Development of Augmented Reality Teaching Materials with Projection Mapping on Real Experimental Settings

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Abstract. An augmented reality (AR) technology was applied in connection with a method of projection mapping to display physical quantities on real experimental settings. Physical quantities such as force and velocity were visualized by AR objects and projected onto real objects in an experiment. This image projection onto real objects was found to be effective in such a case where a user manipulates the real object resulting in changes of the magnitudes of physical quantities and the object position. The time delay between the motion of projected AR objects and the video images of real objects was measured on a simple rotating bar object. It was found that the phase delay between the AR objects and the projected image of the real object increased with the angular velocity of the object. The present method seems to be most relevant to static or quasi-static content in which user manipulation is included.

1 Introduction

Augmented reality (AR) provides an extension of the real physical world by adding virtual elements [1]. AR technology has also been applied to the development of educational materials. Learners can interact with real objects and phenomena through virtual components that bridge between real things and abstract information [2]. The possibilities and limitations afforded by AR for a collaborative and immersive learning environment have been discussed [3].

A fundamental problem of science education is that the visible world is explained on the basis of physical elements that are invisible, such as forces exerted on an object in dynamical systems and electric current and voltage in an electric circuit.

In this study, AR is applied to visualize physical quantities in real experiments. In addition, AR components are projected directly onto the real objects of an experimental setting. The projection of digital images onto the surface of real objects is called projection mapping or video mapping [4]. The addition of visualized AR elements onto real objects is expected to make the explanation of physical phenomena more effective.

In this report, based on an example of the vector sum of forces, we discuss a method of constructing a real experiment supplemented with AR elements. In the method, AR objects are used to avoid video feedback as well as represent physical

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quantities. Inquiries on the educational benefits of the content were conducted using students within a graduate school of teacher education. Finally, measurements of the delay time between the image display and the real moving object were conducted to evaluate the possibility of applying the AR projection mapping method to moving objects.

2 Method

2.1 AR Projection Mapping Method

AR contents were created using the ARToolkit [5] with OpenGL. Images of objects were captured by a C615 Logicool Webcam into a Panasonic Let's note CF-S10 laptop PC in which ARToolkit was installed. An EPSON EB-1760W 3LCD projector was used to project the generated AR images onto the real objects in the experimental setting.

Video image projection onto a target object causes a video feedback [6]. The video feedback typically occurs when a video camera captures its monitor images. Under conditions of video feedback, the marker images are replicated and the generation of AR objects based on the marker images becomes extremely unstable.

To avoid marker replication, an AR object as a mask was located on the video image of every AR marker, as schematically shown in Fig. 1. In the projected images, the projected AR objects masked the patterns of the AR markers. At the same time, the images of the mask AR objects illuminated the real AR markers, so that the video camera can capture the AR marker pattern to generate the AR objects.

In addition, the entire scene captured by the camera was masked with a large dark colored plane in order to not replicate the real images. With this overall masking, only the experimental instruments should be illuminated. This is required when the room illumination is lowered to make the projected image of AR objects clearly perceptible.

A common procedure to set up AR projection is as follows (Fig. 1)

1. A base marker is placed within the camera view but outside of the projection area.
2. A screen mask AR that masks the entire view of the scene is generated on the basis of the base marker. The screen mask AR is dark colored and avoids the occurrence of video feedback.
3. The base marker also provides a reference frame for other markers.
4. AR elements (AR objects that correspond to physical quantities, such as force vector arrows) are generated from the corresponding element markers. At the same time, an illumination AR (an AR object that illuminates the real marker pattern by projection) is generated for each marker. The color of the illumination AR is made changeable from black to white. When the room lighting is lowered to exhibit the AR elements better, the color of the illumination AR needs to be brighter to illuminate the marker pattern.

