Wong, L.-H. et al. (Eds.) (2013). Proceedings of the 21st International Conference on Computers in Education. Indonesia: Asia-Pacific Society for Computers in Education

Virtual Environment for Pulley Experiment using Tablet-PC and Portable Haptic Device

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Abstract: In this study, a virtual experiment environment for pulley learning using a tablet-PC and portable haptic device (SPIDAR-tablet) is developed. A learner drags pulleys on a tablet-PC by finger to construct a pulley system. Then, the learner can experience weight corresponding to the constructed virtual pulley system by dragging a string on the display. The learner can conduct virtual experiments by various pulley systems to recognize the difference between weights through the haptic device by reconstructing the system. Additionally, a SPIDAR-tablet is added to the base for portability; thus, the developed system can be used as a single device. To verify the developed system, an experiment was conducted to confirm that the subject can freely construct the pulley system.

Keywords: Tablet-PC, Portable Haptic Device, Advanced Learning Environment

1. Introduction

Recently, learning support systems have been developed using information and communication technology. Many educational tools (such as video, pictures, and text) on the Web are utilized as e-Learning content, and many science education tools allow students to watch various science phenomena. However, learners cannot directly experience these phenomena. It is difficult for students in junior and high schools to experiment using instruments until the learner has acquired a basic knowledge of science. Moreover, performing scientific experiments outside school (such as in a home environment) is difficult.

To solve these problems, we developed a virtual experiment environment (Takamatsu, Matsubara and Iwane, 2008, Okimi and Matsubara, 2011) for learning about pulley systems. Takamatsu et al. developed a virtual laboratory (Takamatsu, Matsubara and Iwane, 2008) and used a haptic device for recognizing the change of weight by using different pulleys, allowing the learner to arrange a pulley system. This is an important step for pulley learning. However, the learner must construct a system in a virtual environment, which is limited in Takamatsu's system. Okimi et al. developed a virtual environment using augmented reality to improve the process of construction (Okimi and Matsubara, 2011). In this system, the learner arranges a pulley system by using AR markers corresponding to pulleys on a whiteboard. The PC captures the markers using a USB camera and constructs a pulley system based on the marker positions. This allows the learner to construct various pulley systems merely by arranging AR markers in a virtual environment and to experience force feedback. However, this system required some hardware: USB camera, AR-markers, whiteboard, and the haptic device (see Figure 1) with subsequent costs and preparation time.

To solve this problem, many researchers use a tablet-PC. Some examples of learning systems using a tablet-PC include Yamamoto *et al.* who developed an interactive environment for learning in digital storytelling (Yamamoto, Kanbe, Yoshida, Maeda, and Hirashima, 2012), and Liu who developed creativity support (Liu, Wu, Lu, and Lin, 2012). Another system used tablet-PC's interactive software in IC design courses to improve learning (Simoni, 2011). By using a tablet-PC, a portable virtual environment for pulley learning can be developed.

In the developed pulley learning system, the learner drags pulleys on display using only a tablet-PC; however, a tablet-PC cannot provide force feedback. Therefore, in this study, a two-dimensional haptic device is used to provide this. We modified a SPIDAR-tablet (Tamura, Murayama, Hirata, Sato, and Harada, 2011) to construct the system and added the haptic device to the tablet-PC, allowing the learner to perform virtual experiments on a single device and to experience weight by dragging a string on the display.

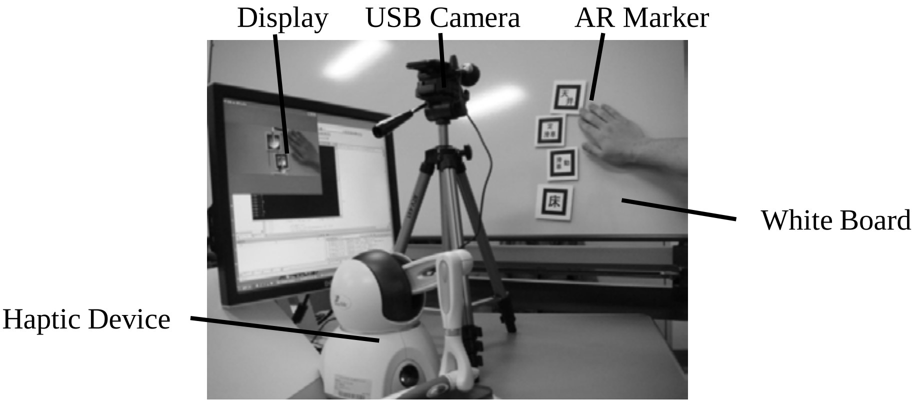


Figure 1. Overview of AR-based System (Okimi and Matsubara, 2011).

