Paper:

Dynamic Shadow Generation System Based on Shape Recognition

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This paper proposes a dynamic shadow generation system that combines the shadow of an object with the artificial shadows of virtual characters. In our proposed system, infrared light is used to capture an object's shadow in order to discriminate between a shadow generated by an object and a virtual shadow generated by the system. Our proposed system determines areas in which shadows do not appear and then the shadows of virtual characters are added to these areas. This paper presents the basic idea of the system, the shadow generation algorithm that it uses, and an empirical study on the sharpness of a generated shadow, along with the distance between an object and a screen used in this system.

Keywords: artificial shadow, shape recognition, image processing, infrared ray

1. Introduction

The shadows that appear when sunlight or artificial light (e.g., fluorescent light) is blocked are familiar to us. The shadow that appears when light is blocked takes the form of a two-dimensional dusky image that reflects the object's shape and motion. We focus on these features. A shadow is easy to process because it is two-dimensional and dusky and moreover it can surprise users by contrary change to an ordinary shadow that reflects the object's exact shape. However, if a shadow shows regular changes, users may get tired of such monotonous expressions. Thus, our research attempted to create a dynamic artificial shadow by selecting dynamic images based on a shadow's shape and combining these with the shadow. A shadow is a physical phenomenon that is generated by blocking light. It has a one-to-one relation to the shade object. Therefore, when a shadow's motion does not correspond to a shade object's motion, media art is created by filling the gap between the shadow's motion and the shade object's motion. A dynamic shadow makes the gap, and this gap is expected not to tire users. In addition, a change in expression is expected to interest users, that is, we expect the system to stimulate positive interaction such as a change of the objects making the shadow.

2. Related Works

We can classify the existing systems into three types according to the utilization of the shadow: (1) the utilization of a real shadow, (2) the processing of token areas of a shadow from a camera, and (3) the utilization of CG images without a real shadow. The following are systems that use each of these utilization methods.

(1) Utilization of Real Shadow

Kato et al. proposed "Graphic Shadow" [1], which gives coloring to a shadow. That system uses two projectors. When a user blocks light from either projector, the image is projected from the other projector in the shadow's area. This colored shadow gives a user a different impression from that of an ordinary shadow.

Kuwakubo created a work of media art called "the Tenth Sentiment" [2]. This work shows the changes in a shadow produced by the changes in the position of a light source. When a model train with a high brightness LED runs in a dark room where various objects are placed, the shadows change dynamically as the LED on the model train moves. This gives users the sense that the shadows seem a view from a train window.

(2) Acquisition and Processing of Shadow Areas

The system "Split Personality" [3] by Kurosaki et al. provides users with a surprise. An infrared camera captures images of the motion of a user's shadow projected by infrared rays, and these images are later displayed as the user's shadow. Therefore, the user's motion does not coincide with the shadow's motion.

Yamamoto et al. proposed "PALMbit-silhouette" [4], which makes semitransparent shadows from images of a user's hand taken by a camera on a desktop and operates icons by the motion of the user's hand such as clenching and opening. This system allows users to perform operations as if they were moving a real object.

(3) Utilization of CG Images

"KAGE" [5], which was created by Chikamori et al., projects CG images as the shadows of conical objects from above. The objects have touch sensors, and the shadows are changed by the user's touch.

"Augmented Shadow" [6], which was created by Moon, turns cubical objects into houses in a shadow world displayed on a table, and the existence of light causes various changes in the shadow world. Images that are different from reality can be seen as the shadows because the images move with the objects.

Our proposed system uses the method of acquiring and processing the shadow areas from a camera image. This allows a greater use of expressions that are not limited by the shape and color of the shadows, as compared to a system that just uses real shadows. Moreover, we believe that this is easier than a system that just generates CG images as artificial shadows.

3. Impression

Our research proposes a method for generating a dynamic artificial shadow by changing an image based on the shape of an object's shadow. In our proposed system, the object used to block the light has holes cut out so that bright areas appear in the generated shadow. A dynamic image is selected based on the arrangement and on the number of these areas.

