Virtual Bogie: Exhibition System to Understand Mechanism of Bogie with Digital Display Case

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Abstract. We aim to construct a digital display case system that effectively conveys background information about an exhibited object, and introduce our system into museum exhibition rooms. In this paper, we present a digital display case system that enables viewers to interact with an exhibited artifact in a manner that conveys its dynamic mechanism more easily than conventional approaches. Based on a field trial at a museum, we report visitors' observations, reviews from museum curators, and a detailed evaluation and discussion of the system.

Keywords: Digital display case · Digital museum · Dynamic mechanism · Virtual reality

1 Introduction

In recent years, museums have demonstrated increasing interest in the use of digital technologies to provide supplementary background information about the exhibits within their exhibitions. The conventional approach to do so has been the placement of static displays, such as panels with text and figures, near the exhibited objects to convey relevant information. However, because the exhibit and the panel are often detached, this is an ineffective and problematic way to help visitors connect to the exhibit and its information. In particular, it is difficult for visitors to understand the dynamic mechanism of an exhibited artifact based on static information displayed on a panel. For example, in order to convey the dynamic mechanism of railway bogies, the Railway Museum of Saitama, Japan has been exhibiting authentic railway bogies alongside descriptions of figures, captions, cut models, and other materials intended to show visitors their mechanism of action (Fig. 1). However, the museum argues that it has been difficult to understand the mechanism of a real moving bogie because it cannot be shown in the static descriptions. On the other hand, a video that describes the mechanism is not always effective. Because it is a non-interactive system, most visitors simply pass by without watching the video to the end. Thus, an interactive exhibition system provides an effective way for visitors to interact with exhibitions and more easily comprehend dynamic mechanisms.

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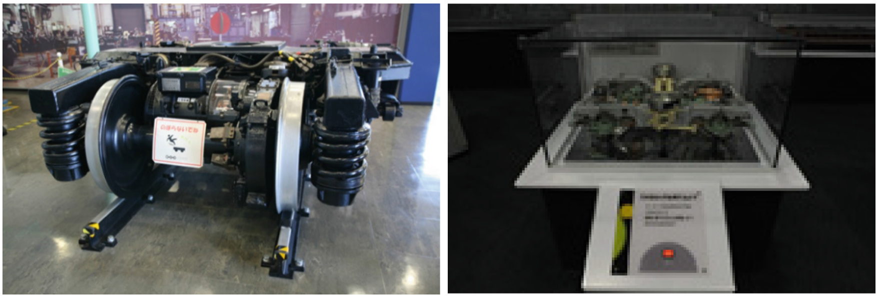

Fig. 1. Exhibition of the railway bogie

The goal of our project is to construct a digital display case system that enables museums to effectively convey background information about exhibits in an exhibition using digital technology and virtual exhibits. While previous studies [1, 2] have examined static exhibits, this study focuses on exhibits with dynamic characteristics such as their mechanisms. The purpose is the development of an exhibition system that assists visitors to understand these mechanisms. In this study, we chose the railway bogie as an example and implemented a digital display case system with which visitors can interact. We conducted a field trial of the system in the Railway Museum and received reviews of the system and exhibition from the curators of the museum.

2 Related Works

Several examples of digital technology have been introduced in museums. One of the most popular technologies is the museum theater. A number of studies have been conducted on gallery talks in theaters [3]. A museum theater can use images to convey a variety of information about the theme of the exhibition to visitors in an effective manner. However, it is difficult to connect the contents in a museum theater to exhibits in the exhibition room, because museum theaters are located away from the exhibition room, beyond separation walls.

Several studies have been conducted on exhibition systems that superimpose images on exhibits. One of them is an exhibition system with a head-mounted display (HMD) [4]. However, wearable systems such as HMDs are problematic when introduced into permanent exhibitions because they are difficult for museum staff to manage. Virtual Showcase [5] can be cited as another example. This system superimposes images on exhibits using a half mirror and allows multiple users to observe and interact with the augmented information in the display. Exfloasion [6] extends this concept, enabling presentation of floating images with different depths by constructing the imaging surface of two layers and placing half mirrors both back and forth. These exhibition systems can effectively present information by superimposing it on the exhibit. However, it is difficult to convey dynamic information such as mechanisms since the exhibit to be stored in the system is static.

