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Development and Evaluation of a System for AR enabling Realistic Display of Gripping Motions using Leap Motion Controller

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Abstract

Augmented Reality (AR) in the traditional systems have a problem that the drawn objects are always displayed in the foreground because 3D models by AR are superimposed later than the picture of the actual world. This paper proposed a system to produce a realistic picture of AR in accordance with every depth. We developed a prototype system to verify the effect of the method. The prototype system was developed by focusing on a human hand. This paper utilized a Leap Motion Controller as a motion capture device to acquire the depth data of the hand and fingers.

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Keywords: "Augmented Reality, depth, Leap Motion Controller, finger, hand, 3Dmodel ;"

1. Introduction

1.1. Background

The technique of fusing the virtual space and real space in Augmented Reality (AR) is becoming a well-known technique with the advent of ARToolKit[1]. However, the drawn objects by AR are always displayed in the foreground, and it might be with an unnatural scene, because 3D models by AR are superimposed later than the picture of the real space.

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In recent years some studies to solve the problem are performed from various approaches.

The system which Silvio R. R. Sanches and others announced in 2012 prepared a marker to measure the distance from a viewpoint with a marker to display 3D model[2]. They stuck this marker on the chest of the person, they let the system recognize a physical position and calculated the positional relation on the space. However, that system is necessary to keep the distance with a camera and a marker than the fixed value, and the marker is necessary to keep the size as to be able to keep a recognition state, because the system must recognize several markers with a single camera at the same time in the same field of vision.

The system which Dong Woo Seo and others announced in 2013 extracted a part of the hand from a picture and adjusted viewport to draw pictures in the foreground by the image processing using the depth camera of Kinect[3]. However, that system does not support a scene that a part of the body is hidden and another part of the body is seen on the near side of the drawn 3D models by AR.

1.2. Goal

In this study, we proposed an AR drawing method to produce a realistic picture of AR in accordance with every depth, and we developed a prototype system to solve the problem that we raised in 1.1 sections. The prototype system was developed by focusing on a movement of human hand which is often used in the human body. Specifically, we focused on the gripping motion. In addition, we didn't consider the part of the body expect the finger because we set the gripping motion in target movement.

The goal of the system function is to show fingers and AR objects with reality according to depth information. Specifically, the system must not show a finger if the finger is on the far side of an AR object. On the other hand, the system must show a finger if the finger is on the near side of an AR object (Fig. 1).

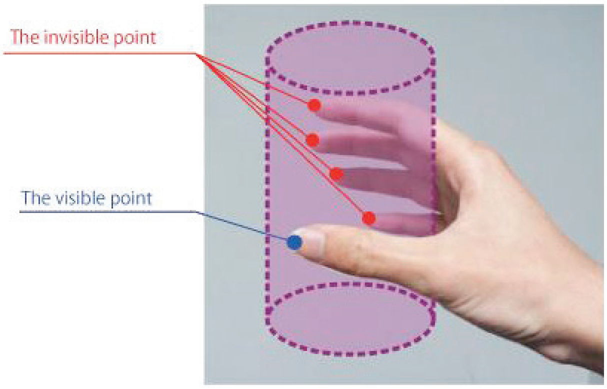

Fig. 1. Goal of the system function

2. Proposed Method

Figure 2 shows the area which this system treats. In this study, using the transparent 3D model of the finger, the 3D model follows each finger of the user in the system. The transparent 3D model of the finger is drawn earlier than the 3D model of an object displaying on a marker. Therefore the area of the finger is not affected even if the 3D model is drawn later. By the method, we don't have to let a camera recognize several markers at the same time, and we can measure the distance relations of a virtual model and the actual world without moving the position of the marker.

We must acquire the positional information of user's fingers exactly so that the transparent 3D model of the finger follows user's fingers. In this study, we use an exclusive motion capture apparatus to acquire the positional information of user's fingers exactly. We adopt Leap Motion Controller specialized as a motion capture apparatus of the fingers. Using this device, we acquire the correct positional information of the fingers. We match the position and the direction of the 3D model with the fingers position of the user.