3.1. Structure of System

Our proposed system includes an infrared light, infrared camera, computer, and screen. **Fig. 1** shows the structure of our system. The system uses infrared rays to generate a shadow to avoid mixing the real projected shadow with an artificial shadow. This is done because the proposed system projects both an artificial shadow and a real shadow at the same position on the screen. If the system used visible light instead of infrared light to generate the real shadow, the real shadow on the screen could disappear because of the light from the projector. Although it is possible to generate a real shadow using the light from a projector as the light source, it is difficult to change the shadow's shape and color because the real projected shadow is visible. The infrared light source is an infrared LED with a peak wavelength of 945 nm. To obtain an object's shadow using infrared rays, a web camera with an attached filter for light with a wavelength greater than 850 nm is used as an infrared camera. The screen is made of tracing paper so that an artificial shadow can be projected from behind the screen. A shaded object has clipped areas. A shadow does not appear in these clipped areas, and the areas in which a shadow does not appear are detected.

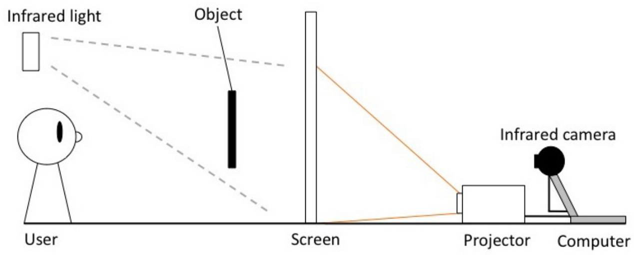

Fig. 1. Structure of proposed system.

3.2. Process of System

The following five processes are used in this system:

(1) generation and capture of a shadow

(2) calibration of camera images

(3) area detection

(4) combination of shadow and images

(5) projection of artificial shadow system

We developed the image-processing programs using Processing and used the image-processing library OpenCV to detect bright areas. OpenCV was written for C/C++, but that used in our system has limited functions for Processing.

3.2.1. Generating and Obtaining Shadow

First, the system generates a real shadow based on the generation of an artificial shadow. When an object moves between an infrared light and screen to block the infrared rays, the object's shadow appears on the screen. A user cannot see this shadow because it is generated by infrared rays. Thus, the user sees nothing on the screen. An infrared camera captures this shadow that is unseen by the user. After the infrared camera behind the screen obtains the shadow, it sends the acquired images to the computer in real time.

3.2.2. Calibration of Camera Images

Because of the difference in the ranges of the camera and projector, the camera images are warped. Therefore, the camera images do not accurately represent the position of the shadow (**Fig. 2(a)**). Thus, it is necessary for the system to calibrate the camera images. In this system, we determine the points of the screen's four corners from the camera images, and a projective transformation calibrates the images. This system transforms the screen in the camera images into the projection area shown in **Fig. 2(b)**. We determine four corners' points when the system starts up, and the system transforms the camera images whenever the camera acquires the images. We referred to a projective transformation program by Sekiguchi for the calibration program.[1]

1. http://unitedfield.net/2010/06/processing/

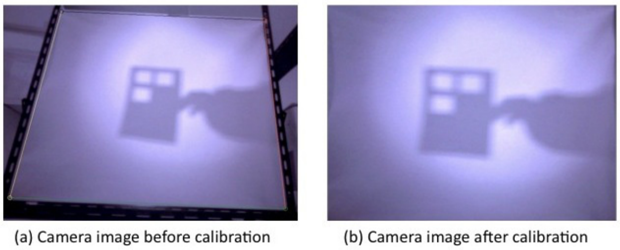

Fig. 2. Calibration of camera image.

3.2.3. Area Detection

Binarization is used for the calibrated images to simplify the shadow recognition, and white areas are detected from the binarized images. In this implementation, we used a binary threshold of 140 because we were able to acquire clear shadows with this setting during the implementation and experiment. This threshold value can be changed based on the situation. When our proposed system detects the white areas made by the object's holes using OpenCV, unnecessary detections are prevented by setting the maximum size of the areas (9600 pixels in this implementation) and the minimum size of the areas (300 pixels in this implementation). After detection, the size of each area and information about the areas' dimensions (x and y coordinates at the upper left, height, width) are obtained.

