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DEVELOPMENT OF SELF-CONTROLLABLE PROTABLE SHAKING TABLE TEST SYSTEM

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ABSTRACT

The scale of vibration is expressed by such measures as the acceleration and seismic intensity. However, it is not realistic for those who have no experiential sense for the scale of vibration. The intuitive understandings of vibration helps to foster the motivation to learn such the subjects as the earthquake disaster prevention, vibration and earthquake resistance in the department of civil engineering and the architecture. This paper introduces the portable shaking experiment device which is developed as a teaching material to support the intuitive understandings of the scale of vibration such as acceleration and seismic intensity. The feature of the shaking table is that it can be controlled in real time by moving the accelerometer. The shaking table follows the movements of the hand of the student who grabs the accelerometer.

Keywords: Portable shaking table; Teaching material; Intuitive understandings; Real time control

1. INTRODUCTION

A questionnaire survey to the students who have difficulties in the vibration engineering class at our college revealed the importance of the enhancement of understandings of the relation between the phenomenon of vibration and the related equation and the intuitive understanding of the strength of vibration such as the seismic intensity and acceleration (Tsujihara et al. 2014). Shaking table tests are considered to be effective to give the intuitive understandings in the subjects such as earthquake disaster prevention, vibration and earthquake resistance in the department of civil engineering and architecture. However, those systems are generally installed at higher education institutions and are mainly used for the purpose of research. The data of the vibration of the structure model on the shaking table are measured by the measuring device such as accelerometers and they are proceeded offline. It is not interested in to be frequently used in the classrooms. Therefore, the development of portable shaking table test systems which can be often used in the classrooms to demonstrate the phenomena of vibration is required.

Recently, some portable shaking tables have been developed which is easy to be carried to classrooms. The hand-turned type shaking table including some building models, which was developed by (Fukuwa et al. 2005), is commercially supplied at a low price. The motor-driven portable shaking table was also developed by (Fukuwa et al. 2005). They support the visual understandings about the phenomena of vibration. However, the functions to support the verification of the theory and the quantitative understandings of the scale of vibration are also required. (Tsujihara et al. 2014) developed the portable shaking table device which enabled real-time measurement of motions and the calculation of their seismic intensity and Fourier spectra. The values of seismic intensity and the graphs of waveform and Fourier spectra can be visualized in real time. (Tsujihara et al. 2015) developed the virtual portable vibration experiment device, in which the shaking table and structure

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models were built virtually in the computer display and the table was controlled in response to the movement of one's hand.

In this study, a new experimental system is developed as a teaching material which is easy to be carried. The system is composed of the devices such as actuator, motion controller, accelerometer and PC. The software is built with VB.NET. The feature of this system is that the shaking table attached to the actuator can be controlled in real time in response to the movement of the hand of the student who grabs the accelerometer. Students can get the body sensory information on the scale of vibration, since they generate vibrations by themselves. Prepared data set of vibrations can be also given and the actuator reproduces the waveforms. The structural model can be mounted on the shaking table. The waveforms of vibration of the structure model and the shaking table can be also shown in real time while processing the data sent from the sensors attached to them. The numerical data of the waveforms can be saved and used to validate the theory of vibration.

2. HARDWARE

The hardware is composed of motion controller, actuator and its driver, accelerometer, RS232 interface, RS232-USB conversion adapter and PC as shown in Figure 1. The accelerometer is used in controlling the actuator in real time in reply to the movement one's hand. Figure 2 shows PMC-S4/00/00A-U produced by Y2 co. ltd. and EASM6X-D020-ARAC produced by Oriental Motor co. ltd. used as the motion controller and the actuator, respectively. GID-SSS and GIS-SSS/IF232 produced by Mathematical Assist Design Laboratory used as the accelerometer and the serial communication interface, respectively. RS232-USB conversion adapter is the accessory of GIS-SSS/IF232. Figure 3 shows the accelerometer. Figure 4 shows the base with roller bearing on which the accelerometer is to be mounted. The accelerometer with the base is operated from side to side on desks or tables. The table attached to the actuator moves according to the motions of the hand-operated accelerometer. The cost of these devices except PC in total is under 1500 US dollar.