In the next section, the details of our system structure and proposed device are described.

2. Virtual Environment for Pulley Experiment

2.1 Virtual Experiment Room Structure

Figure 2 shows the overview of the system. The virtual experiment room is displayed on the tablet-PC. The SPIDAR-tablet is around the tablet-PC.

Figure 3 shows the virtual experiment room. Pulleys (three fixed and three moving) are located in a “parts container area” in the initial state. The learner constructs the pulley system by dragging these pulleys from this area to the “working area” at the center of the virtual experiment room. To modify the pulley system, the learner can return pulleys to the parts container area. Pulleys at the “working area” are recognized as a part of the system. Strings and loads are set for construction of a pulley system by touching the “set strings” button. Construction processes are performed automatically. After the “set strings” button is pressed, the movements of pulleys and loads are simulated while dragging the edge of the string. The sensation of weight is simulated from the SPIDAR-tablet. Additionally, the “experiment value area” (Figure 3, right) presents the value of a load and the length of the moving pulley. Confirming this area, the learner can experience the weights and be given value information corresponding to the experience. If the learner wants to change a pulley system, strings and loads are deleted from the pulley system by touching the “remove strings” button, then re-constructing another pulley system.

Figure 4 shows the framework of the proposed system. The virtual experiment room consists of components for pulleys and visual input information, which manages the visual information of the system and input from the learner. The components decide the pulley system and load’s position based on the pulley position. The haptic device receives the force information for providing feedback to the learner from the component parts.

Next, the method to construct a pulley system with the components is described. First, the system determines whether there are pulleys in the “working area.” If there is no pulley, the components do not create a system, even if the “set strings” button is pressed. If there are some pulleys in the “working area,” the components create a system on the basis of the pulley position. However, the system cannot create a system if pulley’s position is wrong. Then, the components can change the position of a moving pulley that is set in the wrong position. The algorithm for pulley system construction after changing the position of moving pulleys is shown below:

Step 1: Set the pulley on the far left as the checking pulley.
Step 2: If the checking pulley is a moving pulley, check the pulley on the right side.
Step 3: Otherwise, go step 6.
Step 4: If there is a fixed pulley or nothing on the right side of the checking pulley, mark the checking pulley as a candidate for a pulley connection load.
Step 5: Otherwise, connect the checking pulley and the pulley on the right side with a string.

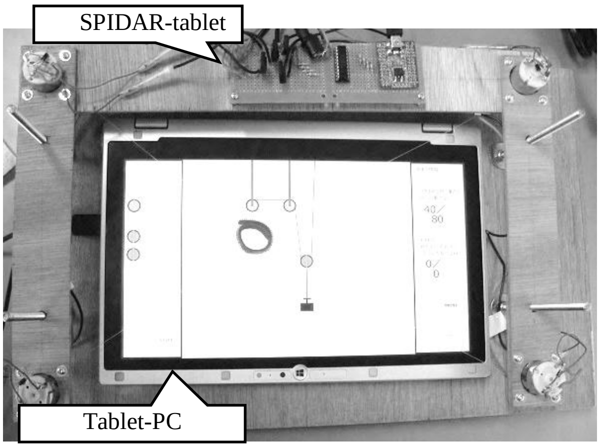


Figure 2. Overview of Proposed System.