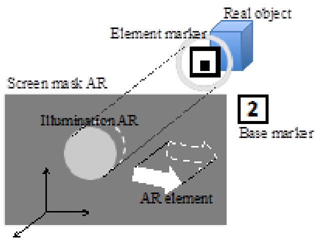

Fig. 1. Schematic representation of AR projection mapping. The entire projected area is masked by a Sscreen mask AR that has been generated from the base marker masks entire projected area. Illumination AR and AR element objects are generated from the element marker attached to the real object.

2.2 An Example of Teaching Material

In this section, an example of the content entitled “Force Vectors and Equilibrium” is briefly described. This content shows the vector summation of forces at equilibrium enabling the visualization of the tactile sensation of force.

As shown in Fig. 2a, a target weight was connected with two suspended weights of the same mass by means of strings hanging on pulleys. The target weight is in a state of equilibrium with the gravitational force directly on the weights and the tension of the strings in two directions. This system was set on the surface of a whiteboard using magnets to attach the pulleys. Two element markers (markers 1 and 2) were attached on the pulleys, and another element marker (marker 3) was fixed on the target weight. These markers provided the positions of the real objects, and three force vectors were calculated. Then, two tension vectors were generated from markers 1 and 2, and the gravitational vector was generated from marker 3. If one of the three markers were removed, two vectors appear in equilibrium.

A string connected to the target weight can be pulled by hand, as shown in Fig. 2b. If the user pulls the string, the summation of the above three forces becomes non-zero, and a net force acts on the system, causing reconfiguration to a new equilibrium state. The user can learn about the summation of force vectors through repetitions of predictions and experiments using this content.

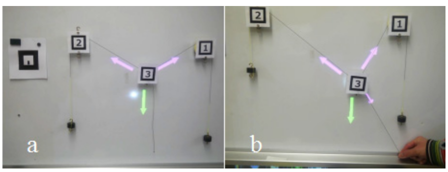

Fig. 2. Snapshots of the content entitled “Force Vectors and Equilibrium.” content. a: 2 two string tensions (upward) and 1 one gravitational force (verticaldownward) are in an equilibrium state. The markers associated with figure elements 1 and 2 correspond to tensions, while the marker associated with a figure element 3 shows a plumb. b: aAnother string tension of sting (left downwards and right) are is added by hand, and the former vectors change their direction. The Mmagnitude of the additional tension changes with the position of the hand.

2.3 Time Delay of AR Projection

First, a digital timer display was captured by the video camera, and its image output from the ARToolkit application without AR elements was projected onto the screen. Side-by-side display of the digital timer and its output image were videotaped, and the time difference between them was measured for each video frame. The time differences associated with the generation of additional AR objects were similarly measured. These additional AR objects were simple, static cubes of the same size.

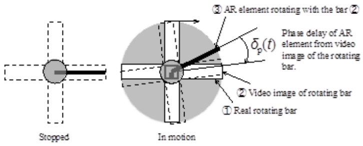

Fig. 3. Measurement of the phase delay of an AR object from the video image of a real bar configuration. Left: The AR bar (black bar) rotates with the video image of the bar configuration (broken line). Right: The video image and the AR bar was projected on the real bar rotating clockwise. Due to the delay times, the video image and the rendering of the AR object demonstrated a phase delay δ.

Second, a configuration comprising two crossed bars of 24 cm length was rotated along its center with a constant angular velocity. This simple apparatus was made using a LEGO EV3 robotic kit. A marker was placed at the center of rotation to generate a rotating AR object. By this marker, an AR bar was added and fixed on the video image of the bar. As the bar rotated, the marker and AR bar also rotated. The time delay was found between the real rotating body and the video image generated through the AR application. We measured the phase delay δ between the rotating AR object and the video image of the rotating body in the state of AR projection mapping, as shown in Fig. 3, for various constant angular velocities.