2.1 Actuator

The actuator is driven by the stepping motor. The primary specification of the actuator is shown in Table 1. The lead denotes the shift amount of the actuator per 1 rotation of the motor. The shift amount and the moving velocity are controlled by the number of pulse and pulse velocity, respectively. They can be calculated by the following equations.

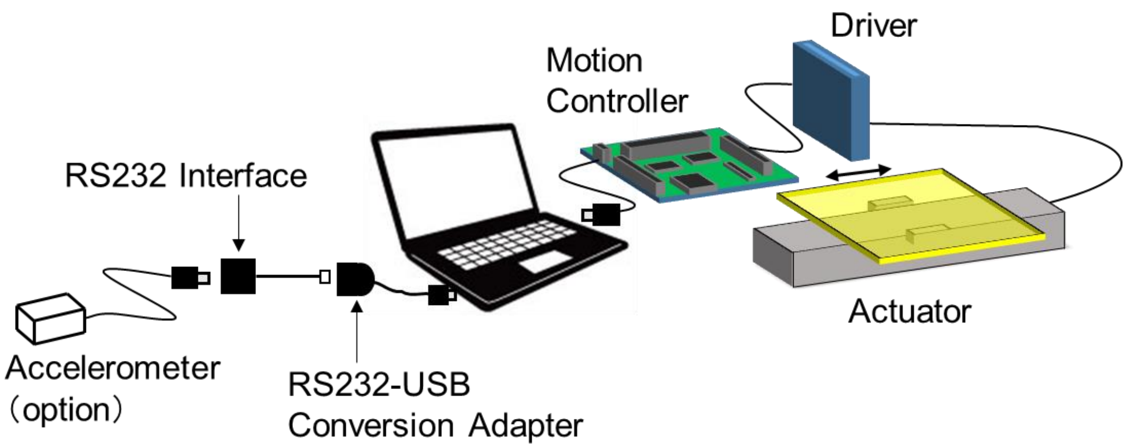

Figure 1. Hardware of portable shaking table

Figure 2. Motion controller (upper left), driver (upper right) and actuator (lower)

Figure 3. Accelerometer

Figure 4. Base of accelerometer

Table 1. Specification of actuator

Size	Length:465mm Width:75.4mm Height:83mm
lead	12mm
stroke	200mm
power supply	AC
minimum shift amount	0.01mm (changeable)
maximum velocity	800mm/s
maximum transportable mass	30kg

(number of pulse in [pulse]) = (required shift amount in [mm]) / (minimum shift amount in [mm]) (1)

(pulse velocity in [Hz]) = (required moving velocity in [mm/s]) / (minimum shift amount in [mm) (2)

2.2 Accelerometer

100 measurements of acceleration per second per axis are carried out and they are sent to the computer via the serial cable from the accelerometer. The communication specification is shown in Table 2. The receive format of data is "*xxxx*, *yyyy*, *zzzz*, *m* [*CR*]" in decimal characters. "*xxxx*", "*yyyy*" and "*zzzz*" denote acceleration in the direction of *x*, *y*, *z* axis, respectively. The actual values of acceleration are obtained by the correction using offset value and correction factor. "*m*" and "[*CR*]" denote the time stamp and the carriage return, respectively.

Table 2. Communication specification

Communication method		RS-232C
Transmission rate		19.2kbps
Bit Configuration	Start	1bit
	Data	8bit
	Parity	none
	Stop	1bit

