Effectiveness of Virtual Hands in 3D Learning Material

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Abstract. A virtual reality model for a motional electromotive force physics experiment, "Fleming's rail," was designed and developed. A hand gesture interface was constructed to control a virtual simulation using a Microsoft Kinect sensor and a finger-gesture interface SDK. A gesture-based object tracking test was performed to examine the effects of virtual hand visualization. In addition, motion trajectories of real hands with and without hand visualization were analyzed. Trajectories obtained with hand visualization exhibited higher Hurst exponent values compared with those obtained without virtual hand visualization. This suggests that the displacement change was more persistent with positive fluctuation feedback, indicating sensory feedback for real hand motions. For comparison, the effects of the model on learning Fleming's left- and right-hand rules were experimentally tested. Results exhibited that knowledge acquisition from the model was almost equivalent to that from the real experiment.

Keywords: Hand gesture interface, virtual reality learning material, Hurst exponent.

1 Introduction

In introductory physics, it is important to understand invisible physical quantities, such as force, energy, electric current, and voltage, because certain visible phenomena are explained from invisible physical quantities; e.g., a visible standing wave is explained as a superposition of two invisible waves traveling in opposite directions. To this end, mathematical simulations have been useful for generating visualizations of such physical mechanisms, and computer simulations have become popular as resources for learning [1].

Attempts have been made to apply virtual reality (VR) technology to the visualization of physics simulations in order to merge theory with real experiments and phenomena [2]. Such attempts have been partially intended for the correction of common beginner misconceptions [3]. The augmented reality technique is effective to visualize invisible components in real objects and phenomena [4]. In addition, projection mapping techniques are applicable to represent virtual components directly onto real objects and to make objects interactive using augmented reality.

With these approaches, one can interact with real physical objects by using virtual components that supplement these with physical properties. This will be effectively

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achieved by designing a natural user interface[5, 6] for the virtual components to be manipulated as real objects.

The purpose of this study is to develop a VR model for a physics experiment of motional electromotive force, i.e., “Fleming’s rail.” A hand gesture interface was introduced using a Microsoft Kinect sensor to manipulate the model. By using the hand gesture interface SDK provided by 3Gear Systems Inc., user hand gestures were exhibited as virtual hand gestures. The virtual hands manipulated the model’s components according to the user’s real hand motions.

This visualization is expected to help the user manipulate the VR model and explore the physical phenomena shown in it. In addition, this virtual experiment is conducted simultaneously with a real (i.e., non-virtual) version of the same experiment. Thus, the user can learn from both the real and virtual experiments at the same time.

In this paper, the motion trajectories of real hands are analyzed both with and without virtual visualization. Results showed that higher positive feedback for the motions was observed with the visualization of virtual hands. In addition, the effect of the model in attaining the basic knowledge of Fleming’s left- and right-hand rules was compared using the virtual and real experiments separately. It was concluded that the effectiveness of the virtual experiment was equivalent to that of the real experiment.

2 Methods

2.1 Development Environment

The gestural interface SDK that tracked hand and finger motion was provided by 3Gear Systems [7]. An application was constructed using Light Weight Java Game Library 2.9.0 with OpenGL for 3D graphics. The motion sensors used were a Microsoft Kinect for Xbox 360 and an ASUSTek Xtion PRO. The development and tests were performed on an Apple Mac mini with a 27-inch display. The Kinect sensor was set 65 cm above the surface of the desk where hand gestures were performed.

2.2 Model

Fleming’s rail consists of two long parallel rails on which a mobile conducting bar is mounted. The virtual model has a scale of 510 × 100 arbitrary units, which correspond to 510 × 100 mm as detected by the Kinect sensor.

The model is switched between generator mode and motor mode. In generator mode, the left sides of the rails are connected, thereby forming a circuit (Fig. 1 left). The mobile conducting bar can be moved according to the motion of the user’s right hand. As the conducting bar is moved in the magnetic field, the electrons of the bar are driven by magnetic force to generate an electric current within the circuit.

In motor mode, the left sides of the rails are connected with an external battery to form a circuit (Fig. 1 right). The electric current provided by the battery is again driven by magnetic force, and the mobile bar moves in the direction of the rail. In this mode, the voltage of the battery varies as per the height of the left hand.