3 Results and Discussions

Our example content entitled "Force Vectors and Equilibrium" is designed for both learners and teachers. In this study, we asked 11 students of a graduate school of teacher education about the usage and possible effects of the present content. This graduate school is aimed at cultivating teachers who will play core roles at schools. Participants included four university students aged 20–29, and seven school teachers aged 20–60. Also, we interviewed six males aged 60–69 who had studied physics in their school days.

Fig. 4 shows histograms of participants' responses to the two questions: "Did you feel the change of force by moving the target point?" (left), and "Do you think manipulation of the object and force in this content is effective for understanding force?" (right). As a whole, we received positive responses on these questions. However, only one in seven schoolteachers chose "strongly agree" for the first question, and two in seven teachers chose "strongly agree" for the second question.

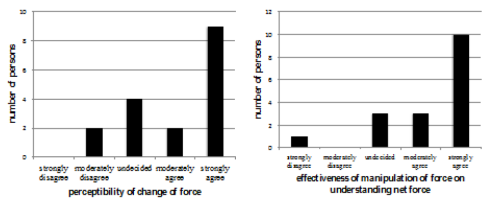

Fig. 4. Histograms of participants' response in using a 5- component Likert scales. Left: rResponses to the question, "Did you feel the change of force by moving the target point?" Right: rResponses to the question, "Do you think manipulation of the object and force in this content is effective on for understanding force?"

In the free comments of the teachers questioned, most of them admitted it was effective for learners to visualize the invisible physical quantity in the real experiment. However, they pointed out that it should be possible to change the original force (gravitational force) by adjusting the mass of the weights, and that quantitative expressions should be included. In this content, although the vector summation of forces changes with the position of the target weight, the extent of that change is not so impressively clear.

With respect to the other free comments, the participants particularly pointed out the disagreement between the motion of real objects and that of the AR elements. Figure 5**a** shows the measured time differences between the real clock and the video image of the clock with 0 to 3 additional AR objects. Without the rendering of additional AR objects, the time delay was 0.2 s. The delay time increased with an increasing number of simple cubic AR objects. Thus, perfect agreement between the motion of real objects and virtual images cannot be obtained by our system.

The above time delay study was for static content. For dynamical contents, the time delay between the video image and the change of the AR element should be considered. Figure 5**b** shows an increase in phase delay between the video image and the AR element for the apparatus described in Fig. 3 with increasing constant angular velocity. As the angular velocity was increased, the phase shift became extremely large, even for the case where only a single AR element was added. This delay of events has to be calibrated both in the interactive function of the content and in the motion content.

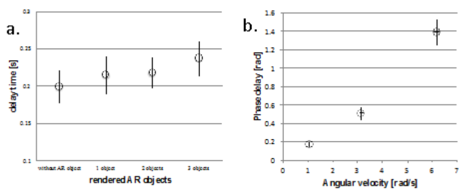

Fig. 5. Delay times of between an AR object display from and the motion of real objects. a: The difference between a real clock and the image of the clock in AR display with the rendering of 0 to 3 additional AR objects. b: The phase delay between the video image of a rotating object and the AR element object that rotates with the object at for various constant angular velocities.

In addition, if the marker was moved too fast, the AR application was unable to succeed in pattern analysis and failed to generate an AR element. In the above case, the marker was placed at the axis of rotation to reduce the frame loss.

4 Conclusions

In this study, an interactive teaching material on force vectors was created using a combination of AR technology and projection mapping. To avoid video feedback, both the real objects and the marker patterns were masked using AR mask objects. At the same time, the superposition of the screen mask AR and the local illumination AR controlled the brightness of projection illumination of the marker patterns.

This method enabled a visualization of invisible physical quantities on the actual experimental equipment. It also enabled a coupling of haptic sensing and visual perception in the content.

However, the process of image capture and projection was accompanied by a time delay. Furthermore, the time delay due to updating the positions of AR images increased with the velocity of marker motions. This may represent a strong restraint on the design method of contents that are based on AR projection mapping. An effective design method has to be developed in order to avoid creating misconception and confusion due to the time delay.

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