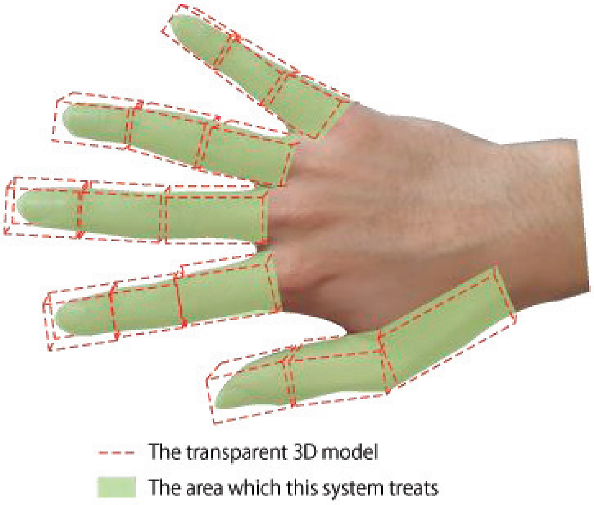

Fig. 2. The area which this system treats

3. Development Environment

The system consists of the following components.

- PC
- Leap Motion Controller
- Webcam
- Marker for AR

We combine these apparatuses and set the working environment of the system. Then, we must consider setting position of Leap Motion Controller and the marker for AR, because the origin of the coordinate system of Leap Motion Controller deviates from the origin of the coordinate system of the AR marker. We use this position relation between Leap Motion Controller and the AR marker for coordinate transformation (Fig. 3).

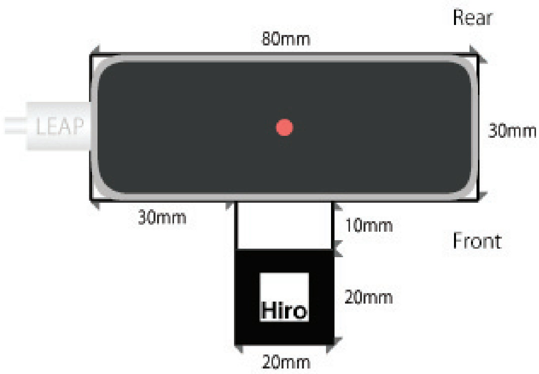

Fig. 3. Positional relationship between Leap Motion Controller and the AR marker.

4. Workflow of the system

Workflow of this system is as follows.

- Initialization Processing
- Reading of the 3D models
- Coordinate Transformation
- Drawing processing

This system achieves the goal by carrying out these processing sequentially.

4.1. Initialization Processing

We store predefined status information in initialization processing before main processing. There are two kinds of the predefined stored status information. They are individual data to set in marker or 3D model, and common data to set in marker and 3D model.

Individual data consist of marker pattern file name, marker pattern ID, marker ID, 3D model name, and 3D model file name. In the pattern ID, we acquire the information about the markers such as Bit Map data and assign the information individually in the initialization processing. In the marker ID, we assign ID number with natural number.

Common data consist of the detection flag of the visible state, position of the origin of coordinate of the marker pattern, and the marker pattern width. In the detection flag of the visible state, we set this flag invisible state. For the position of the origin of coordinate of the marker pattern, we set 0 both to X point and Y point.

4.2. Reading of the 3D models

In this system, we make the 3D model using Metasequoia as 3D modelling software. In order to read of the 3D models, we analyse the text file to save format from Metasequoia, and we save necessary data such as the number of the tops, a top coordinate, or the material information.

4.3. Coordinate Transformation

In this system, we get various information by Leap Motion Controller to support gripping motion. Then, coordinate transformation is necessary, because the coordinate system of the captured values is different from the coordinate system of OpenGL (Fig. 4).