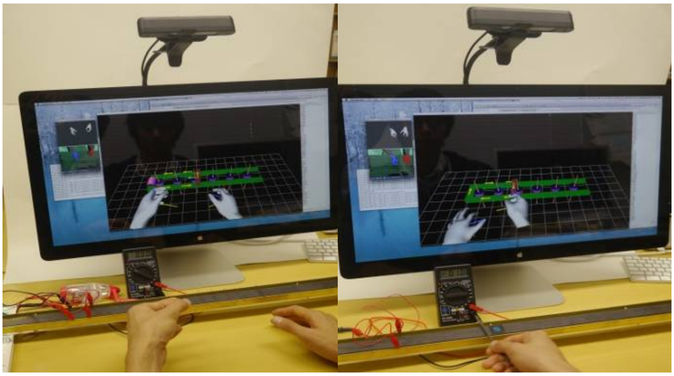

Fig. 1. Real Fleming's rail experiment and the VR model: (left) motor mode; (right) generator mode

Generator mode is initiated by a right-hand pinch gesture, and motor mode is initiated by a left-hand pinch gesture. For the motor, the directions of the electric current, magnetic field, and mechanical force are assigned to the middle finger, first finger, and thumb of the left hand, respectively. Similarly, electric current, magnetic field, and mechanical force are assigned to corresponding fingers of the right hand. In our model, the directions of these vectors are presented on the corresponding virtual hands; thus, the user can verify the relationships of these vectors by comparing them with those shown in the computer display.

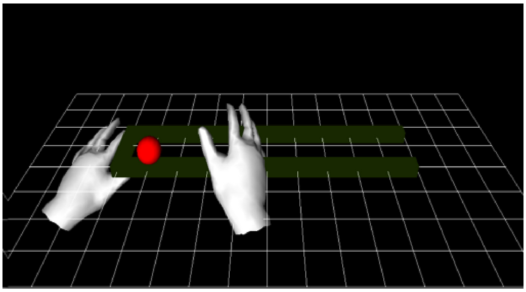

Fig. 2. 1D tracking test

2.3 Tracking Test

To compare the participant's hand motion with and without virtual hand visualization, a simple tracking test was introduced. A spherical object is generated at a randomly chosen position in the virtual space where the model rails are set (Fig. 2). When the participant's right hand point position collides with the sphere, it is moved to another randomly selected position. The position of the real hand was defined as the joint base of the middle finger. The participant tracks the sphere, and the Kinect sensor detects the trajectory of the user's hand motions. The sphere was generated in one, two, and three dimensions. For 1D tracking, the sphere was placed within $-230 \leqq x \leqq 230$

(arbitrary unit; corresponds to mm in real space), $y = 30$, and $z = 0$. The y-axis corresponds to a vertical line, and the z-axis corresponds to depth. For 2D tracking, the area for sphere motion was within $-230 \leqq x \leqq 230$, $y = 30$, and $-50 \leqq z \leqq 50$. For 3D tracking, the sphere appeared within $-230 \leqq x \leqq 230$, $30 \leqq y \leqq 130$, and $-50 \leqq z \leqq 50$. Under these conditions, the target sphere was captured approximately once per 20 frames of position detection.

During the tracking test, participants were asked to practice tracking in 3D for 30 s. Then, they attempted 1D tracking, followed by 2D and 3D tracking with virtual hand visualization. For each dimension, tracking continued for approximately 20 s and was repeated three times. The same procedure was repeated without the virtual hands. There were seven participants: four male and three female undergraduate university students.

For analysis, the following Hurst exponent H was calculated for hand motion trajectories. Let $x(t)$ be the value of a fluctuating variable at time t. Then, for arbitrary time difference Δt, the standard deviation $h(\Delta t)$ of the difference of the variable $X_t(\Delta t) = x(t) - x(t + \Delta t)$ tends to exhibit a power law, which is expressed as follows.

$$h^2(\Delta t) \approx \Delta t^{2H} . \quad (1)$$

The exponent H is the Hurst exponent. If the fluctuation is a non-correlated Brownian fluctuation, $H = 0.5$. Thus, as H increases, the change of fluctuation tends to sustain with the positive feedback. In turn, as H decreases below 0.5, development of fluctuation is suppressed with negative feedback.