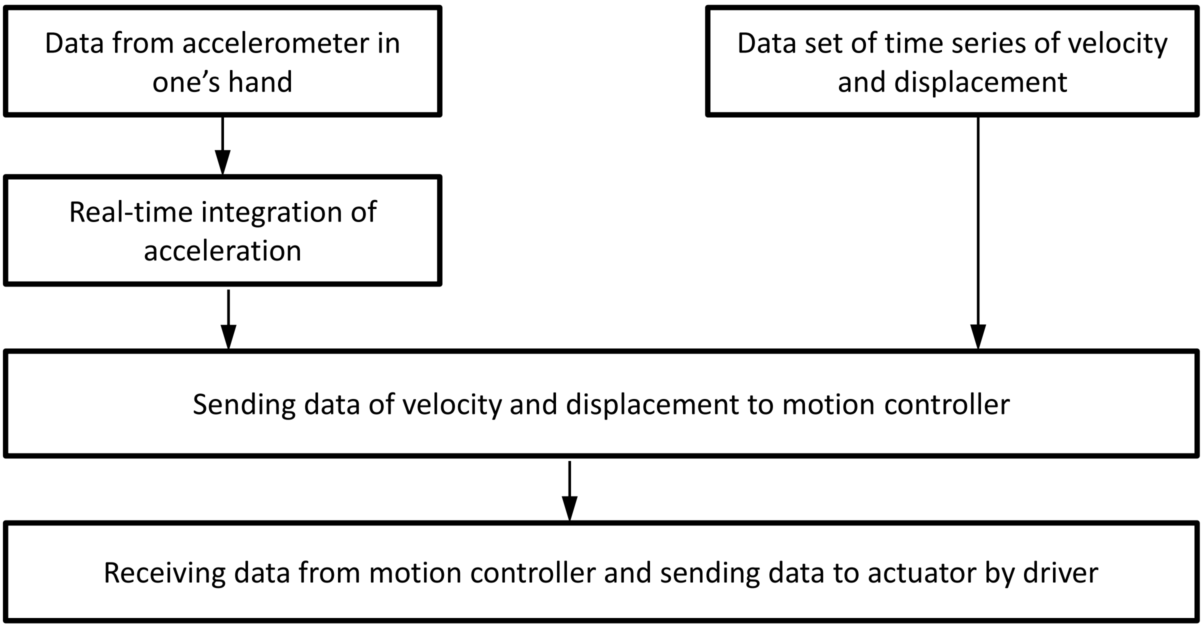

Figure 5. Way of driving of actuator

3. SOFTWARE

3.1 Control of Shaking Table

The software is built using VB.NET. The API functions prepared as the accessary of the motion controller are used to control the actuator. The actuator is basically controlled by receiving the values of velocity and displacement at regular intervals. Two ways are prepared for the control of the actuator as shown in Figure 5. One is the way that the prepared set of time series of data is sent to the actuator. The other is the way that the values of velocity and displace, which are obtained by the real-time integration of the acceleration sent from the accelerometer in the student's hand, are sent to the actuator.

3.2 Conversion of Acceleration to Displacement

Real-time integration of the acceleration is required to drive the actuator in response to the movement of one's hand. The time series of velocity and displacement can be calculated by one time and two times integration of the acceleration, respectively. However, since the noise contained in the acceleration records has significant influence on the calculated displacement, any filtering process is required.

The digital filter used in this study is mentioned in the followings. The filtering should be done in real time. First the calibration of obtained acceleration data is carried out using Equation 3.

$$a_k = a'_k - \frac{\sum_{i=1}^{n} a'_{k-i}}{n} \tag{3}$$

where a'_k and a_k are the original and corrected acceleration at the time t_k, respectively. n denotes the number of acceleration data which are to be used in the correction. If n is too small, the noises of the long period components cannot be eliminated. n $(=100)$ is adopted in this study for the necessity of real time processing. In this case, the components of noise up to the period of 1 second can be eliminated. The velocity v and displacement d at the time t_{k+1} can be calculated in Equations 4 and 5, respectively.

$$v_{k+1} = v_k + \frac{1}{2}(a_k + a_{k+1})\Delta t \tag{4}$$

$$d_{k+1} = d_k + v_k \Delta t + \frac{1}{3}\left(a_k + \frac{1}{2}a_{k+1}\right)\Delta t^2 \tag{5}$$

Figure 6 shows the example of the waveform of the acceleration before the digital filter is applied. The data were recorded at Shiogama (MYG012), Japan by K-NET in 2011 Great East Japan Earthquake. Figures 7 and 8 show the waveforms of displacement calculated with and without filtering, respectively.