3.2.4. Combining Shadow and Images

The coordinates of the detected areas are used in the recognition of the areas' arrangement such as their horizontal and vertical relationships. We can thus prepare patterns of the areas' arrangement in advance. If a pattern that matches the areas' arrangement exists, images having motion based on the areas' arrangement are combined with the object's shadow. If a pattern does not coincide, images having independent actions are combined. We set a range for each area for the patterns. If there is another area in the set range, these areas coincide with the pattern (**Fig. 3**). This system uses gif animation images for the combined images to express motion.

3.2.5. Projection of Artificial Shadow

A projector set behind the screen projects the combined image as an artificial shadow on the screen. Although this artificial shadow is projected on the same screen with the object's shadow, users can only see the artificial shadow, whereas the infrared camera can only see the object's shadow because infrared rays are used to create the object's shadow. Therefore, the artificial shadow is not combined with the object's shadow.

3.3. Application

Our proposed system generates an artificial shadow that expresses a scene with small moving characters, as if small virtual people were living in a shadow world. This

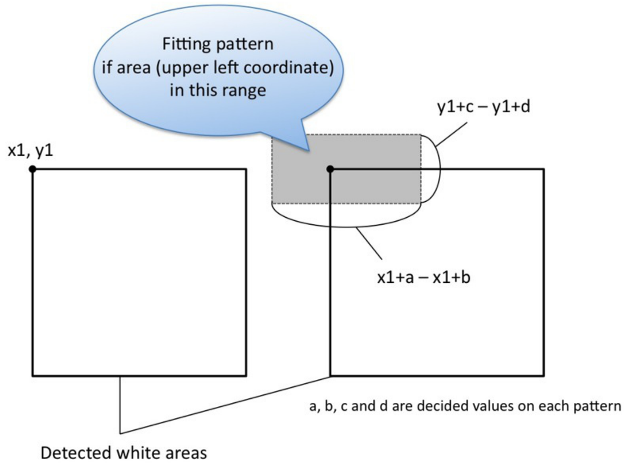

Fig. 3. Checking on arrangement of windows.

Fig. 4. Object with building shape.

system uses an object made of paper, which imitates the shape of a building. The clipped areas from the object are regarded as the windows of the building. When an object's shadow is projected, the window regions where the shadow does not appear become the detection targets. An artificial shadow expresses a scene where small characters live in each room by displaying moving character images in each window (see **Fig. 4**).

Our proposed system judges whether or not two windows adjoin. If a window is located next to another window, the small characters displayed in these windows show mutually synchronized motions. **Fig. 5** shows an example of a generated image. Changes in the characters' behavior arise based on the arrangement of the windows in the building. As shown in **Fig. 5(a)**, images depicting the independent motion of each character are displayed in the windows because the two windows do not adjoin. In contrast, **Fig. 5(b)** shows images of the characters in the windows waving their hands at each other.

Figure 6 shows an example of the actual interaction between a user and the system.

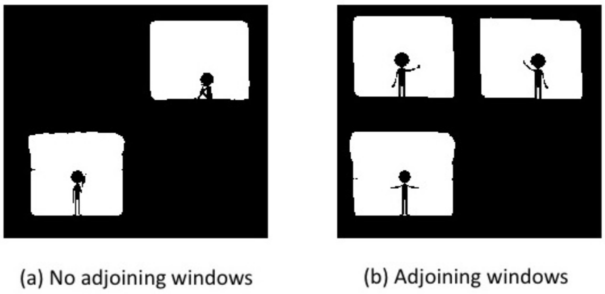

Fig. 5. Example of projected images.

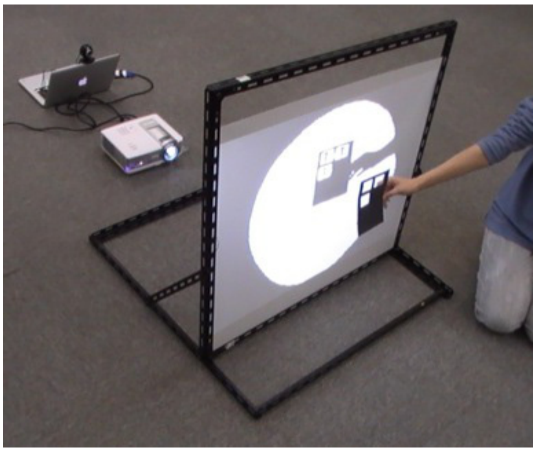

Fig. 6. Interaction between system and user.

