Charrot: Pseudo-haptics with Mid-air CG Character and Small Robot

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ABSTRACT

We propose Charrot, a novel pseudo-haptic approach for interaction with computer-generated (CG) characters that are displayed by mid-air imaging technology. Pseudo-haptic approach is based on the combination of the visual representation of the CG character movement and the vibrotactile cues. The vibrotactile cues are generated by a small robot that can be easily handled by children. We designed the movements of a CG character pushing or pulling the small robot. Experiments have been carried out to evaluate the interaction between the visual representation of the CG character movements and the vibrotactile cues. The results showed that the visual representation of the CG character movement can change the direction of the perceived force. We demonstrated a game that allows to interact with the CG characters using pseudo-haptics at the open campus of the University of Electro-Communications.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)** → **Interaction devices** → **Displays and imagers**

KEYWORDS

mid-air imaging, cross modality, animation

1 INTRODUCTION

Interaction with computer-generated (CG) characters has an appeal because users can play and work with characters that do not exist in the real world. We can find them in movies and animations; in a popular game Pokémon GO, for example, users can easily interact with such CG characters[1]. Through interaction, these CG characters that only exist in the imaginary world of movies and animations come to life in the real world.

We propose Charrot, a new method of interaction with CG characters in the real world. Augmented reality (AR) systems with a video see-through device are used for making CG characters appear on a screen of a game. We propose a method in which CG characters come off the screen with the help of mid-air imaging technology. Mid-air images are formed by the reflecting incident light and can be placed next to physical objects. By displaying CG characters using mid-air imaging technology, users get a feeling of reality of the CG characters.

We achieved such interaction by combining haptic feedback and visual representation by mid-air images. HaptoClone [2] is a system that shows mid-air images and provides haptic feedback via ultrasonic tactile display The experimental results of HaptoClone found that haptic feedback has the effect of causing mid-air images feel more realistic. As shown in Fig. 1, we displayed a CG character using a mid-air image display and generated haptic feedback by controlling a small robot.

Figure 1: Interaction by combining haptic feedback and visual representation in mid-air imaging system

2 RELATED RESEARCH

2.1 Interaction with CG Characters in the Real World

Aoki et al. [3] proposed Kobito, an interaction design with a CG character in the real world using haptic feedback. For interaction with CG characters, their system displays a visual representation on a liquid crystal display (LCD) and provides an indirect haptic feedback through a physical object. A device called SPIDER was used as a haptic display. By providing indirect haptic feedback using a physical object, users interact with Kobito in aggressive ways such as trying to crush Kobito with a physical object.

Mid-air imaging technology has enabled CG characters to go off screen. Kim et al. proposed MARIO [4] that offers an interaction experience with a CG character generated by a mid-air image display in the real world. They developed software by imposing a rule on the CG character's position. The CG character was placed at the highest point of the physical objects. The researchers realized that the users experienced a strong sense of reality when interacting with the CG character. In addition, they used physical objects that children could handle for interaction. Children tried to smash the CG character by swinging a physical object at it.

In our research, we designed an indirect haptic feedback method suitable for interaction using a mid-air image display. We adopted the interaction approach using a physical object that children can handle and the method of indirect haptic feedback.

2.2 Method of Haptic Feedback

For operating the movement of the CG character, we used a small easy-to-handle robot as a haptic feedback device.

We added visual representation to haptic feedback and used the pseudo-haptic feedback that was generated. Pseudo-haptic feedback provides haptic feedback using only visual representation. Hashiguchi et al. [5] changed the appearance of the physical objects by superimposing a liquid computer-generated image (CGI) onto it and thus controlling the sense of weight. Iwai et al. [6] visually controlled the sense of softness perceived by a user pushing a soft physical object. They displayed a two-dimensional deformation of the object's surface and changed the color of the pushing finger. These studies show that various perceptions can be controlled with only visual representation. Therefore, there is a possibility that haptic feedback can be provided by using some pushing or pulling movements of the CG character as visual representations.

3. PROPOSED METHOD

We used the optical design of EnchanTable [7] which projects mid-air images on the tabletop display. It uses a touch screen and a small robot for haptic feedback. In haptic feedback, we used pseudo-haptic feedback generated by a combination of vibrotactile cues and visual representation of the pushing and pulling movements of the CG character.

