Overlayable and Rotation-free Transmissive Circular Color Marker for Augmented Reality

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Abstract

This paper proposes a new design of overlayable transmissive color marker. Each marker is transparent and the marker has different colors, and outside of the marker is a region for estimating order of the overlay. ID patterns are detected from overlaid markers by splitting an input image in red, green and blue channel image. The overlaid order is estimated with the use of average color in the estimation area of overlaid order. Moreover this marker can estimate the relative degree of rotation angle between markers. To evaluate the performance of the proposed marker, we measured the misalignment which can be permitted when detecting each marker and the accuracy of estimated relative angle of the rotation. Moreover the maximum angle which can detect each marker between camera and marker is measured.

INTRODUCTION

A marker is a basic device to estimate three-dimensional position of the camera in augmented reality (AR). ARToolKit is very famous as tool of marker based AR [1, 2, 3]. Markers for specific application have proposed by modifying design and materials of the marker to apply markers to special environment [4, 5, 6]. Bluteau et al. proposed thermal markers consisted of thermal barrier material and thermal camera for supporting medical communication[4]. Park et al. proposed an invisible marker with the use of IR fluorescent pen and IR camera [5], and Nakazato et al. also proposed an invisible marker using translucent retro-reflectors, IR light source and IR camera [6] for tracking. Moreover Yasumuro et al. proposed 3D marker consisted of four 2D markers and spherical mirror for keeping optical consistency in an interactive virtual interior design [7]. However these proposed marker cannot use while overlaying multiple markers. An overlayable marker supports intuitive operation in case of stacking virtual objects.

Imamura et al. proposed an overlayable transmissive color marker [8]. Figure 1 shows their proposed marker. Each marker is transparent and the marker has different colors: cyan, magenta and yellow. Several markers are detected from overlaid markers by splitting an input image in red, green and blue element image. And regions for estimating order of the overlay are added outside of the marker. In their research, interior simulator and video editing application were implemented and these applications have demonstrated an effectiveness of the proposed marker. However their designed marker is square, so the marker can be rotated only each 90 degrees.

This paper proposes an improved design of marker in order to realize rotation-free marker. Moreover a performance of the proposed marker is evaluated through an experiment.

PROPOSED MARKER DESIGN

Figure 2 shows our proposed marker. The markers are printed to transparent OHP sheet in order to detect behind marker. Color of each marker is cyan, magenta and yellow which are primary colors of subtractive mixture. And figure 3 shows the proposed marker design. The circle of outside of marker is area for judging order of the overlaid marker. This area is consisted of colored translucent part and white opaque part, and the order of overlaid markers is estimated by appearing color of this area. Table 1 shows appearing color by the order of overlaid marker. We can see that different color appears in the estimation area of overlaid order by the different order. Using this features, we can obtain the order of overlaid marker.

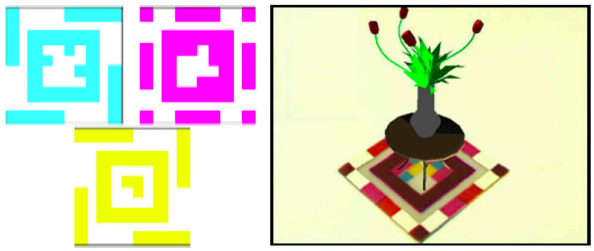


Figure 1. *Existing overlayable transmissive color marker (Left) and its result (Right)*

Moreover the center of the marker has ID pattern region for identifying the marker. This ID pattern is associated with a virtual object, and the system can superimpose the virtual object on the marker.