Other studies have examined systems that enable user interaction through the use of virtual exhibits or touch-enabled systems. Wakita et al. reported a system that allows direct interaction with the virtual fabric using a space interface device for artificial reality (SPIDAR) haptic force display that presents force on the basis of data measured with a laser range scanner [7]. However, the systems above are designed to realize the experience of touching static exhibits and, to the extent of the authors' knowledge, there are very few systems for exhibitions that allow users to manipulate the exhibit itself in order to easily understand its dynamic mechanism.

On the other hand, virtual experiment platforms have been designed and developed for students to understand the mechanism of motion systems in recent years [8]. Fan et al. [9] developed a system for students to perform motion experiments of mechanisms and to understand the composition of the mechanism and its motion principle through simulation.

The development of digital mock-up (DMU) technology and related studies is popular in the modern manufacturing industry [10, 11]. DMU technology enables the design of products and the simulation of their behavior. Therefore, it is possible to improve the quality of products, reduce production costs, and shorten development periods. It is reasonable to infer that visitors can understand the dynamic mechanism of exhibits more easily by applying DMU technology to exhibition systems.

3 Implementation

The purpose of this study is to construct an exhibition system that effectively conveys the dynamic mechanism of an exhibited artifact using digital technology. An interactive exhibition system provides an effective way for visitors to interact with exhibits and to see how the mechanism works, thereby conveying the related information. The use of a digital display case system that displays virtual exhibits is an effective method to achieve this purpose. Therefore, we constructed a system as described in the following sections.

3.1 Digital Display Case System

We constructed a digital display case system composed of three three-dimensional (3D) displays in the shape of a box. The reason we chose the shape of a three-sided display case was that the appearance of the system would resemble a display case that could be introduced seamlessly in place of conventional display cases in museums. To view the exhibit, a user wears a pair of 3D glasses with a Polhemus sensor, which measures the orientation and rotation of the receptor using magnetic fields generated by the transmitter. Based on the point of view measured by this sensor, the system calculates images to display. This enables the user to view an exhibit from many angles as if it were inside the case (Fig. 2).

We will describe the components from which the digital display case system is constructed. The computer that controls the system is a workstation with an Intel Xeon 3.33 GHz CPU. The workstation is connected to NVIDIA Quadro Plex 2200 D2 that

Fig. 2. Digital Display Case system

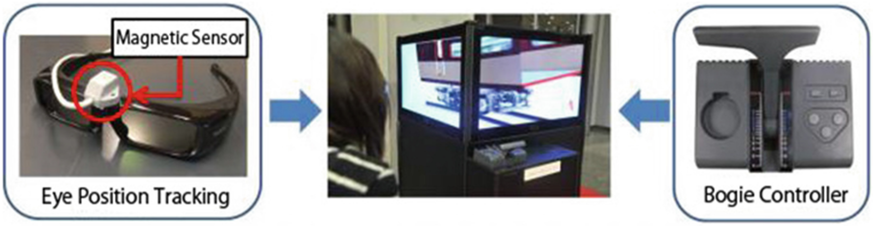

Fig. 3. Components of Digital Display Case for interaction

synchronizes output to the screen with three 40″ 3D displays. The sensor attached to the 3D glasses is Polhemus 3SPACE ISOTRAKII. The controller was used to operate exhibits in the digital display case (Fig. 3). Dynamic computation to operate the system was performed by the Open Dynamics Engine (ODE) [12], a physics engine. In addition, the system runs at 30 fps.

3.2 Contents to Understand the Mechanism of Railway Bogie

We propose an approach for magnifying flexure of components interactively in a digital display case system (DDCS) [1], to provide an understanding of exhibit mechanisms. Because actual flexure of real components is too little to find by users, our system show changed parts and convey mechanism to users by magnifying that flexure (Fig. 4).

A. The mechanism of the railway bogie (DT46)

The mechanism of the railway bogie described in this paper is a hollow shaft parallel Cardin drive system as shown in Fig. 6. The bogie needs to suppress vibration in order to prevent vibration up and down the body when it is running on a rail.