We must consider the position of the origin of coordinate system because we locate Leap Motion Controller and AR marker as Fig.3. The coordinate value acquired by Leap Motion Controller and the flows of the coordinate transformation are as follows. In equation (1), L is the coordinate value acquired by Leap Motion Controller. L consists of elements *leap_x*, *leap_y* and *leap_z*. In equation (2), d_x, d_y and d_z are constants of the distances between the origin point of coordinate system of Leap Motion Controller and the origin point of coordinate system of the AR marker.

$$L = \begin{bmatrix} leap\_x \\ leap\_y \\ leap\_z \end{bmatrix} \tag{1}$$

$$L' = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 0 & -1 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} leap\_x \\ leap\_y \\ leap\_z \end{bmatrix} + \begin{bmatrix} d_x \\ d_y \\ d_z \end{bmatrix} = \begin{bmatrix} leap\_x + d_x \\ -leap\_z + d_y \\ leap\_y + d_z \end{bmatrix} \tag{2}$$

In addition, coordinate transformation is also necessary for the coordinate value of the 3D model made by Metasequoia to display on a marker with AR, because each unit is different. In equation (3), P is coordinate value of 3D model in Metasequoia. In equation (4), M is coordinate value of the 3D model in AR marker.

$$P = \begin{bmatrix} mqo\_x \\ mqo\_y \\ mqo\_z \end{bmatrix} \tag{3}$$

$$M = \begin{bmatrix} mark\_x \\ mark\_y \\ mark\_z \end{bmatrix} \tag{4}$$

The equation (5) shows the relation between P and M. The k is transformation constant. Therefore, the unit transformation is the equation (6).

$$M = kP \tag{5}$$

$$\begin{bmatrix} mark\_x \\ mark\_y \\ mark\_z \end{bmatrix} = k \begin{bmatrix} mqo\_x \\ mqo\_y \\ mqo\_z \end{bmatrix} \tag{6}$$

Where $k = 25.4 / 72$, since the resolution in Metasequoia is 72 dpi and 1 inch equals 25.4 mm.

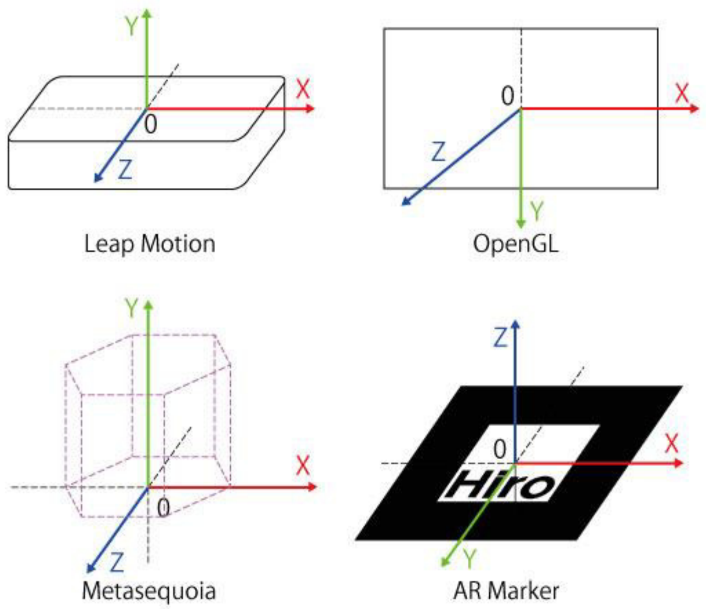

Fig. 4. Each coordinate system

4.4. Drawing Processing

We draw the transparent 3D model of the finger in accordance with the data acquired by Leap Motion Controller. We use a function set up in ARToolKit as a drawing function, a position for drawing is the central position of each bone of the fingers. By drawing the transparent 3D model of the finger earlier than the 3D model of an object displayed on a marker, the area of the 3D model of the finger is not affected even if 3D model on the marker is programmed. Specifically, the system does not show a finger if the finger is on the far side of an AR object. On the other hand, the system shows a finger if the finger is on the near side of an AR object. Consequently, the system achieves the goal (Fig. 5).