2.4 Classroom Practice

To compare the effectiveness of the virtual experiment with the real one, a classroom practice study was performed. Thirty students from a literature class were divided into groups A and B and were made to take a pretest before the main instructions were provided. Group A, which consisted of 14 students (10 female; four male), was instructed using the VR model. Group B, which consisted of 12 students (eight female; four male), was instructed using the real Fleming's rails experiment. After the initial instruction, a posttest was carried out. For the second instruction, instruction materials were exchanged between Groups A and B. Finally, another posttest was performed. Each participant attempted to conduct the virtual experiment once.

The pretest and posttests consisted of two questions regarding the use of Fleming's left- and right-hand rules, and a 5-point Likert scale questionnaire was used to determine the confidence level of the answers. The degree of difficulty was slightly increased from the pretest to the second posttest.

3 Results

3.1 Tracking Test

Figure 3 shows examples of 1D hand motion tracking with and without virtual hand visualization. The range of hand motion in the x-direction is rather large for the case

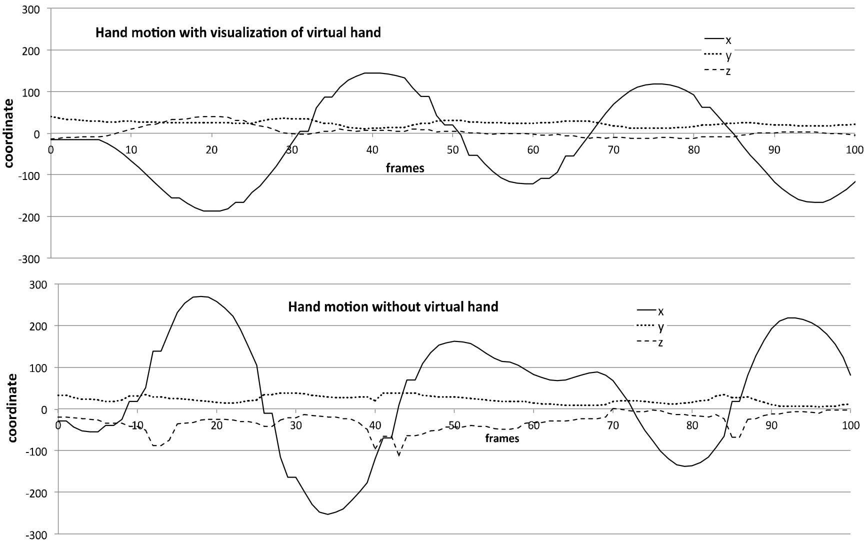

Fig. 3. Real hand motion trajectories for 1D tracking in x-, y-, and z-directions: (top) with virtual hand visualization; (bottom) with virtual hand visualization

with no hand visualization, which indicates that the rendering of the virtual hand reduces excessive motion. In addition, fluctuations in the y- and z-directions are smaller with the virtual hand, which indicates that the real hand motions are smoother and less excessive, and the user may be more careful when tracking motions.

Figure 4 shows log–log plots of Eq. (1) for 1D tracking with virtual hands. In the x-direction, the motion naturally persists and h_x increases. In the y- and z-directions, deviation is suppressed and motions are smooth with high H values.

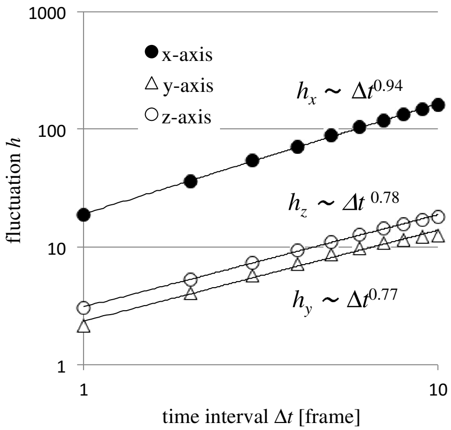

Fig. 4. Log–log plots of displacement h vs. time difference Δt for x-, y-, and z-directions for 1D tracking with virtual hand visualization

Figure 5 shows a comparison of Hurst exponent *H* of the hand motions with and without virtual hand visualization. This figure shows the results of trajectories for all three dimensions. Hurst exponent *H* for the motion with virtual hands showed higher values than without the visualization. This implies that both acceleration and deceleration toward the target were smoother and sustained when the virtual hands were displayed. Paired t-tests did not support the hypothesis that there would be no difference in the mean values of *H* with and without the virtual hands (significance level of 0.05); p-values were 2.0×10^{-5} for 1D tracking, 1.7×10^{-4} for 2D tracking, and 1.1×10^{-6} for 3D tracking.