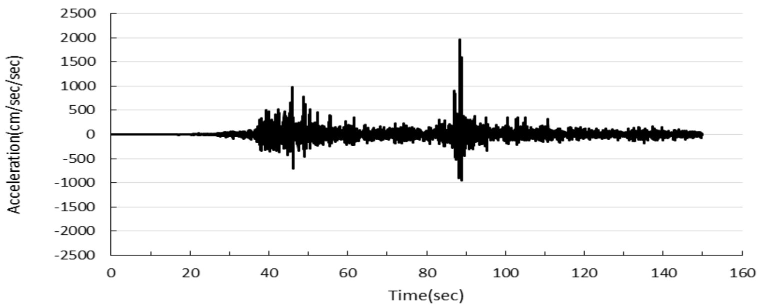

Figure 6. Original acceleration data

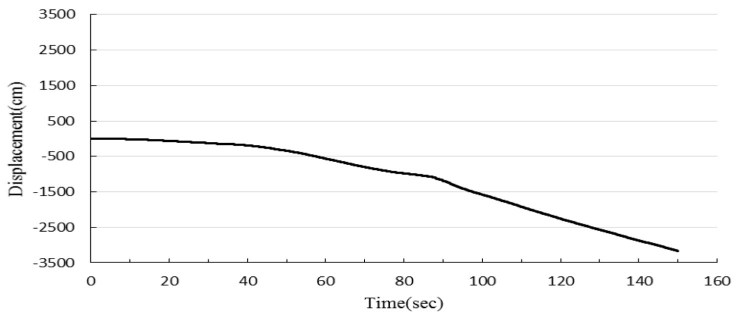

Figure 7. Displacement without filtering

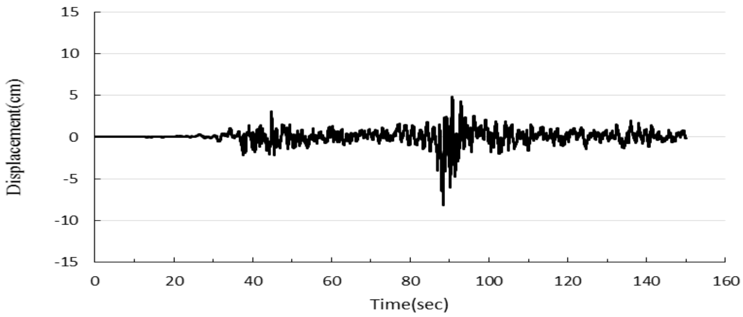

Figure 8. Displacement with filtering

4. BEHAVIOR OF SHAKING TABLE

The comparison of the wave forms of velocity in case of sinusoidal input are shown in Figure 9. Though slight disagreements between the transmitted data and the behavior of the shaking table are recognized, the wave forms are almost identical. Sine sine-waves up to about 10Hz can be expressed by this shaking table depending on the amplitude.

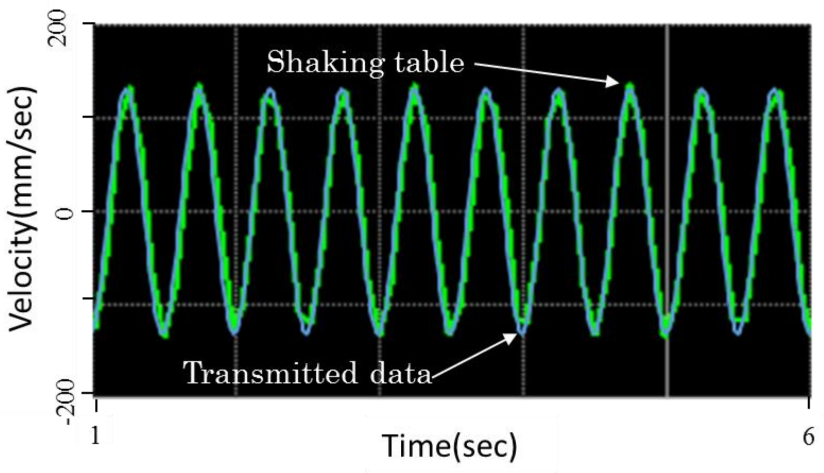

Figure 9. Comparison of wave forms of velocity between behavior of shaking table and transmitted data in case of sinusoidal input

Figure 10 shows the comparison of wave forms in case of random vibration input, in which the scaled acceleration in the event of an actual earthquake was used. Partially disagreement can be recognized between the wave forms. The velocity of the shaking table is larger in some peaks of the wave form. However, if precise behavior of input random vibration is not required, this system seems to be valuable as teaching materials.

