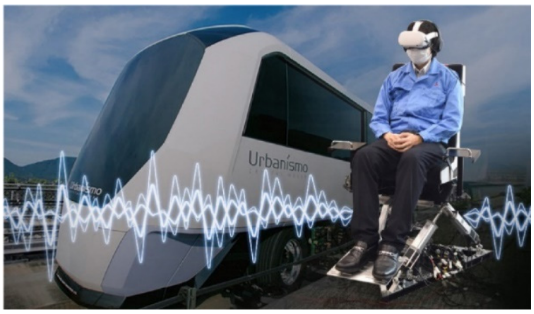
Development of Ride Experience System to Evaluate Comfort of Automated Guideway Transit Using Virtual Reality Technology



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In recent years, the need to improve the comfort of various types of vehicles has greatly increased. Mitsubishi Heavy Industries, Ltd. has continued to improve the ride quality of its AGT (automated guideway transit) products by reducing the vibration of the vehicle through various measures. Until now, implementation of actual vehicle running tests were needed to verify the ride experience effected by such measures. At this time, we have developed a portable experience system using VR (virtual reality) and a motion chair where one can experience the actual ride of a vehicle. With this system, various verifications are possible without running actual vehicles by reproducing the feeling of a ride similar to that of the actual running vehicle. In this report, we would like to describe our efforts.

1. Introduction

AGT is a new transportation system that operates on rubber tires. Compared to standard railways, AGTs can make tighter turns and handle steeper grades, providing greater flexibility in route planning. AGTs have been widely introduced in Japan and overseas as a means to carry passengers between airport terminals and as intra-city transportation systems[(1)].

Conventionally, vibration acceleration occurring in an AGT vehicle while running on the target route has been predicted using detailed numerical simulations based on MBD (multi-body dynamics) technology, and measures to reduce such vibration have been considered in order to improve ride comfort. However, even when the degree of vibration acceleration is predicted in a numerical simulation, it is difficult for designers and customers to imagine how comfortable the ride would be. Consequently, fabricating an actual vehicle and running it has been required in order to check ride quality.

One method often employed by major railroad companies and automobile companies to experience the ride of an actual running vehicle is to use a large simulator with full-scale equipment, but this requires significant time and expense. In addition, when customers from overseas or other distant places are involved, it is necessary for them to come to the factory where the equipment is located to experience the ride. To address these issues, we have combined VR and a motion chair to construct a portable and simple system that enables a person to experience the ride comfort of the vehicle. This report describes our efforts to construct this system.

2. Overview of ride experience system

2.1 System configuration

The overall configuration of the ride experience system is shown in **Figure 1**. The motion chair is a Stewart platform-type device using six electric actuators to support the seat and has high portability, and operates on a household power supply (100 VAC). The seat of the motion chair is a G-Fit[(2)], which is used in AGTs designed and manufactured by us, such as the 7300 and 7500 series of Yurikamome (a new transportation system operating through Tokyo Waterfront City), and is installed using fittings. The PC used for control sends a signal to operate the motion chair, and also

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outputs the video image and sound for the HMD (head-mounted display) that displays the VR video image. As input data for displacement of the motion chair, simulation results from the MBD analysis were used, but actual running data can also be used. Although the system is basically a combination of commercially available products, a highly immersive experience is created by accurately synchronizing the video image, vibration, and sound.

Figure 1 Configuration of ride experience system

2.2 Acquiring actual running data for verification

In order to verify the developed ride experience system, vibration data of the actual running car is necessary. To acquire this data, as well as video images and sound for the VR, data of high-speed AGT vehicles[1] running on our Mihara test line[3] were used. Vibration data necessary to calculate the amount of displacement which is used to control the motion chair was acquired using a strain accelerometer and a gyro sensor, which is an angular rate meter, and is installed under the G-Fit seat. Measurements were taken with a person sitting in the seat. As shown in **Figure 2**, to acquire data during actual running, a 360° camera was installed at eye level of a person sitting in the seat and was used to record a video image of the inside of the vehicle. An ambisonics, binaural microphone capable of recording 360° surround sound was positioned near the person’s ear. By reflecting the acquired data in the ride experience system, a ride with vibration, video image, and sound similar to those in an actual running vehicle can be experienced.