3.1 System

For the optical system design that displays mid-air images, we referred to the design of the EnchanTable. Fig. 2 shows the implemented system. "Aerial-Imaging Plate" (AIP) [8] consists of two layers of micro-mirrors, which are orthogonal to each other.

The incident light is reflected once in each layer of the AIP. The AIP can form a mid-air image at the position that is plane-symmetrical to the AIP.

The mid-air imaging display consists of a display (Apple, iPadPro), a touch screen (Dell, P2314T), an XY plotter (SmartDIYs, FABOOL Laser Mini), and an AIP (ASUKANET). The light emitted from the iPad becomes the incident light of AIP. The light through the AIP forms a temporary image I'. The light is reflected by the touch screen. The mid-air image is formed on the touch screen. The distances from the mid-air image to the AIP and from the iPad to the AIP are equal. When moving the iPad back and forth by the XY plotter, the mid-air image moves the same distance. When moving the iPad left and right, the mid-air image moves the same distance left and right.

Louver Film (LF, Lintec, W-0055) was used to disguise the optical system behind the desk. The LF diffuses the incident light traveling upward and transmits the incident light traveling downward (upward 0° to 55°: diffusion, other: transmission).
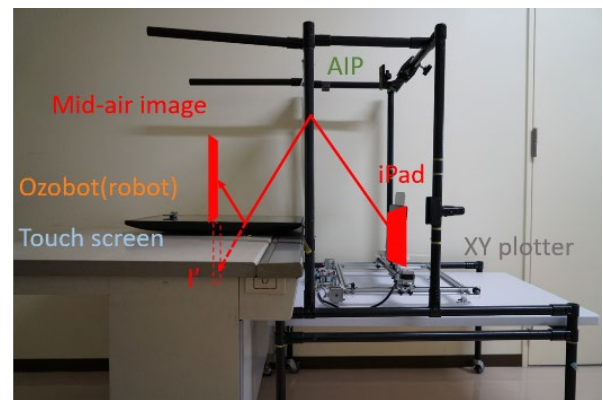

Figure 2: Implemented system

3.2 Small Robot for Vibrotactile Cues

We decided to use a small robot for the following three reasons. Firstly, it has no code. Secondly, it is of the size that children can hold with their hands. Finally, the position of the device can be recognized by the system. We selected a combination of a 3-cm robot (Ozobot & Evollve, Ozobot Bit) and a touch screen. This robot can be controlled by a program written in advance and can execute the program by the color sensor embedded in it.

4. DESIGN

4.1 Selection of CG Character

We prepared two types of CG characters: a close-to-sphere type named Red Jelly and a mannequin type. The reason for selecting the close-to-sphere CG character is that it can be easily seen even in low resolution. It is difficult to form high-resolution characters with mid-air imaging display. On the other hand, the mannequin type is better for representing human movements.

4.2 Movement Design for CG Character

For the experiment, we designed four types of movements for Jelly. We designed two types of movements of the CG character pushing a small robot and two types of movements of the CG character pulling a small robot. The two types of pushing movements are as follows: a movement of the CG character pushing the small robot while shrinking (movement A, upper left drawing in Fig. 3) and a movement of the CG character hitting the small robot while rotating (movement B, upper right drawing in Fig. 3).

In movement A, Jelly first moves to the left while shrinking, as shown by arrow 1 in the upper left drawing of Fig. 3. Then it returns to its original position while extending to the original width, as shown by arrow 2. The movements of arrow 1 and arrow 2 are alternately repeated. We referred to the representations that shrink when the CG character hits, in reference [9]. In movement B, Jelly first hits while rotating, as shown by arrow 1 in the upper right drawing of Fig. 3. Then it bounces while rotating as shown by arrow 2. The movements of arrow 1 and arrow 2 are repeated. This movement refers to the mobile game named "Touch! Kirby" [10] where Kirby moves and attacks with the movements like movement B. It also jumps when receiving an attack.
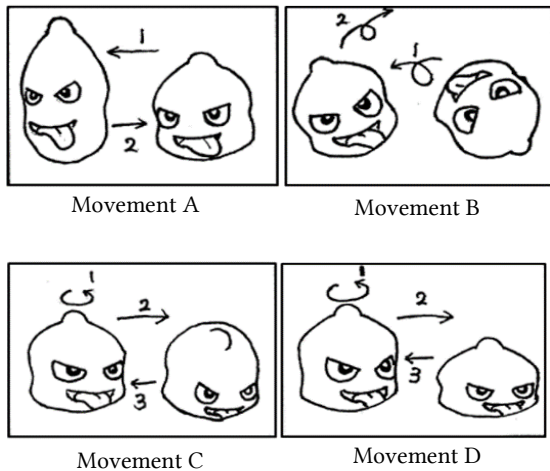