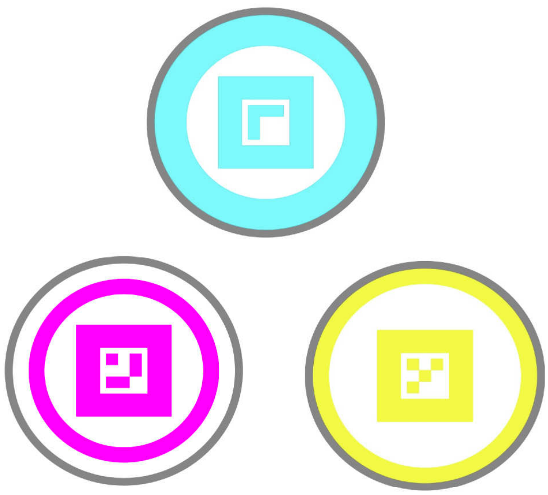


Figure 2. *Examples of Proposed Marker*

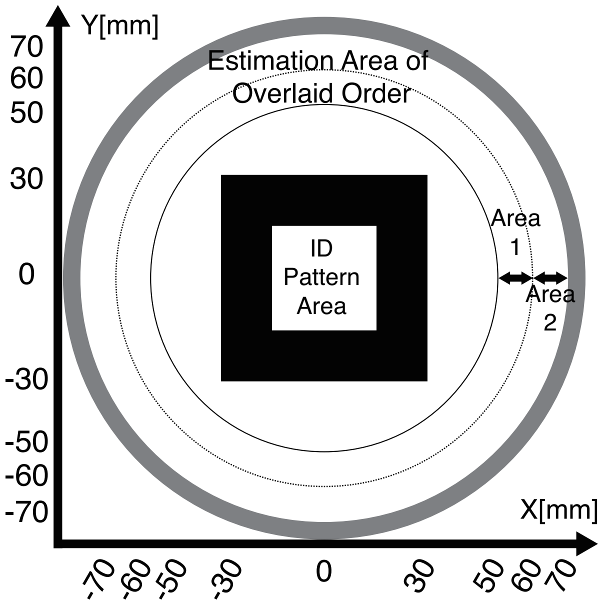


Figure 3. *Proposed Marker Design.*

Table 1. Appearing Color by Order

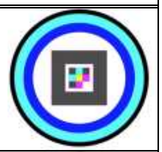
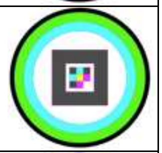
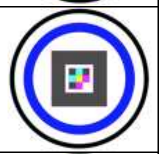
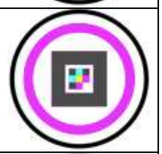
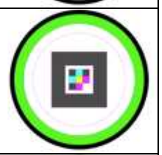
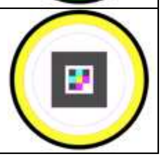
Order	Area 1	Area 2	
C-M-Y	Blue	Cyan	
C-Y-M	Cyan	Green	
M-C-Y	Blue	White	
M-Y-C	Magenta	White	
Y-C-M	White	Green	
Y-M-C	White	Yellow	

Figure 4 shows the processing flow of the detection of the marker and estimation of overlaid order. In the first, input image is split into R, G and B color channel. A complementary color of each marker color (Cyan, Magenta and Yellow) becomes R, G and B, so we can detect marker by binarizing each color image. ARToolKit is used for detecting a marker from the each color image. If a marker is detected, outside estimation area is checked in order to estimate order of overlaid marker. Finally virtual objects are displayed on image.

