Development of Portable 3D Earthquake Simulator: Design of Mechanism and Preliminary Experiments

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In recent decades, the devastating earthquakes, which can damage a lot of houses and buildings, have frequently happened. To slow down or prevent the disastrous damages of the earthquake, the various technologies have been required. Of these technologies, the ground motion simulator of the earthquake is used to alert people to the dangers of the earthquake. The authors have developed a potable earthquake simulator, called a Zishin-The-Vuton, which has the function to make holonomic omni-directional motions of the earthquake on a plane. In this paper, the more advanced simulator Zishin-The-Vuton 3D is presented. It realizes the up-and-down motion with the holonomic omni-directional motions in order to simulate three-dimensional ground motion of the earthquake. Focusing on the design concept, structure, and feature of this new simulator, we discuss its implementation and validity.

Key Words: Earthquake simulator, Omni-directional robot, Ground motion, Three-dimensional motion simulation,.

1. Introduction

Since there are seismically active regions of the world, technologies and activities to reduce the risk of latent earthquakes are required. As most of damages by the earthquake are due to the collapse of buildings and unban infrastructures, it is crucial to evaluate their existing seismic capacities and then to retrofit and rehabilitate accordingly [1]. For full-scale experiments of this evaluation, a big shaking table has been developed in order to simulate high level ground motions; this table is called a ground motion simulator of the earthquake (or an earthquake simulator). In the world, at least hundreds millions of people are exposed to a substantial seismic risk of catastrophic damage. However, many people are not conscious of its serious effect on their lives. The earthquake simulator can be utilized to alert people to the dangers of the earthquake from the simulation of its disaster. The authors have developed an earthquake simulator, called a Zishin-The-Vuton, which has the function to make holonomic omni-directional motion of the earthquake on a plane [2]. Existing earthquake simulators have been designed for estimating the effects of the ground motion of the earthquake on large-scale structures such as buildings, while the proposed portable simulator was developed for people who can experience destructive ground motions of the earthquake. In this paper, the more advanced and upgraded simulator Zishin-The-Vuton 3D is presented. It realizes up-and-down motions as well as horizontal holonomic omni-directional motions in order to simulate the 3-D ground motion of the earthquake. In Section 2, the design concept, structure, and feature of Zishin-The-Vuton 3D are presented. Section 3 discusses the implementation of the proposed simulator and then provides its validation through demonstration. In Section 4, conclusions are followed.

2. Proposition of Design Concept

Earthquake ground motions which human beings feel are directly caused by seismic acceleration and velocity. Thus, in order to develop a simulator for experience of the ground motion, it is needed to design an earthquake focal mechanism which can produce the acceleration and velocity. The proposed earthquake simulator Zishin-The-Vuton 3D has been developed based on this design concept. As shown in Fig. 1, Zishin-The-Vuton 3D largely consists of a horizontal driving mechanism, a vertical driving mechanism, and a chair on which subjects seat. The horizontal driving mechanism driven by powerful DC motors provides holonomic omni-directional motions to reproduce such acceleration and speed on a plane caused by the ground motion; its performance has been already evaluated [2].

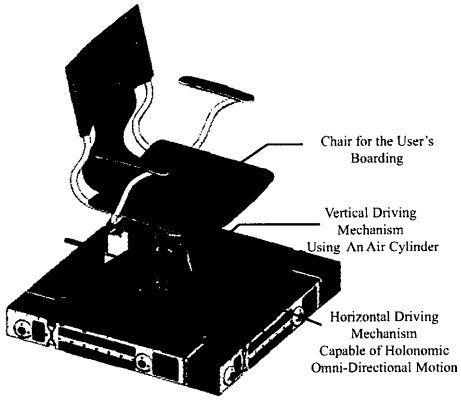


Fig. 1. Structure overview of Jishin-The-Vuton 3D.

The vertical driving mechanism that is newly introduced in this paper is equipped with an air cylinder as its driving actuator, as depicted in Fig. 2. The air pressure of the air cylinder is steplessly controlled in proportion to an electric signal by the electro-pneumatic regulator, which is connected to an air compressor. The end of the rod of the cylinder is attached to the chair. Two linear guides, which are mounted to the bottom of the chair and to the two sides of the housing of the cylinder, support the linear vertical motions of the simulator, as shown in Fig. 3. The up-and-down motions can be realized due to the relation between the given force $\boldsymbol{W}$ in the $-y_s$ direction by the subject's weight and the controlled force $\boldsymbol{F_a}$ in the $+y_s$ direction by the operating pressure of the air cylinder (where y_s is y-axis of the coordinate frame Σ_s on the subject's center of mass). In other words, the subject who is constant in weight is moved up and down by the control of the air pressure of the electro-pneumatic regulator. A linear potentiometer that measures the displacement of this motion is used for the feedback control of the motion. An earthquake sensor attached to the chair detects the three-dimensional earthquake ground motions, which are produced by Zishin-The-Vuton 3D.

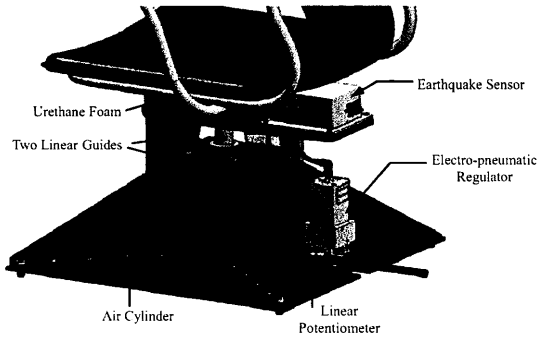


Fig. 2. Components of the vertical driving mechanism.