In previous system [12], we showed 0 series Shinkansen's bogie in the DDCS (Fig. 5). It has axle and bolster springs. It also has flexible joints consisting of an

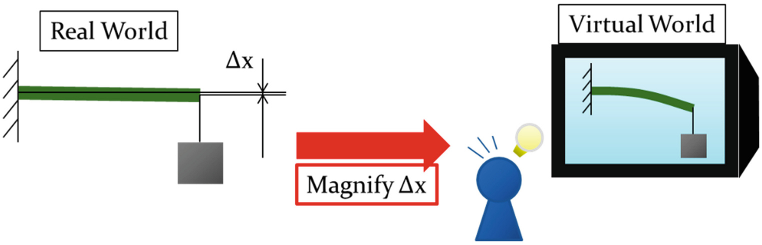

Fig. 4. Concept to provide understanding by magnifying Δx

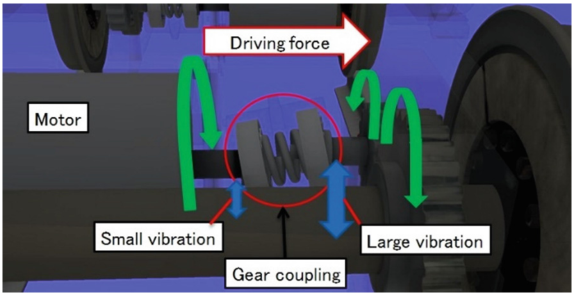

Fig. 5. Mechanism of the railway bogie (0 series Shinkansen)

annular gear, external gears, a spring, and so forth. The role of flexible joints is to transmit driving force from the motor to the wheels and to prevent vibration from being transmitted to the motor. Owing to this joint, trains can remain stable while running.

In this study, we choose hollow shaft parallel Cardin driving devices of DT46 which is popularly used bogie mechanism in Japanese commuter train. This mechanism have features that the motor shaft is a hollow shaft (pipe-like axis) and that shaft include another shaft to transfer driving force to gears and wheels as shown in Fig. 6. When misalignment between motor shaft and gear shaft are occurred while running, this system keep to transfer driving force to gears and wheels by bending flexural plate and declining gear shaft (Fig. 7). In order to convey such a complicated mechanism, the exhibition system requires functionality that enables visitors to interact with the exhibit and see how the mechanism works visually. Therefore, we implemented the system to allow the visitor to operate the railway bogie with acceleration or deceleration. In addition, this system possesses a function to make its parts transparent in six steps as shown in Fig. 5, so that visitors can see both the outside and the inside. Using these functions, visitors can observe the hidden parts of the mechanism as if the railway bogie was real and running.

In this system, the railway bogie in the digital display case is designed to run on a rail defined by a sine curve. In addition, the amplitude of the rail is defined to be larger than an actual rail since it is necessary to distend the mechanical movement of the bogie in order to convey the mechanism to visitors (Fig. 8). When the railway bogie runs above a certain speed, users are unable to see it run because the speed is too fast and the

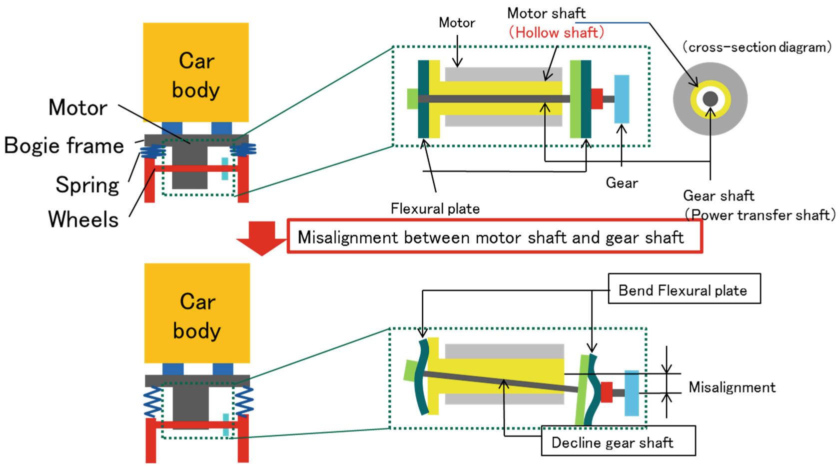

Fig. 6. Mechanism of hollow shaft parallel Cardan drive system (DT46)