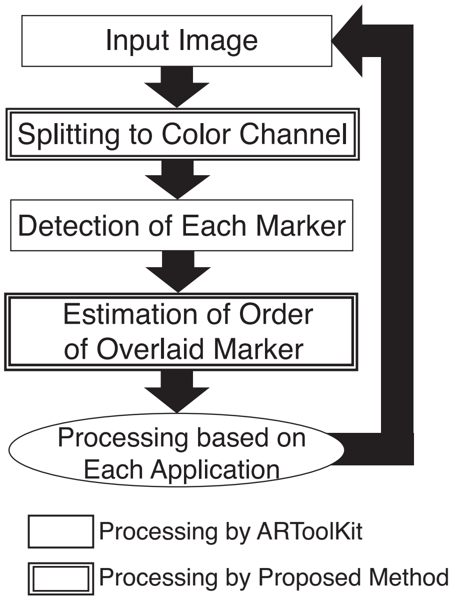


Figure 4. *Processing flow*

Color Correction

The ideal colors of marker are cyan $(C_r, C_g, C_b) = (0,1,1)$, magenta $(M_r, M_g, M_b) = (1,0,1)$ and yellow $(Y_r, Y_g, Y_b) = (1,1,0)$. However the measured color does not have the ideal color because of a property of printer, camera and so on. This color change influences the accuracy of marker recoginition. Therefore we have to correct the color of captured image before the recognition of marker.

First of all, the color of each marker is measured by the camera in an experiment environment. This measurements are performed for each marker. Let the average color of each marker be C_n, M_n, Y_n $(n = r, g, b)$. Then the measured colors are corrected by following equation (1).

$$\begin{bmatrix} C_r & C_g & C_b \\ M_r & M_g & M_b \\ Y_r & Y_g & Y_b \end{bmatrix} X = \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix}, \qquad (1)$$

where X is the transformation matrix for correcting color. When R, G and B values of the input image are (r_{in}, g_{in}, b_{in}), the corrected colors (r', g', b') are provided by following equation (3).

$$\begin{bmatrix} r' \\ g' \\ b' \end{bmatrix} = X \begin{bmatrix} r_{in} \\ g_{in} \\ b_{in} \end{bmatrix} \qquad (2)$$

$$= \begin{bmatrix} C_r & C_g & C_b \\ M_r & M_g & M_b \\ Y_r & Y_g & Y_b \end{bmatrix}^{-1} \begin{bmatrix} 0 & 1 & 1 \\ 1 & 0 & 1 \\ 1 & 1 & 0 \end{bmatrix} \begin{bmatrix} r_{in} \\ g_{in} \\ b_{in} \end{bmatrix}. \qquad (3)$$

This color correction enables the robust recognition of markers.

Estimation Method of Overlaid Order

The order of overlaid marker is estimated with the use of average color in the estimation area of overlaid order. Figure 5 shows the configuration of estimation area. The estimation area has two concentric zones with different color. The average color $C_{i,n}$ (i = 1, 2 and n = R, G, B) is calculated by equation (4).

$$C_{i,n} = \frac{1}{(r_{i+1}^2 - r_i^2)\pi} \int_0^{2\pi} \int_{r_i}^{r_{i+1}} P_n(r,\theta) dr d\theta \tag{4}$$

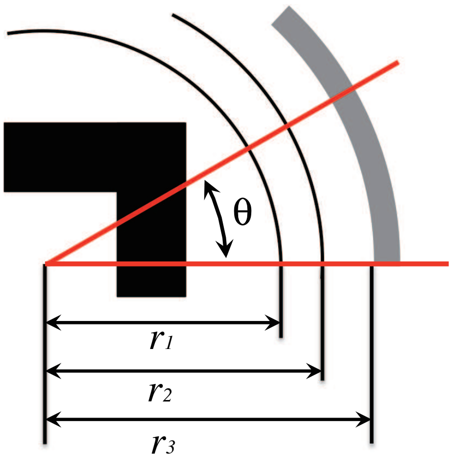


Figure 5. Configuration of estimation area

$P_n(r,\theta)$ is RGB color values at polar coordinates (r,θ) whose origin is center of the marker. r_i is radius of inside and outside of each zone.

To estimate the order of overlaid marker, discrimination of color is very important. Imamura has used threshold in order to discriminate the color [8]. However this method is strongly affected by lighting, shading and so on. So our proposed method uses correlation between ideal color and average color of estimation area.