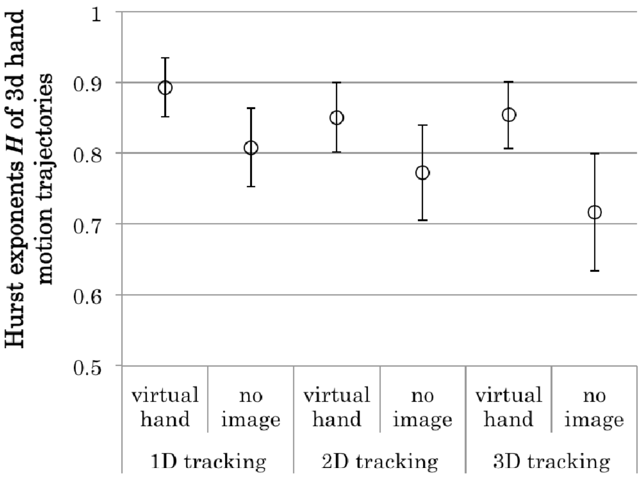

Fig. 5. Comparison of Hurst exponents of hand motion trajectories with and without virtual hand visualization for 1D, 2D, and 3D tracking (error bars show standard deviations)

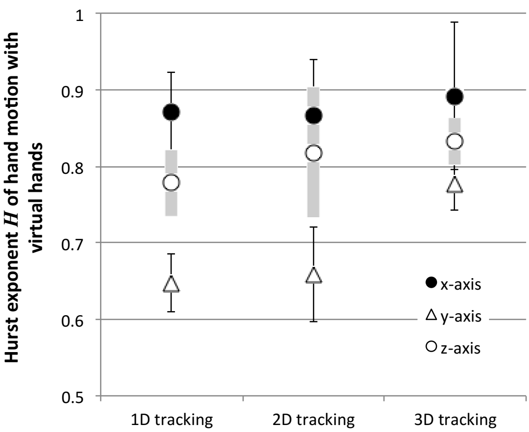

Fig. 6. Spatial dimensions dependency of Hurst exponents of hand motion with virtual hand visualization. The target sphere appears on the x-axis in 1D tracking, and it appears on the xz-plane in 2D tracking. The error bars show standard deviations; error bars for the z-axis are thick and light gray.

Figure 6 shows the dependence of Hurst exponent H to the spatial dimensions of tracking with virtual hand visualization. For 1D and 2D tracking, hand motion was primarily restricted to the xz-plane, which corresponds to the surface of the desk. In these cases, motion in the y-direction was not persistent; thus, more non-correlated randomness was observed, as is shown by the H-values that are close to 0.5. In 3D tracking, the range of motion was extended vertically, and the motion was also smooth, as is shown in the increased H-value as compared with the 1D and 2D tracking.

3.2 Classroom Practice

Figure 7 shows the rate change of correct answers. In addition, Fig. 8 shows the change of the self-confidence histograms for the participants' answers. Before instruction, 51% of participants strongly denied self-confidence, and the total rate of correct answers was 39%.

