resolution problems and blurring.

After acquiring continuous images of the vibrating structure, Fig. 1 shows the influence of the vibration on the brightness changes and brightness variation rates in the edge area. As shown in Fig. 1A, a vibration measurement point (edge area) with a size of 9 × 9 was selected from the whole image S (m × n size). Here, the edge is in the horizontal direction, whereas the subject vibrates in the vertical direction. In Fig. 1B, nine pixels in the vertical direction are selected arbitrarily, and the brightness changes in the time domain are shown in Fig. 1C. The brightness value changes of each pixel from pixel P0 to P8, which correspond to the edge area, were due to the vibration of the subject, and the changes appeared clearly at the boundary between the background and subject. Fig. 1D shows the brightness values of P0~P8 from the 38th and 70th frame images, which correspond to the vibration P-P. The vibration of the structure affected the images, and it can be seen that the brightness values in the edge area changed as a result of the vibration.

Fig. 2 shows the first and second derivative results in the edge area using a regular image processing technique. Most of the regular image processing techniques for determining the edge in an image use the first or second derivative.

The first derivative of an image determines the gradient between pixels by obtaining the differences in neighboring pixel values, as shown in Eq. (1). The conventional image processing techniques for detecting the edge using the first derivative include the Sobel, Prewitt, and Roberts methods [7].

$$G(x) = f(x-1,y) - f(x+1,y) \tag{1}$$

$$G(y) = f(x,y-1) - f(x,y+1)$$

where x is a vertical axis coordinate value of the image, y is the horizontal axis coordinate value, f is an input image, and g is a first derivative for f. In general, the edge detection method using the first derivative determines the integer-type pixel coordinate having the maximum derivative value as the edge. A method has been proposed whereby these values are expressed in the form of a Gaussian distribution, and by regarding it as a probability distribution and obtaining the center of mass value, the real number-type edge is determined [6]. However, it is difficult to accurately determine the edge area used in the calculation, and measurement error occurs if the calculation area is incorrectly determined.

The conventional methods for detecting edges using the second derivative, which reacts more sensitively to the edge, include the Laplacian and Laplacian of Gaussian [7,8].