For example, when markers are overlaid in order of C-M, estimation area 2 does not include red component because its color is cyan or green. On the other hand, when markers are overlaid in order of M-C, estimation area 2 includes red component because its color is white or yellow. As seen from the above, we can estimate the order of C and M by means of checking the correlation between the color of estimation area 2 and red. Also we can estimate the order of other markers.

Estimation of Relative Angle between Markers

In this section we describe how to calculate the relative angle between markers in the case of two markers. Let the camera coordinate system be $[X_c\ Y_c\ Z_c\ 1]^T$, and let the coordinate system of marker 1 and 2 be $[X_{m1}\ Y_{m1}\ Z_{m1}\ 1]^T$ and $[X_{m2}\ Y_{m2}\ Z_{m2}\ 1]^T$, respectively. Then relations between camera and each marker become equation (5) and (6).

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} = T_1 \begin{bmatrix} X_{m1} \\ Y_{m1} \\ Z_{m1} \\ 1 \end{bmatrix}, \tag{5}$$

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} = T_2 \begin{bmatrix} X_{m2} \\ Y_{m2} \\ Z_{m2} \\ 1 \end{bmatrix}, \tag{6}$$

where T_1 is a transformation matrix from the coordinate system of marker 1 to the camera coordinate system, and T_2 is a transformation matrix from coordinate system of marker 2 to the camera coordinate system. The equation (7) is obtained by these equations.

$$\begin{bmatrix} X_{m1} \\ Y_{m1} \\ Z_{m1} \\ 1 \end{bmatrix} = T_1^{-1} T_2 \begin{bmatrix} X_{m2} \\ Y_{m2} \\ Z_{m2} \\ 1 \end{bmatrix}, \tag{7}$$

The equation (7) shows that the transformation matrix between markers by multiplying the transformation matrix from the camera coordinate system to the coordinate system of a marker by the transformation matrix from the coordinate system of other marker to the camera coordinate system. This transformation matrix is a homogeneous transformation matrix with 4 rows and 4 columns, but ARToolKit provides the transformation matrix with 3 rows and 4 columns (equation (8)).

$$\begin{bmatrix} r_1 & r_2 & r_3 & t_x \\ r_4 & r_5 & r_6 & t_y \\ r_7 & r_8 & r_9 & t_x \end{bmatrix}, \tag{8}$$

where $r_i (i = 1...9)$ are elements of the rotation matrix between markers, and t_x, t_y and t_z are elements of the translation matrix. If the centers of overlaid markers correspond exactly, the transformation matrix is obtained by equation (9) when one marker rotates angle ϕ since the markers lie on a $x-y$ plane normal to z axis.

$$T_\phi = \begin{bmatrix} \cos\phi & -\sin\phi & 0 & 0 \\ \sin\phi & \cos\phi & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix}. \tag{9}$$

We can estimate the relative angle between markers by menas of calculating this angle ϕ.

EXPERIMENTS

We have experiments to verify whether our proposed marker can estimate the order of overlaid marker and measure the rotation angle correctly or not. The design of used marker is under of figure 2. And the virtual objects that are superimposed on image are teapot with complementary color (red, green and blue) of the marker. In experiment, we use a camera (Logicool HD Pro Webcam C910) for image acquisition and Desktop PC (Windows 7, Intel Corei3 i3-550, 4Gbyte Memory).

Figure 6 shows an input image. The order of overlaid markers is C-M-Y. We can see the appearing colors are just as table 1. Also figure 7 shows split images in each color channel. The each image is almost split to each color channel.

Figure 8 shows the result that superimposing virtual objects on the image. In this result we can see that virtual objects are stacked same order of the marker.