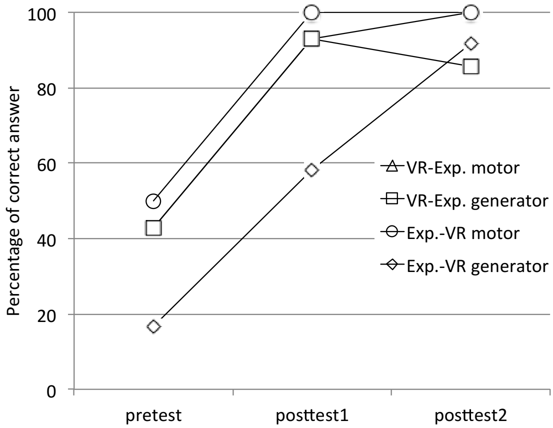

Fig. 7. Change of the percentage of correct answers for two types of instructions and two types of questions

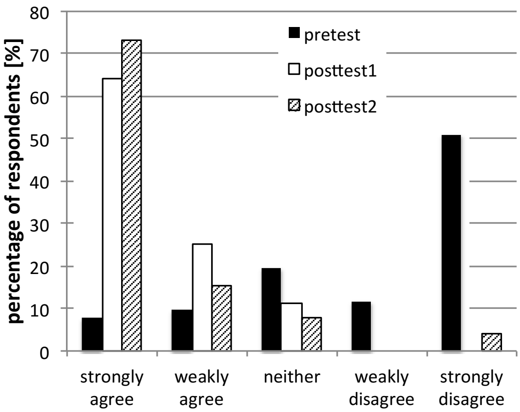

Fig. 8. Changes in confidence levels for student answers from the pretest and two posttests

After the first instruction, 64% of participants strongly agreed that were confident, and the total rate of correct answers was 87%. For the total seven failed answers, six cases were for the question on the generator, and five were from group B, which was first instructed with the experiment. This may partially reflect the fact that Fleming's right hand rule is not always taught in Japanese high schools. After the second instruction, 78% of participants strongly agreed that they were confident in their answers, and the total rate of correct answer was 94%.

The results, which show that the rate of correct answers increased and the distribution of confidence reversed, indicate that both the VR experiment and the real experiment were effective for learning Fleming's left and right rules. In addition, several subsequent tests were conducted for the same participants. The test results show that the rate of total correct answers obtained the following week was 83% and was 98% the week after that.

Figure 9 shows a comparison of confidence level histograms between the two instruction orders, i.e., from VR experiment to real experiment type (light color) and from real experiment to VR experiment type (hatched dark color). No obvious deviation was found between the confidence distributions of these instruction orders. A Welch two sample test showed that the hypothesis, i.e., the difference in means for the first posttests was expected to be zero, was supported at a significance level of 0.05 (p-value of 0.78). In addition, the test showed that the hypothesis for the second posttest was rejected with a p-value of 0.53.

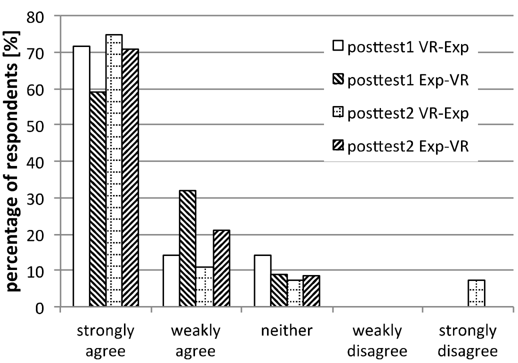

Fig. 9. Comparison of the student self-confidence histograms for two types of instruction through two posttests

These results suggest that the effectiveness of the VR model for learning Fleming's left- and right-hand rules does not differ between the real and virtual Fleming's rails experiments. However, from the descriptions of the impression of this entire session, many students commented that the virtual experiment was effective for confirming what was learned in the real experiment. This suggests that it is helpful in general to use VR material during or after a real experiment. In addition, some participants commented that this VR content was memorable because the virtual space manipulation was similar to the real experiment.

4 Conclusion

VR learning material for Fleming's rails was constructed, and a natural interface for manipulation was produced using hand gesture input through a Microsoft Kinect sensor. A virtual space object-tracking test demonstrated that the Hurst exponent of trajectories of real hand motions was higher when the virtual hands were visualized. This suggests that visual hand motion feedback results in smoother physical motion, which in turn facilitates more effective tracking.

Classroom practice revealed that the virtual experiment is almost equally effective as a real experiment for learning Fleming's left- and right-hand rules. By simulating hand manipulation, the VR material was a relatively natural and effective supplement to the real experiment. This may be partially due to the strong relationship between hand movements and Fleming's left and right hand rules. In this sense, the gestural interface may be applicable to learning materials that are related to somatosensory stimulation.

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