4. Verification Experiment

We confirmed the recognition ratio of an object's shadow in accordance with the position of a shading object. The purpose of the experiment was to examine the distance at which our system generates the expected artificial shadows and the type of shadows that are generated at other distances. The distances of the infrared light, projector, and infrared camera from the screen were 300, 85, and 110 cm, respectively. We used an object that had the shape of a building with two adjacent windows and a single window under them (see **Fig. 2**). The dimension of each window was 30 mm by 35 mm, and the distance between the windows was 15 mm. We placed a shading object in different positions 10-cm increments away from the screen to verify what type of artificial shadow and real shadow were generated at each position.

In this experiment, we determined that the most suitable state of the shadow involved reflecting an object's shape and then displaying images in all the white areas based on the object's arrangement of cutout areas.

Table 1 lists the results of the experiment. The shapes of the artificial shadows were evaluated to determine whether they reflected the shapes of the real shadows. From **Table 1**, if the shape of an artificial shadow reflected the shape of a real shadow, especially parts of the shadow between windows, an open circle was marked; otherwise, a cross was marked. When the results changed because of the movement of the object, a triangle was marked. Similarly, the evaluation of the recognition ratio for the artificial shadows was based on whether characters appeared in all of the windows and whether the motions of the characters in adjacent windows were connected to each other. If these conditions were satisfied, an open circle was marked. If not, a cross was marked. When the results were changed by the movement of an object, a triangle was marked. The movement of the object was a result of holding the object in our hand while the system was generating its shadow.

Figure 7 shows four artificial shadows observed at different distances from the screen. When the position of the object was less than 20 cm away from the screen, the object's shadow appeared clearly and the generated artificial shadow reflected the object's shape. However, the adjoining white areas were not recognized, and the character images displayed had only independent motion. This is because the adjoining areas were too small for the system to detect. When the position of the object was 20 cm to 90 cm, the projected object's shadow was clear, and the artificial shadow reflected the object's shape. These generated artificial shadows were the most suitable because the character images displayed in the white areas were connected to each other. When the position of the object was 100 cm or more from the screen, the shadow projected between the windows was fuzzy and the upper windows were connected in the artificial shadow. Moreover, when the position of the object was 120 cm from the screen, the entire outline of the projected shadow was fuzzy. This implies that the white areas were not created, and the artificial shadow did not reflect the object's shape well.

According to this verification, the generated artificial shadow seemed to be the most suitable when the distance of the object from the screen was between 30 cm and 70 cm.

5. Evaluation Experiment

We performed an evaluation experiment over three days from October 18, 2011, in our university. Twenty-seven students (17 males and 10 females) 18–24 years of age participated in our experiment. We next describe the process used for this experiment. First, we explained to the test subjects that they could generate shadows freely while we ran two programs. We then made them use their hands and objects to create shadow pictures while we ran a program that only projected shadows. Next, we had them use objects shaped like a building with a program that combined shadows and characters. After that, we explained that the characters would appear in the white areas, and we let them play freely (see **Fig. 8**). Finally, we asked them to fill out a questionnaire. We had them answer questions about the program that combined the shadows and characters compared with the program that projected only shadows. The following gives the contents of the questionnaire.

Table 1. Verification results.

distance [cm]	10	20	30	40	50	60	70	80	90	100	110	120
reflection of shadow's shape	○	○	○	○	○	○	○	△	△	△	×	×
result of recognition	×	△	○	○	○	○	○	△	△	×	×	×