Figure 9 shows another experimental results. (a) is the result when the markers are overlaid the order of C-M-Y, (b) is the

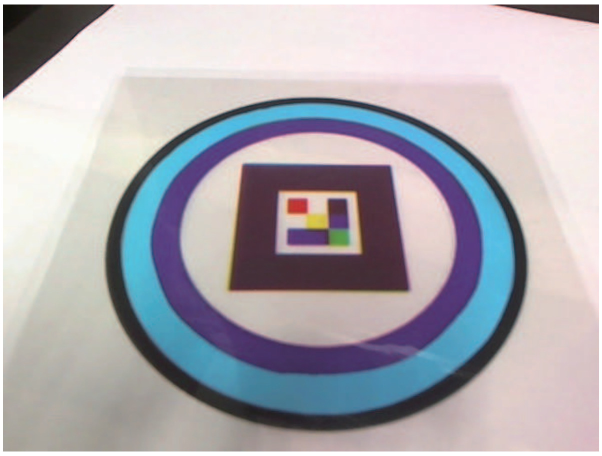


Figure 6. Input Image (Order: C-M-Y)

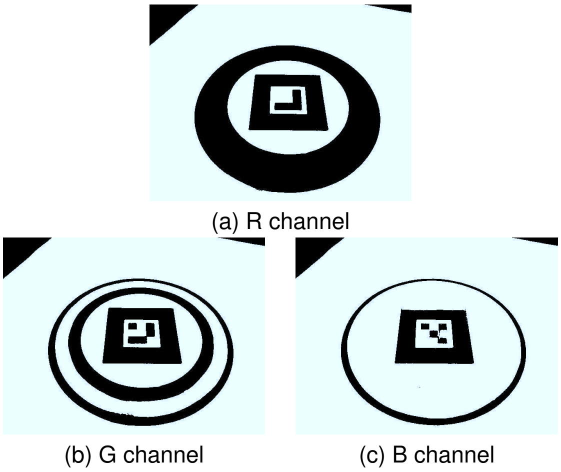


Figure 7. Separated and Binarized Images. Left: Red-channel, Center: Green-channel, Right: Blue Channel.

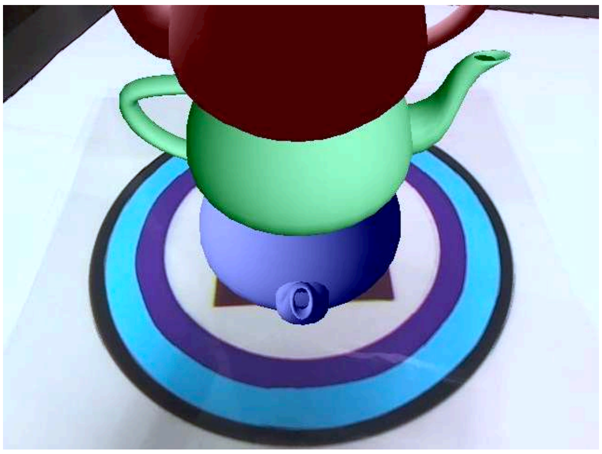


Figure 8. Superimposing Result

result of the order of Y-C-M and (c) is the result of the order of C-M and only Y. These results show that the order of overlaid markers is recognized correctly by the proposed marker. We have also confirmed that the proposed marker can be estimated the all order of overlaid marker.

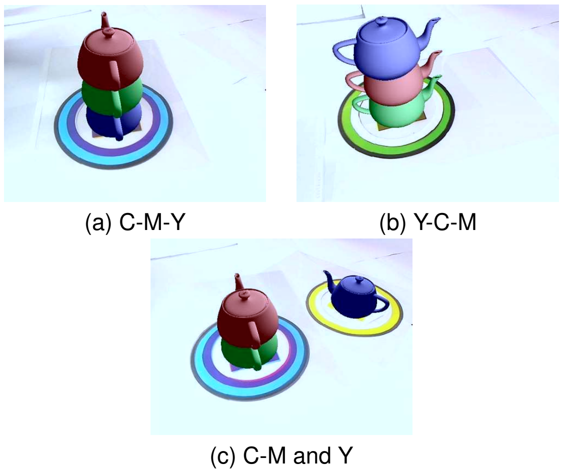


Figure 9. Examples of other results.