Figure 11 shows the actuator working in response to the movement of one's hand. It helps the intuitive understandings of the strength of vibrations such as maximum acceleration and seismic intensity, since the student can see the behavior of the shaking table as well as the current values of the indexes updated in real time shown in computer display. When structure models are set on the shaking table, the resonance frequency can be searched by moving the acceleration in the hand at an appropriate interval.

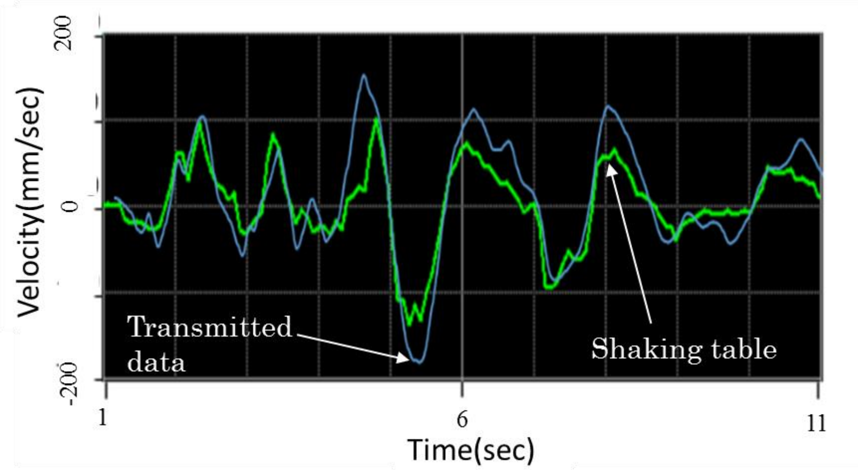

Figure 10. Comparison of wave forms of velocity between behavior of shaking table and transmitted data in case of random vibration input

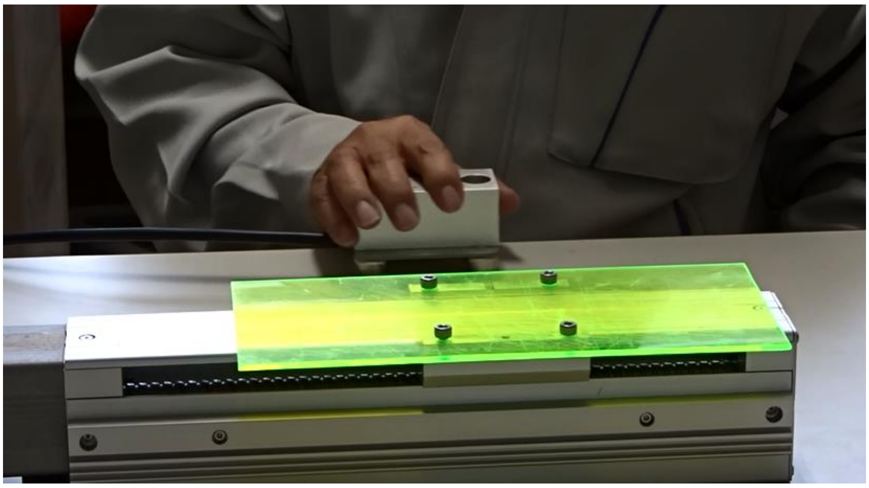

Figure 11. Actuator moving in response of movement of one's hand

5. CONCLUSIONS

New teaching materials are developed to promote intuitive understandings of vibration. The portable shaking table developed in this study is composed of the devices such as actuator, motion controller and accelerometer. The feature of the shaking table is that it is controllable by the movement of the hand. The major results are shown in the followings.

1) The wave forms of the behavior of shaking table and the transmitted data are almost identical in case of sinusoidal input.
2) Disagreements between the behavior of shaking table and the transmitted data are recognized in case of random vibration input. However, the shaking table helps the understandings of the behavior of structure model excited by random vibration, since the disagreements are not so significant.
3) The shaking table moves successfully in response of the movements of one's hand.

6. ACKNOWLEDGEMENTS

National Research Institute for Earth Science and Disaster Prevention in Japan is greatly appreciated for providing seismic ground motion records of K-net.

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