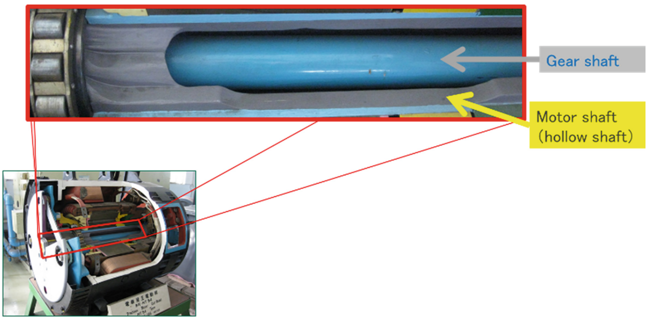

Fig. 7. Real exhibit of the railway bogie (DT46)

gears and wheels do not appear to rotate. Therefore, we assigned a different color to parts of the gears and wheels. This makes it possible to perceive that the railway bogie is running at high speed.

An interface for museum exhibitions needs to be sufficiently easy such that anyone is able to operate it. Therefore, to operate the railway bogie, we used the controller shown in Fig. 3, which is mainly used for operating trains. Using the controller, acceleration and braking can be performed by manipulating the lever. Furthermore, it is possible to change reproduction speed, the mode of flexure plate (Fig. 9) and the transparency (Fig. 10) by pressing each of two buttons and the mode by pressing each of the other buttons (Fig. 11).

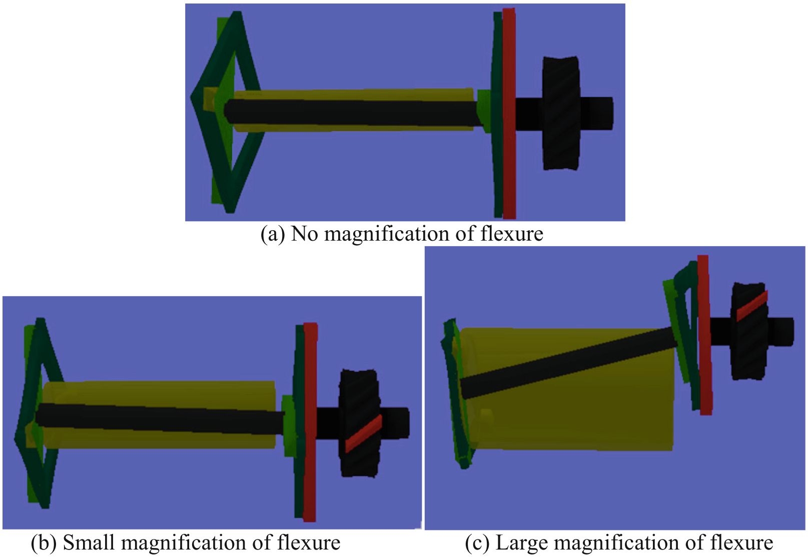

Fig. 8 Magnification of flexure to present understanding of mechanism

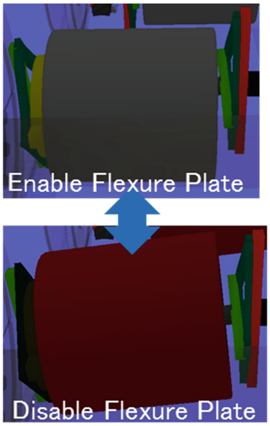

Fig. 9. Mode of flexure plate

4 Exhibition and User Study

4.1 Exhibition of the DDCS with the Level of Abstraction Switching

We exhibited the DDCS with the proposed level of abstraction switching method at the Railway Museum

The exhibition period was 14 days (January 8–13, 15–20, 26, 2014) and was open from 10:00 to 18:00. At the time of the exhibition, one or two docents assigned to explain the system generally remained near the digital display case (Fig. 12).