Evaluation of Recognition Performance

Next, we evaluate the recognition performance of our proposed marker. Figure 10 shows the setting of the performance evaluation. θ is an angle between the optical axis of the camera and the normal of markers, and l is a distance between the camera and the center of markers. In this evaluation the distance l is fixed $30cm$ because the stacked virtual objects can display in the image and the recognition accuracy of the marker is good.

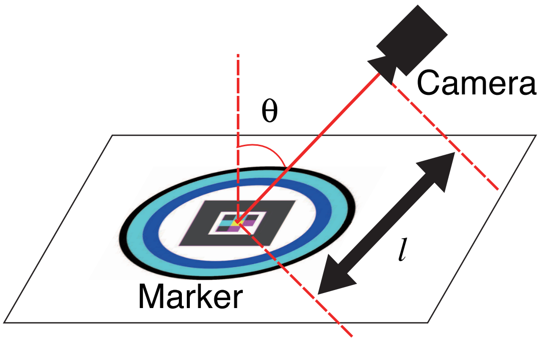


Figure 10. Setting of Evaluation

The light source used in this evaluation is a conventional white fluorescent light, and a white paper is set under the marker in order to remove influence of floor color. When the image is acquired, the function of auto white balance of camera is disabled in order to prevent a color information changing. But the function of auto focus and auto exposure are used. Also the size of marker used for the evaluation experiment is radius $70mm$ shown in figure 3. The evaluation is the following three items.

Permitted Misalignment The proposed marker assumes to position the edge of each marker, but if the misalignment between markers occurs, the order of overlaid marker may be estimated incorrectly because the color information of the estimation area changes.

This evaluation verifies the influence of the misalignment between markers. Figure 11 shows the given misalignment. When the markers overlay exactly, the value of misalignment is $0mm$. The maximum value of misalignment is measured as the permitted misalignment Δx while shifting every $1mm$. The angle θ is $45degree$. The result of the evaluation experiment is shown table 2.

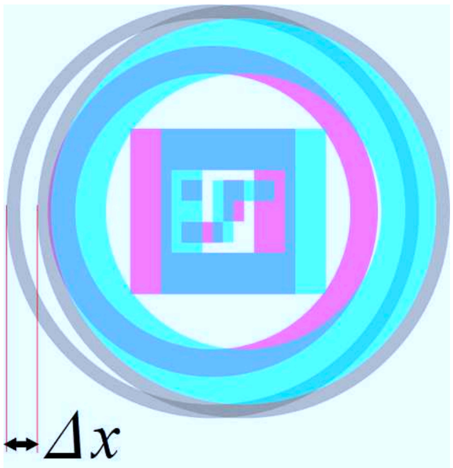


Figure 11. *Definition of Permitted Misalignment Δx*

Table 2. Permitted Misalignment of Markers

Overlaid order	Permitted Misalignment
C-M	21 mm
C-Y	25 mm
M-C	21 mm
M-Y	21 mm
Y-C	11 mm
Y-M	12 mm

Table 2 shows the permitted misalignment changes with the order of overlaid marker, and the smallest permitted misalignment Δx is $11mm$ in the case of using 2 markers. The proposed marker design has white opaque part. Since the permitted misalignment is limited by this white opaque part, this result is reasonable.

Estimation Accuracy of Relative Angle between Markers This evaluation verifies the accuracy of estimated relative angle of the rotation between markers. The relative angle is estimated by the transformation matrix between markers (equation (9)). This estimated value changes each frame slightly. Therefore we verify the accuracy of relative angle between markers by the difference between the maximum estimated angle and the minimum estimated angle. The relative angles are estimated from the images of rotated marker in arbitrary angle that are captured during 10 seconds. Then the camera and markers are fixed.

Table 3 shows the results of the estimated relative angle between Cyan marker and Magenta marker.