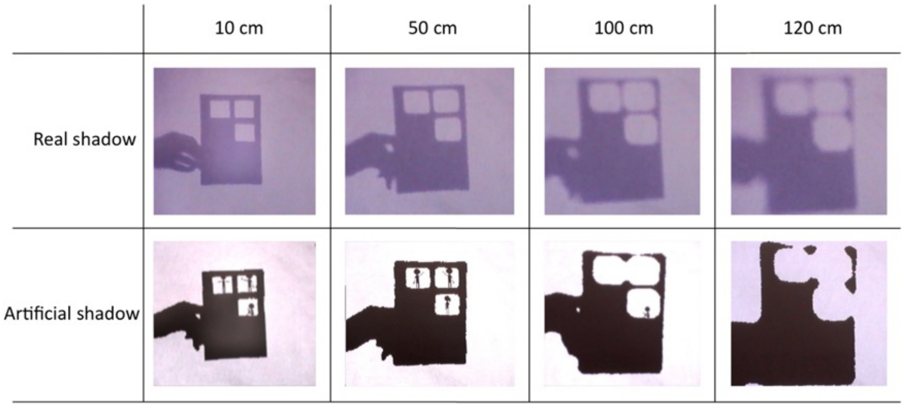

Fig. 7. Real shadow and artificial shadow.

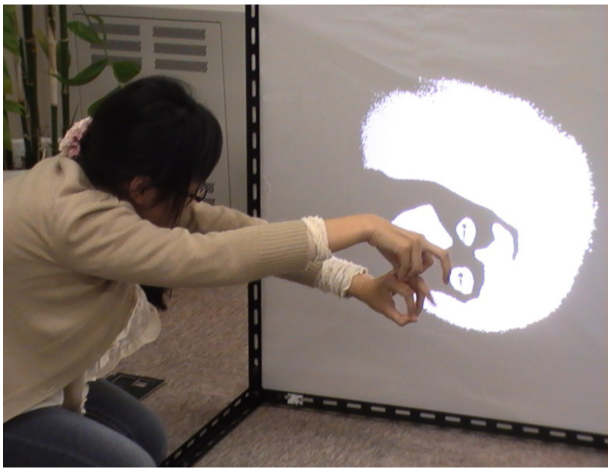

Fig. 8. Scene from evaluation experiment.

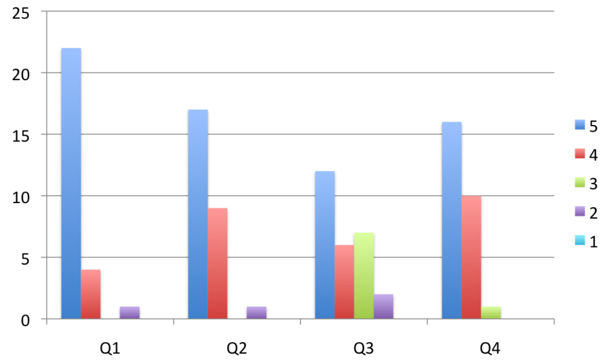

Fig. 9. Results of questionnaire.

Q.1. Did you enjoy playing with our system?

Q.2. Did you want to play positively?

Q.3. Did you feel bored immediately?

Q.4. Did you want to see it again?

We had them answer these four questions using a 5-Likert scale (1: negative impression, 5: positive impression). Moreover, we asked them whether or not they noticed that the motions of characters in adjacent windows were connected and what their impressions were of our system. The graph of **Fig. 9** shows the results of the questionnaire. Our system received a high evaluation in all of the questions. The average values of Q.1, Q.2, Q.3, and Q.4 were 4.74, 4.56, 4.04, and 4.74, respectively. Therefore, we determine that they enjoyed our system more than the projection of just the shadows. However, some of them were bored immediately. One of the reasons was that our system had few motions for the characters. Seven subjects (almost 25%) noticed the connections between the characters. We think that the characters needed to have more obvious motions such as moving back and forth as if visiting each other for the connection to be noticed by a large number of users.

Most of the subjects made characters appear in a circle that they made by using their hands, after we explained the mechanism of our system. Moreover, some of them placed the building-shaped objects next to each other and made characters wave their hands to the characters in the next building. Based on the subjects' impressions, we found that most of them were surprised and interested. Therefore, we believe that our system will attract the interest of users and cause a positive interaction, as compared with the projection of shadows only.