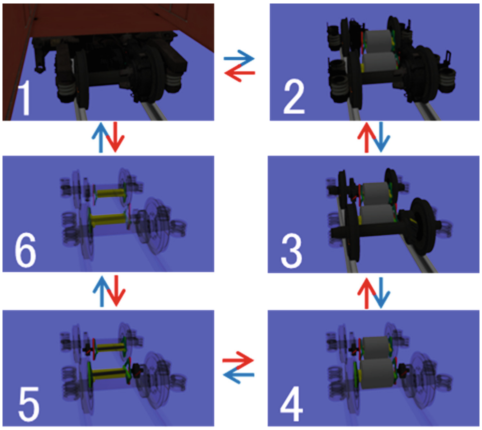

Fig. 10. Step-step transparency

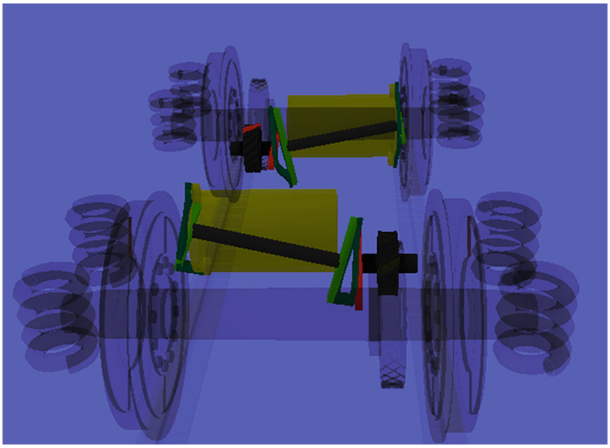

Fig. 11. Typical view of proposed contents (enable flexure plate, transparency mode 5)

4.2 User Study for Evaluating the Effectiveness of Magnification

We performed a user study to evaluate the effectiveness of the interactive switching method for the level of magnification as an approach to provide a deeper understanding of exhibits' mechanisms. We exhibited two types of interactive model, switching the method every other day. The first method enabled the visitor to switch the level of abstraction (with abstract switching condition). In this condition, the users could abstract the model shown in the DDCS step by step. Figure 8 illustrates each step and the pattern of level of abstraction switching with the abstract switching condition. The second method enabled the visitor to switch only the transparency of the parts that are unrelated to the principle of the mechanism (without abstract switching condition). This method was used in the previous study [3]. In this condition, the visitor could

Fig. 12. Exhibition of the DDCS at the Railway Museum

Table 1. Quiz to investigate user's understanding of mechanism

Q1	Allingment between the hollow shaft adn gear shaft in cross-section diagram
Q2	Allignment between the both flexure plates of gear shaft
Q3	Shape of the flexture plates (static secne)
Q4	Shape of the flexture plates (with misallignment between motor and gear shaft)
Q5	Atitude of gear shaft (with misallignment between motor and gear shaft)

switch the model between 1 and 2 in Fig. 8. We asked the visitors to take a brief quiz on the mechanism of the pendulum bogie to determine their comprehension. Each cooperating visitor took the quiz twice, before and after experiencing the sys-tem. We compared how the percentage of questions answered correctly increased after trying the system between conditions. We prepared two types of quiz; one with sixteen questions for adults, and another with sixteen questions for children. This is because the difficulty of the quiz related to abstract concepts depends on age. Based on the one for adults, we simplified the quiz for children (Table 1 and Fig. 13).

4.3 Results and Discussion

Figure 14 shows the average and standard deviation of the percentage of questions answered correctly under each condition. The number of cooperating adults was 10 for "small magnification" condition, and 8 for "large magnification" condition.