Figure 2 Recording video images and sounds of actual running vehicle

2.3 Reproduction of actual running vibration

Among the results of comparison of the vibration measurement on actual vehicle and the results of reproduced vibration using the motion chair, an example of acceleration on vertical direction for the vibration acceleration speed at each 1/3 octave band is shown in **Figure 3**. In compliance with JIS B 7760-2:2004 (ISO 2631-1: 1997) which is used to consider the effect of vibration on the human body on health, comfort, and vibration perception, the frequency-corrected acceleration effective value, to which the frequency coefficient depending on the direction of acceleration action, posture, etc. has been applied, can be reproduced within ±10% accuracy of the actual measurement. Furthermore, reproducibility deteriorates at 10Hz and higher because it is out of the control frequency range of the motion chair.

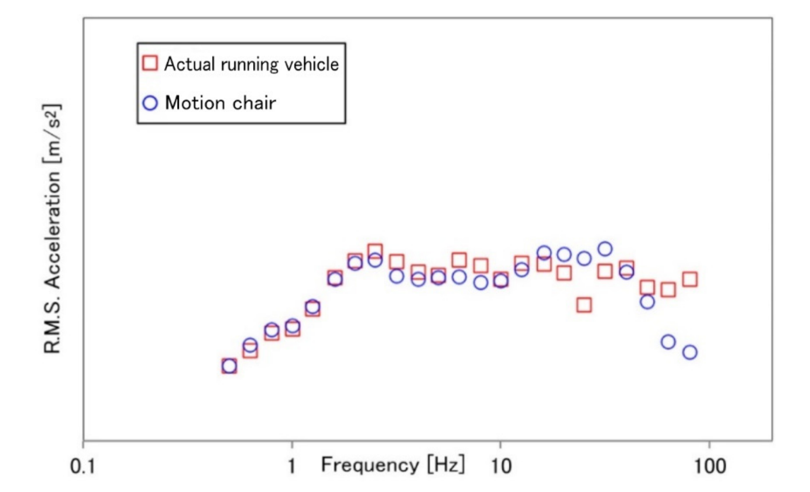


Figure 3 Vibration reproduction by a motion chair

2.4 Evaluation of immersiveness of system

This system combines the vibrations, video images, and sounds obtained from an actual running vehicle as shown in **Figure 4**. In this system, a person sits in the same seat as that of an actual vehicle and experiences the same level of vibration as that of an actual running vehicle, along with the video image and sound through HMD and surround headphones, creating a ride experience that feels similar to that of an actual running vehicle.

Figure 4 Display screen of the system

A questionnaire-based evaluation was conducted with 20 participants of various ages in order to determine which elements of this system strongly contribute to improved immersiveness. Results of the evaluation are shown in **Figure 5**. The participants compared the immersiveness of an experience case with the previous-condition case they experienced and rated immersiveness on a 5-point scale, where 1 represents feeling more immersiveness than that of the previous case and 5 represents feeling less immersiveness. When the degree of freedom to operate the motion chair was changed from 6 (3 translation directions and 3 rotation directions) to 3 (only 3 translation directions), no significant difference in the ratio of participants who felt immersiveness was observed. From this, reproduction using only the vibration component of 3 translation directions could be confirmed to be sufficient since AGT runs without any significant inclination. However, when 6-degree freedom with sound is changed to only 3-degree freedom vibration, the ratio of participants who felt an immersiveness decreased, and the ratio of those who felt the connection between the images and movements was strange increased. This indicates that sound is important in the improvement of immersiveness in the ride experience system.

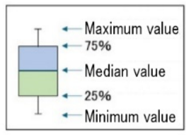
Persons targeted by the questionnaire

- Gender

Male	Female
18	2

- Age

20s	30s	40s	50s	60s
3	4	6	5	2



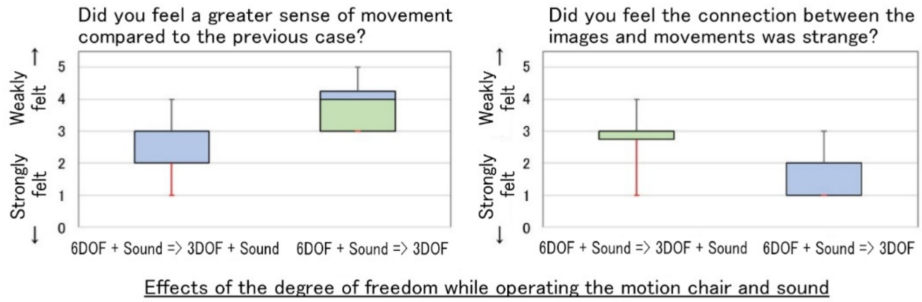


Figure 5　Results of immersiveness evaluation

3. Utilization of this system

With this system, a simplified vehicle riding experience, without actually riding in a vehicle, is possible. The following are examples of utilization of this system.

