Hidden Surface Removal for Interactions between User's Bare Hands and Virtual Objects in Augmented Reality

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Abstract

Augmented reality (AR) technology is a technique of superimposing information generated by a computer on perceptual information that we receive from real space. Recently, much attention has been focused on interaction techniques between users and virtual objects, such as the user directly manipulating virtual objects with his/her bare hands. On the other hand, in AR technology, since the 3-dimensional (3D) model is superimposed on the image of the real space afterwards, it is always displayed on the front side than the hand. Thus, it becomes an unnatural scene in some cases (occlusion problem). In this study, this system considers the object-context relations between the user's hand and the virtual object by acquiring depth information of the user's finger. In the evaluation experiment, it is confirmed that the hidden surface removal in this study not only makes it possible to consider the object-context relations but also can distinguish between finger boundaries and to clarify and process finger contours.

Keywords: Augmented Reality (AR), Occlusion Problem, Hidden Surface Removal, Hand Detection.

1. Introduction

In recent years, augmented reality (AR) has become widespread [1]-[3]. Further, interaction with the virtual objects is required in those papers.

Therefore, we think that it requires a more accurate technology, because it is expected that interaction technology using AR technology will be more and more developed in the future.

On the other hand, since hands are our main means of interaction with objects in real life, it is necessary for AR interfaces to be able to manipulate virtual objects with the user's bare hand.

However, since the 3-dimensional (3D) model displayed by the AR is superimposed on the image of the real space afterwards, the 3D model is always displayed on the front side and user's hand is hidden by virtual objects. Thus, the scene may become an unnatural scene, and the user cannot see the object-context relations of the virtual object and his/her hand, and feels that it is difficult to manipulate the virtual objects.

In the existing study [4], the system used a transparent 3D model and the 3D model followed each fingers of the user. In this way, they performed hidden surface removal based on the depth information of user and 3D model. However, since the 3D model to be followed is larger than the finger, a wider range than the actual finger was displayed on the front (see Fig. 1).

In this study, we realize hidden surface processing along the fingertips of the user. Thus, we will be able to apply this system to more advanced interaction operations.

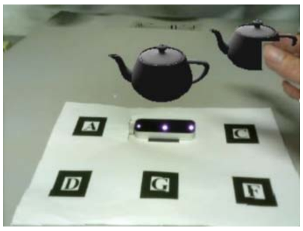

Fig. 1. Hidden surface removal in existing study.

2. Proposal

In order to realize hidden surface removal along the contour of the user's hand, this system detects hand area of the user by extracting depth information, color information and edge detection in the user's hand.

2.1. *System Component*

This system consists of a Web camera, the Leap Motion Controller, PC and AR marker.
In this study, in order to get accurate position information of user's fingers, we use the Leap Motion Controller.

This system controls the position and orientation of the virtual objects by recognizing the AR marker with Web camera.

However, when the user manipulates virtual objects, the AR marker may be covered by his/her own hand.

Therefore, this system adopts a method of treating Marker A to Marker F as one marker (see Fig. 2). Thus, even when a part of the marker is covered, the virtual objects can be displayed properly. We place the Leap Motion Controller on the position of Marker B.

This system displays the virtual objects on the position of Marker C and Marker G (see Fig. 2).

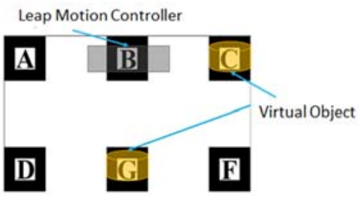

Fig. 2 AR marker.

2.2. *Determination of "skin color"*

This system extracts the area of skin color for detection of the user's hand area. Therefore, it is necessary to define the "skin color" color.

TaFirst, this system plots blue points on the finger which are the closest to the camera from the position information obtained from Leap Motion Controller (see Fig. 3).

Fig. 3 Blue Points.

This system converts RGB images obtained from a web camera into HSV images.

Next, the HSV image pixel corresponding to the pixel position where the blue point group is located is partially acquired.

In this study, in order to determine the range of "skin color", this system separates H, S and V for each pixel of the image, and creates the histograms. In the histogram, pixels with a small number are rejected. After that, a certain range is determined for the average value, and a color falling within the range is recognized as "skin color".

In this study, we assume that each of obtained H, S, and V data follow a normal distribution.
3 σ rule [5] is known as a simple method for outlier detection.

In this method, an observation is considered as an outlier if its least squares residual exceeds three times its standard deviation.

Thus, in this study, a pixel that falls within the range of 3σ from the average value of each of the HSV values of the colors acquired from the red dot group is taken as "skin color" using 3σ rule.

2.3. *Generation of binary image*

This system generates binary image to detect the user's hand area using "skin color".
The generated image contains noise, so remove it. (see Fig. 4)

Fig. 4 Binary Image.

2.4. *Generate image considering depth information*

This system acquires 3D coordinates of the distal bone, middle phalanx, basal bone and metacarpal bone of the user's hand with Leap Motion Controller.

Based on the acquired position information of the fingers, this system generates images plotting blue point group (following the position of the thumb) and green point group (following the position of a finger other than the thumb).

Blue point group displays at the positions of each joint of the thumb when the user's thumb is front of the back object (see Fig. 5).