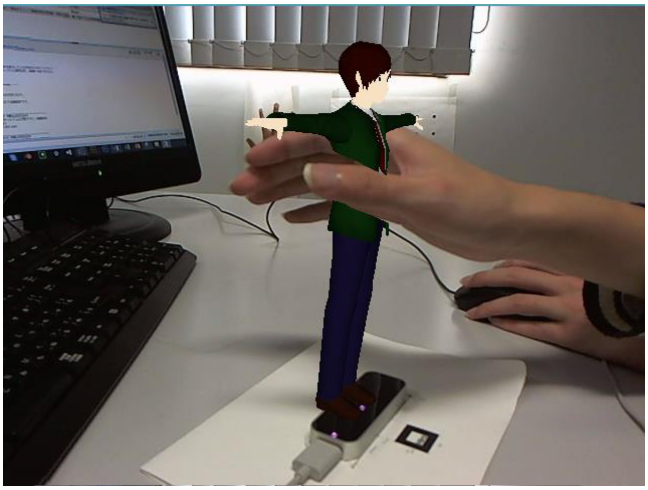

Fig. 5. The scene drawn the 3D model.

5. Verification Experiment

We performed two verification experiments after we developed the system. In verification experiment I, we confirmed that the behavior of the system does not depend on kinds of the 3D model displayed on a marker. In verification experiment II, we performed questionnaire survey with subjects.

5.1. Verification Experiment I

We checked whether the system was able to work for various kinds of the 3D model drawn on a marker or not. Furthermore, we also prepared some kinds of movement performed by users besides gripping motion. We checked whether or not the system performed correctly regarding every each model for each movement.

5.1.1. Verification Method

We tried six movement patterns five times for each 3D model (Fig. 6). In case of the system was able to work five times normally, we recorded +1 point in table 1. In case of the system was able to work between two times and four times normally, we recorded 0 point in table 1. In case of the system was able to work less than once or less normally, we recorded -1 point in table 1. After that, we evaluated each movement for the system by each total point.

Each tried movement was as follows.

(A) Gripping from the side

(B) Gripping from the top

(C) Hold up the hand above the sensor of Leap Motion Controller, then, gradually hold the hand down to the sensor.

(D) Hold up the hand above the sensor of Leap Motion Controller, then, gradually hold the hand down to the sensor, keeping finger tops bending.

(E) Put the 3D model on a marker between the index finger and the middle finger

(F) Inserting a hand from the side

For (A) to (E), we started the movement, after Leap Motion Controller recognized the hand once over the device, For (F) we started the movement without recognition of the hand by Leap Motion Controller.

5.1.2. Experiment Result

As a result of performance of gripping Motion from the side (A), the system behaved normally for fourteen models in the prepared fifteen 3D models (Table 1). By this result, we proved that the system was able to treat gripping motion. In addition, we also checked other five movements, and found the system was not able to treat the movements by each total point. We confirmed that the kind of 3D model does not affect the behavior of the system, because any 3D model did not get -1 point.

Since each top of finger was bended in the movement (B), (D), and (E), the sensor of Leap Motion Controller lost each finger junction position. Therefore, the total points of the movements were small and we found the system was not able to treat the movements stably.

From the above, we conclude that the behavior of the system does not depend on the kind of 3D model, but depends on the kind of finger movement.