We used the student's paired t-test for the percentage of questions answered correctly by each participant in "before-experience" and "after-experience" conditions. This test revealed that there is a significant difference between the percentages of question Q2 answered correctly when the adults tried the test with the small

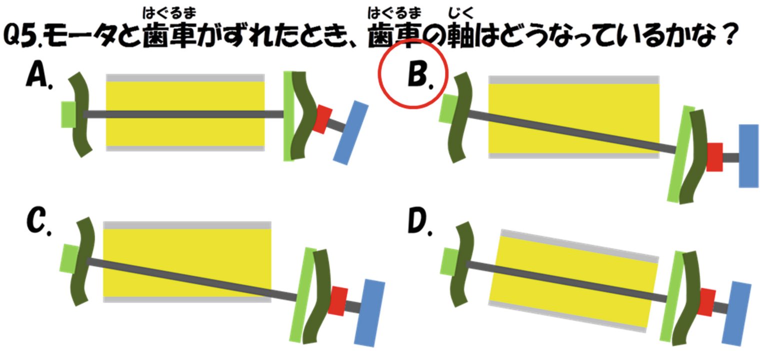

Fig. 13. Actual question to konw user's understanding of Q5

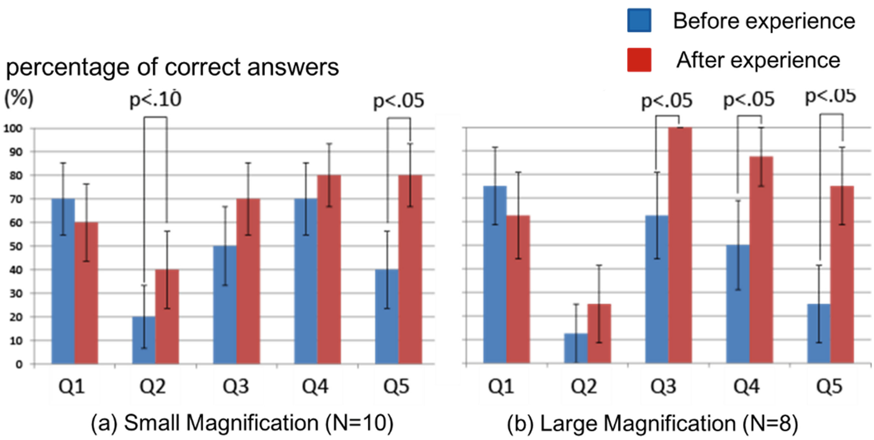

Fig. 14. Percentage of Questions Answered Correctly under each condition (Average and Standard Deviation).

magnification ($p < 0.05$). This test revealed that there is a significant difference between the percentage of questions Q3 and Q4 answered correctly when the adults tried the test with the large magnification ($p < 0.05$). The test also revealed that a significant difference between the percentages of question Q5 answered correctly when children tried the test with both small and large magnification condition ($p < 0.05$). There was no significant difference between the percentages of other questions answered correctly. These Q2, Q3, Q4 and Q5 are question to investigate user's understanding of function of flexure plates. These results indicate that the proposed method can provide a deeper understanding of the complicated mechanisms of hollow shaft parallel Cardin driving devices.

We asked participants to fill in a questionnaire with a seven-point rating scale and free descriptions after they experienced the exhibition. Almost all participants answer that they understand well and increase their interests about mechanism.

After the exhibition, we received a review of the system from the standpoint of the Railway Museum curators. The curators evaluated the visitors' reactions as very good, and reported that the exhibition was very effective in helping visitors understand the mechanism. On the other hand, they pointed out that they felt it was too difficult for visitors who were not familiar with physics to understand the principle of the mechanism, although they could grasp the way that the pendulum bogie works.

5 Conclusion and Future Works

In this study, we aimed to propose and construct an exhibition system enabling visitors to understand a dynamic mechanism of an exhibited artifact using a digital display case system that effectively conveyed background information about the exhibit. We chose a railway bogie as an exhibit with dynamic mechanisms and constructed the exhibition system such that visitors could interact with the railway bogie and comprehend its mechanism and function. We also exhibited this system at the Railway Museum. The usefulness of this system to convey the dynamic mechanism of exhibits was demonstrated in the reactions and opinions of visitors who had experienced it, in questionnaires, and in evaluations by the curators of the museum.

After the system was exhibited in a museum for this paper, we found that there were some points requiring improvement. During the exhibition, one or two docents were generally near the digital display case system and they explained the system to viewers. However, it is difficult to ensure that docents are always near the case in permanent exhibitions in museums. Therefore, we need to modify the system so that visitors are able to experience it intuitively and understand the background information that the museum wishes to convey about the exhibit, such as a dynamic mechanism, even if there is no docent nearby. Moreover, though this system was designed to convey the mechanism of railway bogies, we must improve it to convey other railway mechanisms or other types of exhibits. To do that, we believe it is necessary to examine the technique in this paper in more detail. Moreover, the system should be improved for experience by multiple users, as the current system cannot display an appropriate image for this situation.