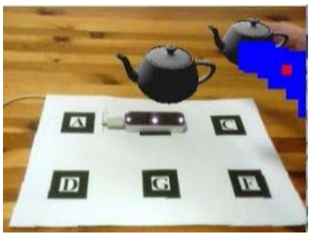

Fig. 5 Blue point group following the thumb.

In addition, green point group displays at the positions of each joint of the fingers except thumb when the user's fingers except thumb are front of the back object (see Fig. 6).

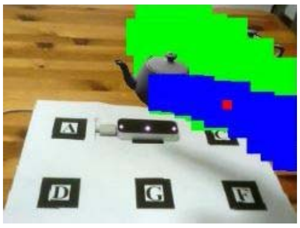

Fig. 6 Blue point group and green point group following the whole hand.

Furthermore, this system makes it possible to handle multiple virtual objects of different depths. The object-context relations between the back virtual object and the hand of the user is determined depending on whether or not blue point group and green point group are displayed. On the other hand, the object-context relations between the virtual object on the near side and the user's hand is determined by using the Z-buffer method.

Using the Z-buffer method, when a finger is positioned behind the virtual object, blue point group and green point group following the position of the finger are hidden by the virtual object.

In this way, this system can determine the object-context relations between the user's hand and the virtual objects even if there are multiple virtual objects.

2.5. *Generate images which always display the hand in front of virtual objects*

This system synthesizes the original RGB image (see Fig. 7-a) only in the white area in Fig. 4 to the image in Fig. 7-b. Thus, this system generates images that the user's hand is always displayed on the front of the virtual object (see Fig. 7-c).

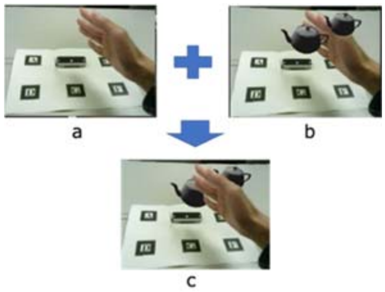

Fig. 7 Generation of images which hand is displayed front.

2.6. *Generate result image*

The area in Fig. 7-b corresponding the area of the blue point group, the green point group and the red point group (in the case where the position of the proximal phalanges of thumb is in front of the virtual object) of Fig. 8-a are replaced with the image shown in Fig. 8-b (Fig. 7-c).

Thus, based on the depth information, this system generates images that the hand is displayed in front of the virtual object (see Fig.8-c).

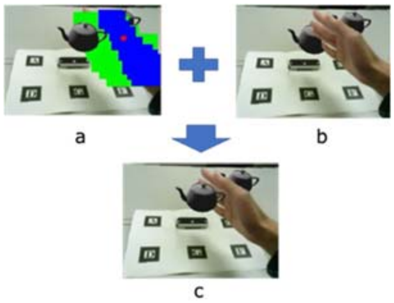

Fig. 8. Generation of result images.

3. EXPERIMENTAL RESULTS

We executed this system to confirmed whether hidden surface removal along the fingers is possible or not.

First, we checked whether this system can cope with multiple virtual objects.

The object-context relations between the virtual object on the near side and the user’s hand is determined by using the Z-buffer method.

In order to confirm whether this is properly processed, we placed the virtual object at position G in Fig. 2 and performed manipulation that a user grabs the virtual object.

3.1. *In the case of an object behind*

Since only the thumb comes to front side than Marker C, the blue point group follows only the thumb (see Fig. 5) and draw the thumb properly on the front of the virtual object (see Fig. 9).

Fig. 9 Result at the position of C in the AR marker.

3.2. *In the case of an object in front*

This system conducted the hidden surface removal considering multiple virtual objects by the Z-buffer method. The blue point group follows only the thumb and the green point group follows the other fingers (see Fig. 6).

Besides, only the point group of the thumb was drawn on the front of the virtual object by the Z-buffer method. As a result, it was possible to draw only the thumb on the front (see Fig. 10).

The blue point group and green point group in Fig. 6 are based on the depth information of the user's fingers.

Also, the anteroposterior relationship between the blue point group and the green point group is correctly displayed by the Z-buffer method.

In this way, when the thumb is positioned behind the other fingers, the green point group is displayed on the front side of the blue point group.

Fig. 10 Result at the position of G in the AR marker.

4. Consideration

We confirmed that this system can perform correctly hidden surface removal even when a user manipulates multiple virtual objects by Z-buffer method from the experiment result.

The distinction between the virtual object and the user's hand was not clear when using the Z-buffer method when considering the depth between the virtual object and the user's hand.

Therefore, if there is only one virtual object or if the depth coordinates of the virtual objects are all at the same position, it is better to have blue point group follow the thumb of the user only than to have blue point group and green point group follow the palm of the user's hand.

On the other hand, the processing may be delayed, so we need to solve this.

5. Conclusion

In this study, we paid attention to detection the contour of the hand to realize hidden surface removal along the user's fingers. In this system, processing based on hand depth information, color information and edge detection is conducted to detect hand contours.

By these processes, hidden surface processing along the fingertip was realized.

In the evaluation experiment, it was shown that it can cope with multiple virtual objects.

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