Figure 3: Movements of Red Jelly

The two types of movements of the CG character pulling a small robot are the movements of the CG character pulling while rotating (movement C, lower left drawing in Fig. 3) and a movement of the CG character pulling while shrinking (movement D, lower right drawing in Fig. 3). In movement C, Jelly directs the face to the participants as shown by arrow 1 in the lower left drawing of Fig. 3. Then it moves to the right while rotating, as shown by arrow 2. After that, it returns to its original position at the original angle, as shown by arrow 3. The movements of arrow 2 and arrow 3 are alternately repeated. These were selected after a discussion by the authors. In movement D, Jelly directs the face to the participants, as shown by arrow 1 in the lower right drawing of Fig. 3. Then it moves to

the right while shrinking, as shown by arrow 2. After that, it returns to the original position while extending to the original height, as shown by arrow 3. The movements of arrow 2 and arrow 3 are alternately repeated. We selected this movement because the shrinking representation was used as the representation for adding force in the reference [9].

Vibration cues time was set to 0.7 seconds as the vibrations need to be provided in a short time to represent the instantaneous force of movement B. On the other hand, the vibration time should not be too short because the small robot needs to vibrate reliably.

As a preliminary experiment, we verified that these movements are not incongruous in an exhibition and in an interview at the university open campus.

4.3 Movement Design for Mannequin

The movements of the CG character were created based on human movements. We measured the movements of human beings with the Microsoft device Kinect. We used a unity asset named Kinect MoCap Animator to apply human movements to characters.

Figure 4: Making movements of the mannequin CG character

Figure 5: applying human movements to the mannequin CG character

5. EXPERIMENT

The experiment verified the effect of the pseudo-haptics by combining the visual representations of the CG character

movements and the vibrotactile cues from the small robot. Using the interview report, we clarified the influence of the interpretation of the CG character movements on the perception of the direction.

5.1 Experiment Design

We evaluated four types of movements of the CG characters displayed by the mid-air imaging technology. The size of the CG character was about 1.2 times the size of the small robot. The CG character moved to the small robot in the horizontal direction from the participant's right when the participant was facing the CG character. The movement distance was 15 cm in every movement. The speed was 2.1 cm/s.

We chose the position of the small robot as close to the position of the CG character as possible because we displayed the movement of the CG character pushing or pulling the robot. Before the experiment, we visually adjusted the position of the small robot and the position of the CG character.

The small robot moved towards the participant's left side during 10 ms at 50 mm/s speed. Alternating between these movements, it provided vibrotactile cues. Then it returned to the right side at the same speed for 10 ms. We controlled the vibration of the small robot at 50 Hz. When the CG character started to push or pull the small robot, it vibrated.

5.2 Procedure

In the experiment, the participants were asked about the direction of the force that they perceived by the vibrotactile cues of the small robot.

Before the experiment, we instructed the participants to move the chair so that their body and face were located at the center of the width of the touch screen. In addition, as shown in Fig. 1, we instructed them to grasp the small robot lightly with the thumb and the index finger of the left hand and put the elbow on the touch screen gently. The participants were asked to try this procedure once to get used to it.

In the experiment, we randomly displayed the movements of the CG character. Five vibrotactile cues were generated by the small robot according to the movements of the CG character. Thereafter, eight arrows extending radially around the small robot were displayed on the touch screen in the range of 0° to 360° at intervals of 45°. Participants selected one of the arrows close to the direction of the force perceived by them. After each movement was finished, the participants could talk about the CG character's behavior with respect to the small robot. Each subject performed four trials for the four CG character movements. Eight adult volunteers (2 female and 6 male) participated in the experiment.
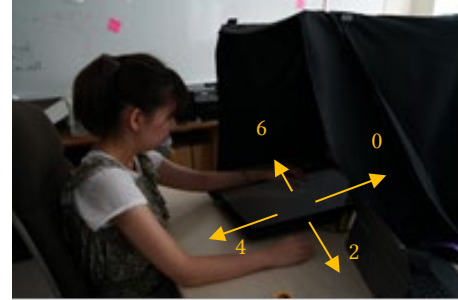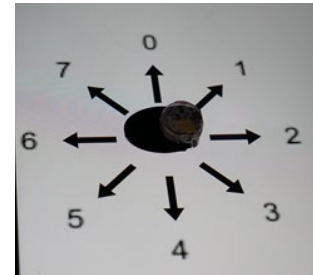