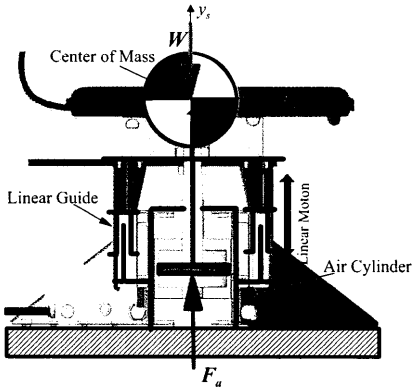


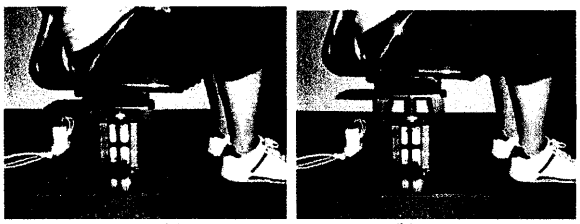
Fig. 3. Schematic diagram of the vertical driving mechanism.

3. Implementation

Fig. 4 Prototype of Zishin-The-Vuton 3D.

The developed Zishin-The-Vuton is shown in Fig. 4. It weights about 85kg and measures 744mm x 744mm x 905mm. The vertical moving mechanism with the air cylinder to realize the up-and-down motion drive (model: MB1 series, bore size: 100mm, maximum operating pressure: 1.0MPa, stroke: 50mm, manufacturer: SMC) and the electro-pneumatic regulator to control air pressure (model: ITV3000series, regulating pressure range: 0.005 to 0.9MPa, manufacturer: SMC) is combined with four triangle-shaped frames and fixed on the horizontal moving mechanism .

To evaluate the proposed mechanism, one experiment after another was performed by using the real earthquake ground motion data such as the acceleration waveform recorded at JMA Kobe in Southern-Hyogo Prefecture Earthquake, 1995.



(a) (b)

Fig. 5. Experiment of the vertical movement. (a) Lowest position (-25mm). (b) Highest position (+25mm).

As shown in Fig. 5, after the subject boards Zishin-The-Vuton 3D, the air pressure of the air cylinder is increased by the regulator until the subject begins moving upwards, in order to find the subject's weight (when W is equal to F_a in Fig.3, the subject's weight can be measured considering the relation of the two forces). Then, the supplying air pressure to realize the up-and-down motion is set up to offset the subject's weight and the subject starts to experience the earthquake ground motion of the vertical stroke 50mm.

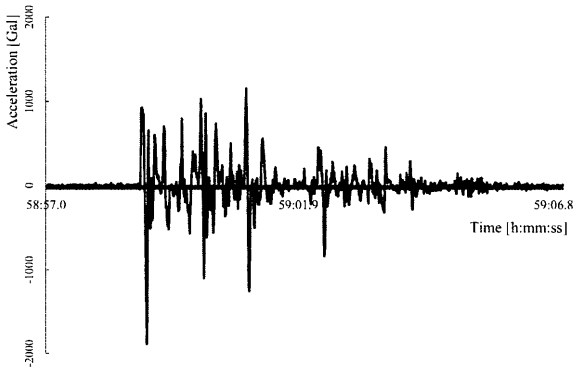


Fig. 6. Acceleration waveform of the up-and-down motion simulated by Zishin-The-Vuton 3D.

Fig. 6 shows the acceleration waveform sensed by the embedded earthquake sensor, which is produced by the vertical ground motion of Zishin-The-Vuton 3D.

Based on this reliable experimental results, the authors demonstrated the earthquake ground motion simulation by using Zishin-The-Vuton 3D at Tokyo Tech, Japan for two days. In this demonstration, more than forty subjects experienced the motion as shown in Fig. 7. The movie that shows the simulated room shaken and vibrated by an earthquake plays in the front of the subjects to add realism to them. They told us that this experience has awakened them to the dangers of earthquakes again.

4. Conclusions

In this paper, the authors introduced the new earthquake simulator Zishin-The-Vuton 3D which simulates three dimensional ground motion of the earthquake, and evaluated its mechanical performance by using real earthquake motion data. In the future, the proposed simulator will be improved for more realistic simulation which can provide peak values in accordance with empirical ground motion prediction relationships and also produce good waveforms with satisfactory resolution in time and frequency domain.

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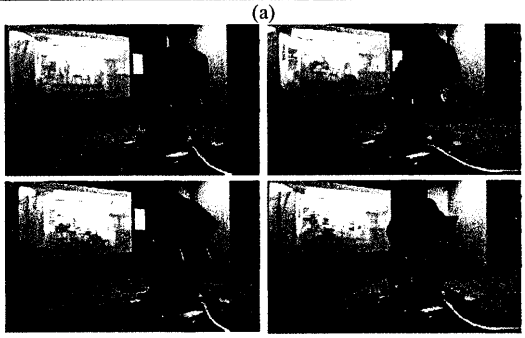
(a)



(b)

Fig. 7. Demonstration of Zishin-The-Vuton 3D. (a) Setup. (b) Subject's experience of the earthquake ground motion.