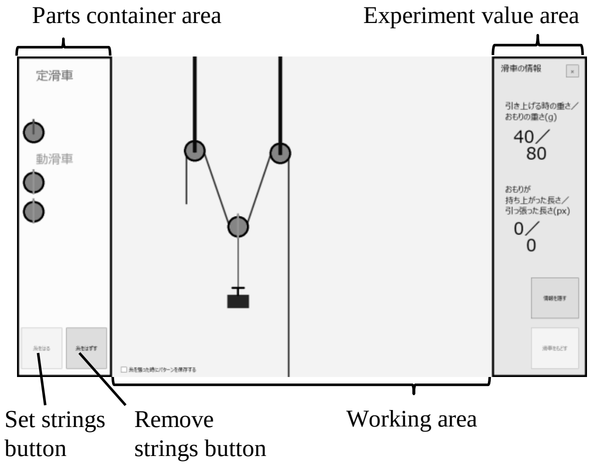


Figure 3. Virtual Experiment Room in Tablet-PC.

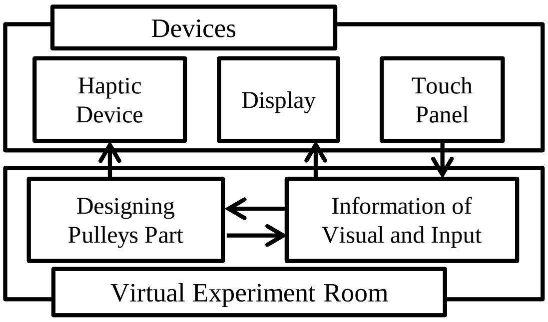


Figure 4. Framework of Proposed System.

Step 6: Set the pulley on the right side of the checking pulley as the next checking pulley and return to step 2.
Step 7: When all pulleys are checked, connect the load with the candidate pulley. If it is not a candidate pulley, connect the load after connecting their pulleys.
In this way, a pulley system with strings and a load is constructed from the arranged pulleys in the working area.

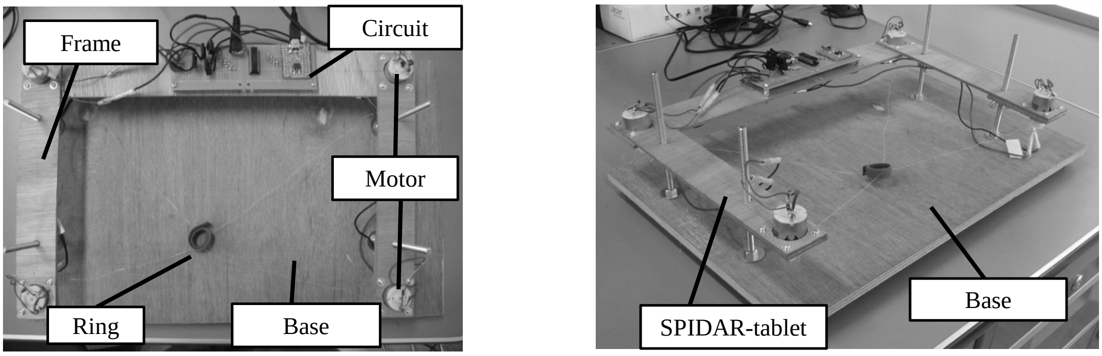
2.2 Haptic Device for Tablet-PC

The haptic device improved in this study is developed for a tablet-PC to add force feedback when the learner drags a string on the display. Figure 5 shows the overview of the haptic device, with Figure 5 (a) being the overview from above and Figure 5 (b) being the SPIDAR-tablet and the base. To recognize the difference in the weight by changing the pulley system, the haptic device is utilized as the feedback interface for a virtual load. The haptic device developed in this study is based on the SPIDAR-tablet (Tamura, Murayama, Hirata, Sato, and Harada, 2011). SPIDAR-tablet is a haptic device that presents two-dimensional force feedback. The learner fits the ring (Figure 5 (a) center) to experience the weight.

First, the frame of the SPIDAR-tablet is described. The frame's role is to hold the motors and the circuit. The motors are set on each corner of the frame. The string attached to the motor winds the pulley. As each string is pulled by motor rotation, the ring is pulled by the strings. If a learner puts the ring on one's finger, the learner can experience the force by rotation of each of the four motors. The two-dimensional force is presented to the learner by this process.

Second, the circuit that controls the motors is explained. To provide the desired force, each motor has to be controlled correctly. The circuit consists of various components (such as a programmable IC and four MOSFETs (metal-oxide-semiconductor field-effect transistors)) and is connected by a USB cable to the tablet-PC that gives the signals to control the circuit and supplies power to the motors.