Figure 6: Experimental set-up

Figure 7: display of direction arrows

5.3 Result

The vertical axis in Fig. 8 denotes the correct answer rate. The horizontal axis denotes the movements of the CG character. We regarded the direction of force perceived by the participants that matched the movement interpreted by them as a correct answer. For example, if a participant feels that the CG character pushed, the direction in which the participant perceived the force is the arrow number 6 in Fig. 7.
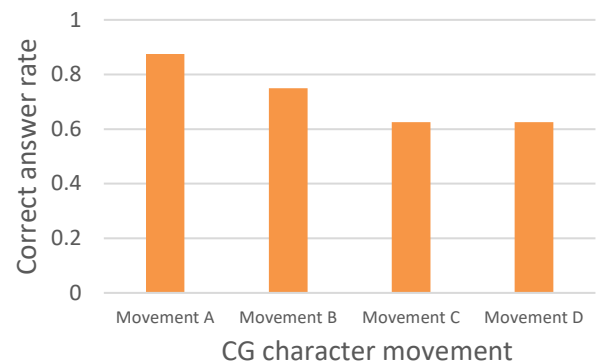

Figure 8: Correct answer rate

6. DISCUSSION

The participants understood the behavior of the CG character with interpretations unintended by the authors. When movement B was displayed, one of the eight participants interpreted it as pulling the small robot. According to the

interview report, the subject said that the small robot seemed to repel the CG character. It was expected that the direction of the perceived force would be the direction of arrow 2. It is considered difficult for the participants to perceive the direction of force intended by authors if the interpretations of the visual representations are different among the participants.

The correct answer rate for movement A was higher than for the other movements. This might be due to the time for which the CG character touches the small robot: in movement A it is the longest (1.5 seconds).

7. GAME

We designed a game using pseudo-haptic feedback. The game was exhibited at the open campus of the University of Electro-Communications and at a domestic conference in Japan.

Figure 9: Game

We selected a Santa Claus CG character for this game and displayed winter town graphics on the touch display. We thought that using a mannequin CG character would eliminate the difference in interpretation of the CG character movements among users. Santa Claus CG character is suitable for this game because he pushes and pulls things.

There are three steps in the game. First, Santa Claus is looking for a gift. The player puts the small robot that is dressed as a gift onto the touch display. Then Santa Claus finds the small robot and walks towards it. After that, Santa Claus pushes or pulls the small robot while walking. At the same time, the background is scrolled according to the movement of Santa Claus.

In this game, the player holds down the small robot and perceives pseudo-haptic feedback. Enemies such as bears come while Santa Claus pushes or pulls the gift. The player holds down the small robot and keeps its position to prevent the attack. When the player holds down the robot, the robot vibrates to provide pseudo-haptics.

8. CONCLUSION

We propose Charrot, a method of interaction with the CG characters in the real world. We achieved interaction by combining haptic feedback and visual representation using mid-air imaging technology. In our proposed method, we use the design of Enchan Table [7] with a touch screen and a small robot for haptic feedback. In haptic feedback, we used pseudo-haptic feedback generated by a combination of vibrotactile cues and visual representation of movements of the CG character pushing and pulling. The experiment verified the effect of pseudo-haptics caused by combining visual representation of the CG character movements and vibrotactile cues from the small robot. Experimental conditions were four patterns in total, with four types of movement of the CG characters. According to the results, the correct answer rate for the movement A was higher than for the other movements. We think that this is because of the time for which the CG character touches the small robot. The results indicated that the visual representation of the CG character movements causes the direction of perceived force to change, despite the vibration being the same. We created a game using pseudo-haptic feedback. The game was exhibited at the open campus of the University of Electro-Communications.

ACKNOWLEDGMENTS

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