Table 3. Estimated Relative Angle (C-M) [degrees]

Set Angle	Minimum	Maximum	Max - Min
0	-0.55	0.54	1.09
45	44.59	45.91	1.32
90	89.31	90.16	0.85
135	134.41	135.88	1.47
180	179.21	180.95	1.73
225	224.82	225.87	1.05
270	269.36	270.20	0.84
315	314.37	315.88	1.51

This result shows that the accuracy of relative angle between markers is within ± 1 degree when the angle between the optical axis of camera and the normal of marker is 45 degrees and the distance between the camera and the center of marker is $30cm$. This was also the same in other combination of markers and angle.

Angle θ between Marker and Camera Next we verify the maximum angle between the optical axis of camera and the center of marker which the markers can be recognized. In the experiment, the angle is changed in increments of 5 degrees, and three markers are overlaid. Table 4 shows the results.

Table 4. Recognizable Maximum Angle

Overlaid Order	Maximum Angle [deg]
C-M-Y	65
C-Y-M	65
M-C-Y	60
M-Y-C	60
Y-C-M	60
Y-M-C	60

This result shows that the maximum angle between the optical axis of camera and the center of marker is about 60 to 65 degrees. In the case of conventional black and white marker, the angle is about 80 degrees. So this value becomes smaller than the value of black and white marker. This reason is that it is difficult to recognize under-marker according to the shadow occurs by the thickness of OHP sheet and the gap between markers by the distortion of sheet.

DISCUSSIONS

Our proposed circular color marker could be estimated the overlaid order of the marker and expressed the stacked virtual objects.

Moreover we measure the accuracy of estimated relative angle of the rotation. Though the accuracy of estimation depends on the distance and angle between marker and camera, our proposed method could estimate the rotation angle with accuracy of ± 1 degree or less in the distance is 30 cm and angle is 45 degrees between camera and marker.

However the detection of marker was sometimes failed. We made the marker by OHP sheet. The surface of OHP sheet is smooth. Therefore highlight was sometimes observed by lighting condition, then the marker could not be detected correctly. We need more improvement of detection method of marker.

EXAMPLE OF APPLICATION

As an example of application, we propose that an authoring system of manipulating virtual objects. The proposed marker can manipulate intuitevely with the use of estimated relative angle. We show an application can manipulate information of virtual object that is superimposed on a marker by other marker. In this paper, a teapot is used as the virtual object, and we manipulate the color and size of the teapot by this application.

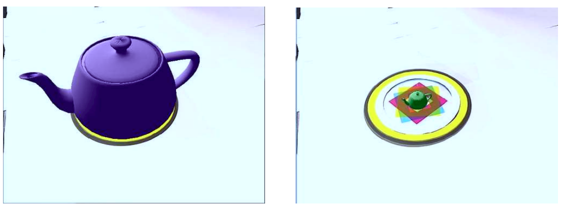
Cyan marker is used as a standard marker. The virtual object is superimposed on this cyan marker, and the relative angle between marker is estimated based on the cyan marker. Figure 12 shows the superimposed image on the cyan marker.

Magenta marker is used for changing the color information of the virtual object. In this paper, hue value changes based on

Figure 12. Superimposed Image on Cyan Marker

the relative angle with the cyan marker. Yellow marker changes the size of the virtual obejct.

Figure 13 shows the result of the application. (a) is an output image before rotating the marker, and (b) is after rotating the marker. This result shows that we can manipulate the color and size of the teapot by rotating the marker intuitively.



(a) Before Rotating (b) After Rotating

Figure 13. Result of Application

CONCLUSIONS

This paper has proposed an improved design of marker in order to supports intuitive operation in case of stacking virtual objects. The proposed marker is also rotation-free design. The experiment results shown that our proposed marker could be overlaid and rotated freely. However sometimes the marker detection is not robust. So we will improve the detection method of marker that is not affected by lighting condition and so on.

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