However, the SPIDAR-tablet, as described above, lacks portability. Therefore, we modified it (Figure 5 (b)) with the haptic device underneath the tablet to create a combined device.



(a) Overview from Above (b) SPIDAR-tablet and Basement

Figure 5. Overview of the Developed Haptic Device.

3. Example of Learning Scenario

Table 1: Process of construction pulley system in the proposed virtual environment.

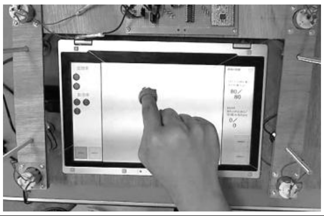
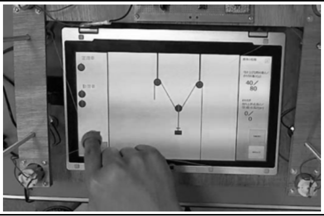
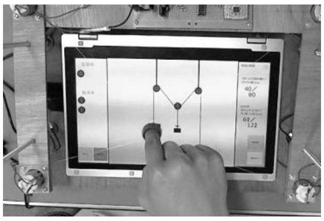
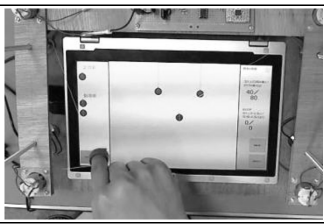
Process	System	Explanation
(1)		First, the learner arranges pulleys by dragging components to the working area from the parts container area.
(2)		When the learner arranges pulleys, the system decides the connection of pulleys and position of the load when the “set strings” button is pressed.
(3)		The system presents a simulation where pulleys and loads move, and the system provides force feedback. The simulation results are in the experiment value area displayed on the right side.
(4)		Strings and loads are removed when the “remove strings” button is pressed. Then, the system can be reconstructed.

Table 2: Example of pulley systems.

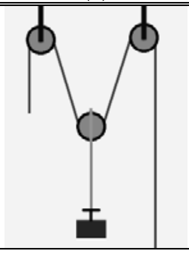
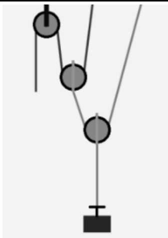
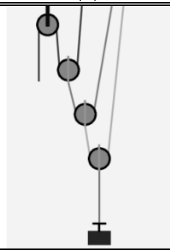
	(a)	(b)	(c)
Pulley system			
weight	1/2	1/4	1/8

Table 1 shows the process of constructing a pulley system in the proposed virtual environment. The figures describe the process: (1) arranging pulleys, (2) deciding the pulley system, (3) experiencing weight by dragging strings and the simulation load moves, and (4) removing strings and the load. The learner can construct various pulley systems and experience differences between weights in each pulley system.

Table 2 shows examples of pulley systems. The learner constructs the pulley system by the process shown in Table 1. The pulley system constructed by the learner is shown in Table 2 (a). The learner can experience a half weight of the load. Then, by adding a moving pulley to the system, as shown in Table 2 (b), they can experience a weight load of one-quarter. This can be reduced to one-eighth by adding a moving pulley as shown in Table 2 (c). By constructing the pulley system in Table 1, the learner arranges pulleys in a virtual environment and learns pulley's characteristic by changing the system.

4. Experiment of Pulley System Construction

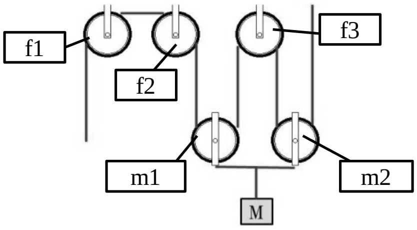


Figure 6. Pulley System Presented to Subjects.