We intend to introduce the digital display case system into permanent exhibitions in museums, and then to improve the system. In response to this exhibition, we learned that there are some points that should be taken into consideration if we intend to introduce the system into a museum. One point is that it is necessary for museums to make this system easier to manage. Moreover, we must adapt the system in consideration of the environment of the museum.

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References

1. Kajinami, T., Hayashi, O., Narumi, T., Tanikawa, T., Hirose, M.: Digital Display Case: Museum exhibition system to convey background information about exhibits. In: Proceedings of Virtual Systems and Multimedia (VSMM) 2010, pp. 230–233, October 2010
2. Kajinami, T., Narumi, T., Tanikawa, T., Hirose, M.: Digital display case using non-contact head tracking. In: Shumaker, R. (ed.) Virtual and Mixed Reality, HCII 2011, Part I. LNCS, vol. 6773, pp. 250–259. Springer, Heidelberg (2011)
3. Tanikawa, T., Ando, M., Yoshida, K., Kuzuoka, H., Hirose, M.: Virtual gallery talk in museum exhibition. In: Proceedings of ICAT 2004, pp. 369– 376 (2004)
4. Kondo, T., Manabe, M., Arita-Kikutani, H., Mishima, Y.: Practical uses of mixed reality exhibition at the national museum of nature and science in Tokyo. In: Joint Virtual Reality Conference of EGVE - ICAT - EuroVR, December 2009
5. Bimber, O., Encarnacao, L.M., Schmalstieg, D.: The virtual showcase as a new platform for augmented reality digital storytelling. In: Proceedings of the Workshop on Virtual Environments 2003, vol. 39, pp. 87–95 (2003)
6. Nakashima, T., Wada, T., Naemura, T.: Exfloasion: multi-layered floating vision system for mixed reality exhibition. In: 2010 16th International Conference on Virtual Systems and Multimedia (VSMM), pp. 95–98, October 2010
7. Wakita, W., Akahane, K., Isshiki, M., Tanaka, H.T.: A texture-based direct-touch interaction system for 3d woven cultural property exhibition. In: Koch, R., Huang, F. (eds.) ACCV 2010 Workshops, Part II. LNCS, vol. 6469, pp. 324–333. Springer, Heidelberg (2011)
8. Fritzson, P., Engelson, V.: Modelica – a unified object-oriented language for system modeling and simulation. In: Jul, E. (ed.) ECOOP 1998. LNCS, vol. 1445, pp. 67–90. Springer, Heidelberg (1998)
9. Fan, X., Zhang, X., Cheng, H., Ma, Y., He, Q.: A virtual experiment platform for mechanism motion cognitive learning. In: Shumaker, R. (ed.) Virtual and Mixed Reality, Part II, HCII 2011. LNCS, vol. 6774, pp. 20–29. Springer, Heidelberg (2011)
10. Gomes de Sa, A., Zachmann, G.: Virtual reality as a tool for verification of assembly and maintenance processes. Comput. Graph. **23**(3), 389–403 (1999)
11. Xin, X., Gangfeng, T., Xuexun, G., Menghua, C.: The study of automobile chassis design and development based on Digital Mock-Up. In: 2011 International Conference on Electric Information and Control Engineering (ICEICE), pp. 2814–2817, April 2011
12. Kiyama, R., Kajinami, T., Ueta, M., Narumi, T., Tanikawa, T., Hirose, M.: Digital display case to convey dynamic mechanisms of exhibits. In: The 18th International Conference on Virtual Systems and Multimedia, pp. 299–306 (2012)
13. Open Dynamics Engine. http://www.ode.org
14. Sreng, J., Bergez, F., Legarrec, J., Lecuyer, A., Andriot, C.: Using an event-based approach to improve the multimodal rendering of 6DOF virtual contact. In: Virtual Reality Software and Technology - VRST, pp. 165–173 (2007)