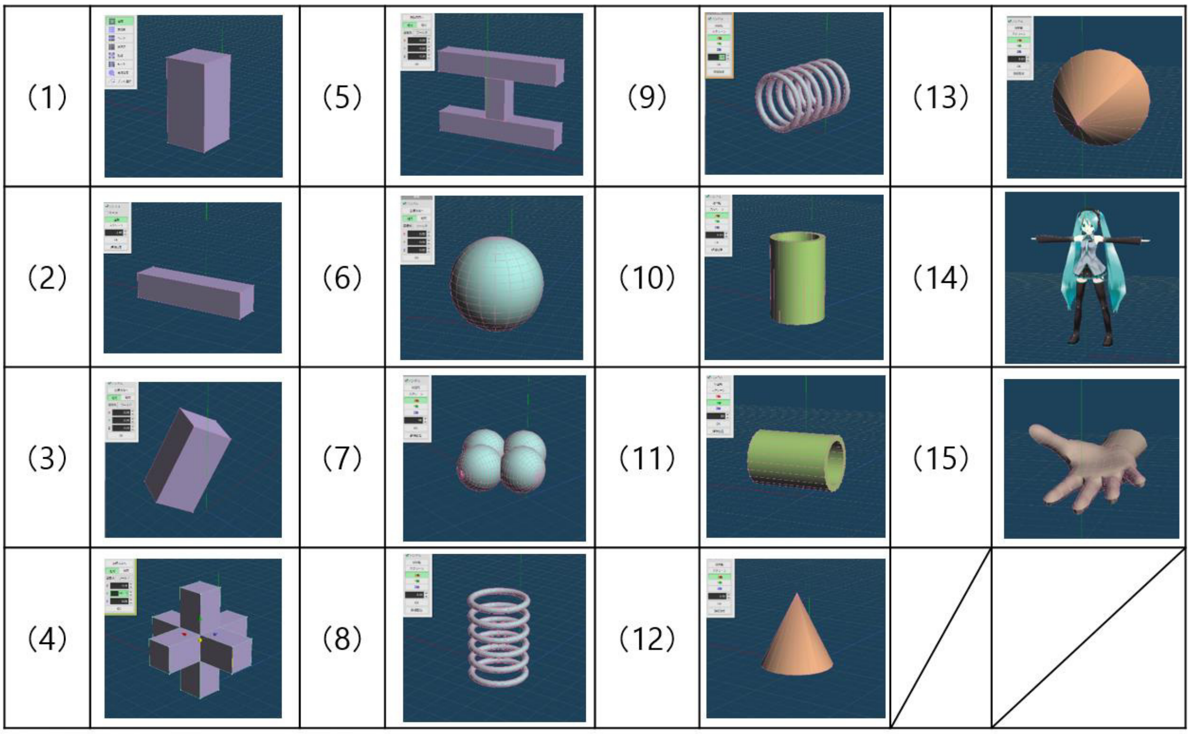

Fig. 6. The 3D models that we used for Verification Experiment I. (1 to 15: ID of each 3D model)

Table 1. Result of Verification Experiment I. (1 to 15:ID of each 3D model, A to F: ID of each movement)

3D Model		1	2	3	4	5	6	7	8
Movement	A	+1	+1	+1	0	+1	+1	+1	+1
	B	0	+1	0	0	+1	0	+1	0
	C	+1	+1	+1	+1	+1	+1	+1	+1
	D	0	0	0	0	0	0	0	0
	E	+1	+1	+1	+1	+1	0	0	0
	F	+1	+1	+1	+1	+1	+1	+1	+1
3D Model		9	10	11	12	13	14	15	total
Movement	A	+1	+1	+1	+1	+1	+1	+1	14
	B	0	0	0	0	0	0	0	1
	C	+1	+1	+1	+1	+1	+1	+1	15
	D	0	0	0	0	0	0	0	0
	E	0	0	0	0	0	0	0	5
	F	+1	+1	+1	+1	+1	0	+1	14

5.2. Verification Experiment II

The goal of experiment II is to extract problems of the system.

5.2.1. Verification Method

11 subjects tried both the traditional system and the developed system, we extracted the problems of the system by free description in a questionnaire survey. In addition, we recorded the movement that subjects performed during trial and made the problem clearer.

5.2.2. Experiment Result

As a result of experiment, three problems were extracted.

- There is the transparent space around the user's finger
- A sensor cannot recognize a finger position for long time
- Additional function to return dynamic feedback is necessary, when a hand touches or approaches the 3D model on the marker

We consider these problems for future refinements of the system, and will incorporate them in the system of the next stage.

6. Conclusion

In the traditional systems for AR have a problem that the drawn objects are always displayed in the foreground, and researchers tried to solve the problem by various approach. In the precedent study, they prepared another marker to measure the distance from a viewpoint besides a marker to display 3D model.

In this study, we proposed a new method and developed a prototype system to produce a realistic picture of AR in accordance with every depth. The prototype system was developed by focusing on gripping motion. We developed the objective system with the transparent 3D finger model which follows each finger of the user. We used Leap Motion Controller which is an exclusive motion capture apparatus to acquire the positional information of users' fingers exactly.

We performed two verification experiments. In verification experiment I, we conclude that the behavior of the system does not depend on the kind of 3D model, but depends on the kind of finger movement. In verification experiment II, we made subjects try the developed system, and extracted problems for future refinement by questionnaire survey.

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