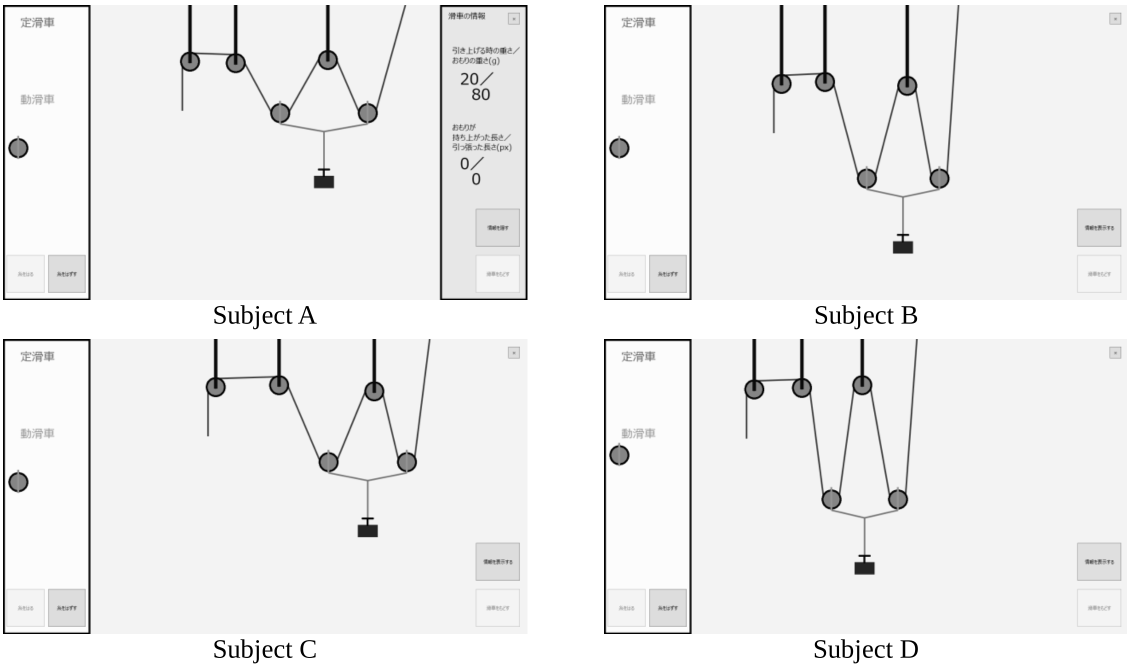


Figure 7. Pulley Systems Constructed by Subjects.

Table 3: Difference of process that subject arranged pulleys.

	Subject A	Subject B	Subject C	Subject D
Process 1	f1	f1	f1	f1
Process 2	f2	f2	f2	f2
Process 3	m1	m1	f3	m1
Process 4	f3	f3	m1	m2
Process 5	m2	m2	m2	f3

A verification experiment was conducted. Four college student subjects (A, B, C, and D) participated in the experiment. Each subject constructed a pulley system in the virtual environment. Subjects freely arranged some pulleys. Figure 6 shows the pulley systems presented to subjects, and Figure 7 shows the resulting constructions.

The difference in the arrangement of pulleys in Figure 7 was confirmed. None of the subjects arranged the pulleys in the same positions, although all subjects could correctly construct the pulley system. This result shows that a learner can arrange pulleys to construct a pulley system in a virtual environment without limitations on the location of pulleys. Next, the difference in the arrangement process of pulleys from Table 3 shows the difference in the construction of the pulley system in Figure 6. All subjects could construct the pulley system, even though most of processes in Table 3 are different. This result shows that there is no limitation in the process of the construction of pulley systems.

5. Conclusion

This study proposed a virtual environment for learning about pulleys through performing pulley system experiments using a tablet-PC and a SPIDAR-tablet. The learner freely arranges pulleys to construct a pulley system using dragging operation on a tablet-PC. The system can provide force feedback to the learner, which corresponds to the pulley system. The learner can reconstruct a pulley system simply by rearranging pulleys. Therefore, the learner experiences a virtual pulley experiment by various pulley systems to recognize the difference in weights through the haptic device. To improve portability, the haptic device is added to the tablet-PC, creating a single device with greater portability than systems using multiple devices. The system was verified and showed that there is no limitation on either the location of pulleys or the process of pulley system construction.

This research has been made possible through Grant-in-aid for Scientific Research C (No.24501199) from the Ministry of Education, Culture, Sports, Science and technology of Japan.

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