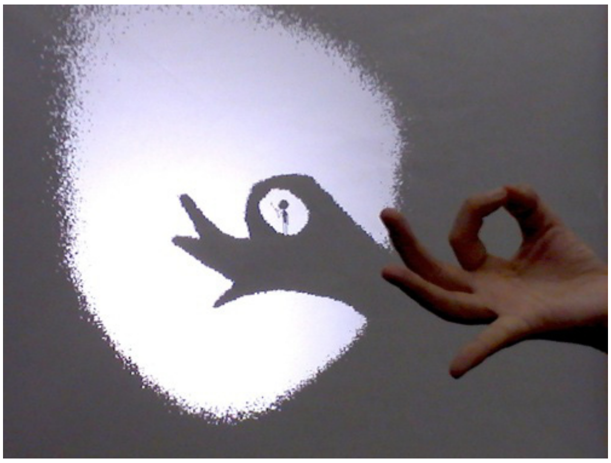

Fig. 10. Using fingers as object.

6. Exhibition

We exhibited the system at our university's open day for new students, which was held on Oct. 30th, 2010. This event was attended by 351 people. There were various sections in this event, and we exhibited our system at the research introduction section. After that, we asked attendances to fill out a questionnaire about our event, and 241 questionnaire sheets were returned. Based on this questionnaire, 95 people (almost 27% of attendances) visited the section where the system was installed. This questionnaire asked their satisfaction of our section using the 5-Likert scale (5: very satisfied, 1: definitely unsatisfied) and we found that 35 of the 95 people selected "5: very satisfied," whereas 44 selected "4: relatively satisfied." Only 1 participant selected "2: relatively unsatisfied" and 2 participants selected "1: definitely unsatisfied."

Our exhibition seemed to be better received than other exhibitions at our university's open day. When an object was placed in front of the projector, visitors were surprised that characters appeared in the white regions, and then they observed the characters following the shadow.

We observed that some of the visitors tried to make a shadow with their fingers to make characters appear after they understood the function of the system (see **Fig. 10**), that is, they were having positive interaction with our system.

7. Concluding Remarks

In this paper, we proposed a dynamic shadow generation system based on the shape of an object's shadow generated by infrared rays. The experiment in Sections 4 and 5 and the exhibition observations in Section 6 revealed several defects in the system that should be fixed.

First, we pointed out the problem of fuzziness caused by the light source. Our proposed system uses 56 infrared LEDs arranged in the form of a 7×8 matrix on a 47 mm $\times$ 72 mm board. Therefore, outside a certain range, the light diffuses, and the edges of the generated shadow become unclear. This defect causes a decrease in the recognition rate of a shadow. When the distance between the light and an object is short, a problem appears where a white area is connected with another area on the generated artificial shadow because the shadow projected between the white areas becomes too narrow to recognize. To solve these problems, it seems better to use a point light source and suppress the amount of light by decreasing the number of LEDs.

Second, we pointed out a problem with the recognition of the white areas' arrangement. In our proposed system, we set each pattern by setting the x and y coordinates from the coordinates of each area. This means an area did not coincide with the pattern if the area existed outside the set range. For example, windows adjoined each other on the object, but the system could not recognize that they adjoined if the object generating the shadow was tilted. Thus, the detection of an inclination is desirable to solve this problem. The detection of an inclination would make it possible to recognize the pattern in the case where an object is tilted. Moreover, it would permit a new expression, making it appear that a character in a shadow tumbled based on the inclination of the object. Furthermore, a shadow changes its size in relation to the distance from light, and the detected areas' coordinates dynamically vary in accordance with the size. Our current system does not account for this change in size. Thus, expressions that reflect the size of the shadow are desired, such as a change in expression based on the position and size of the objects.

Third, we pointed out the problem with shadow processing. When our proposed system generates an artificial shadow, its outline is not smooth, like a real shadow, because of the low resolution of the calibrated images. In addition, the delay in the shadow's ability to follow the real object is a problem that needs to be overcome.

Our proposed system will increase the expression possibilities by increasing the arrangement patterns and dynamic images in the future. Moreover, not only white areas but also real shadow projected areas will be detected. Therefore, the system will make it possible to express more active motions such as motions where the people in the window areas come and go, birds fly around the building, etc. Furthermore, more free expression for the shadows will be possible by changing the color and shape of the acquired shadow. For example, a virtual train will run on a railroad track in a shadow world if the object's shadow has the shape of a railroad track and a Ferris wheel will rotate with people in a shadow world if an object's shadow has the shape of a Ferris wheel. In this way, it will be possible to create free expressions of an object's movement in a shadow world without changing the real object.

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