(1) Experiencing the results of a running simulation

An example of an MBD model that can calculate the vibration acceleration generated by a vehicle through a simulation is shown in **Figure 6**. This model is a combination of modeled AGT components and is supported by air springs and vertical dampers in the vertical direction, while the body and bogie are coupled by parallel links in the front-back direction[4]. The bogie has an axle and tires driven by a motor via gears, and a guide steering mechanism is used to steer the tires. The model track on which the AGT vehicle runs reflects the track alignment of the actual route and the unevenness of typical AGT track surfaces and guideways. The vehicle and track models are combined to predict vibration acceleration by simulation, and the results are used to command the motion chair. In addition, a video image of the running vehicle created by 3D CG, etc. is displayed on HMD in combination with the running sound of a similar vehicle. As a result, this system can create a ride experience before the actual route and vehicle are completed.

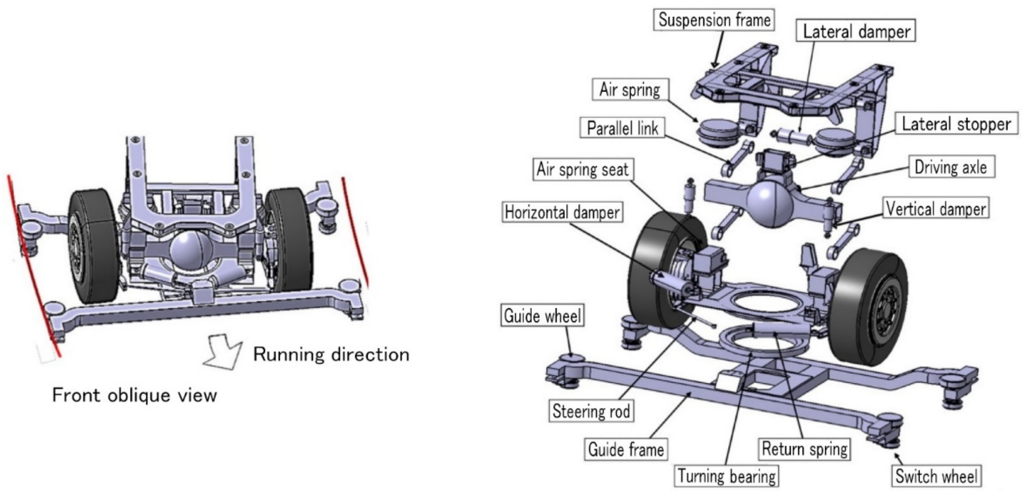


Figure 6　AGT vehicle MBD model

(2) Experiencing the effect of improved ride comfort

Changes in car vibration acceleration predicted by measures to improve ride comfort which have been considered in the running simulation can be reproduced and experienced prior to manufacture or modification of the actual car. As such, vibration characteristics felt by actual passengers which are necessary to improve ride comfort can be evaluated not only numerically but also physically, and effective measures can be considered while reducing running test costs.

In the case of AGTs, the track surface may deteriorate over many years of operation, and repairs may be necessary to improve the track surface. By evaluating how such repairs affect the reduction of vibration acceleration in the vehicle not only numerically but also by experiencing it through this simulator, the need for track repairs can be better understood.

(3) Remotely experiencing a ride using VR video images

When a person experiences a ride using this system, the image displayed on the HMD changes depending on the movement of the person's head. By recording the video image displayed on the HMD, the ride can be experienced in a simplified manner using the recorded video and sound with only the HMD, without the motion chair. In this case, the recorded video image reflects eye movement in response to the actual running vehicle vibration and immersiveness can be improved to a greater extent than that just with a normal video image projected on the HMD. Consequently, even customers in remote areas who would have difficulty visiting a site equipped with a motion chair can experience the ride with high immersiveness.

4. Conclusion

In order to construct a system to experience the ride comfort of the vehicle, vehicle acceleration from an actual running vehicle was measured, and a 360° video image with sound was recorded while running the vehicle. A commercially available motion chair was used to accurately reproduce the measured vehicle acceleration, the video was displayed using HMD and the sound was played back using headphones. As a result, a system that can create a ride experience similar to that of an actual running vehicle could be constructed. With this system, the effect of improvements in ride comfort can be verified by reproducing the simulation results of the running vehicle based on MBD analysis, even before the actual vehicle is completed.

We plan to actively apply this system to actual construction projects in order to reduce the time and cost required for an actual running test, and seeks to promote the system to our customers. In addition, we wish to promote the application of this technology, which combines VR and a motion chair, not only to new transportation system vehicles, but also to our other vehicle products such as ships and aircraft.

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