The Design of a New Marker in Augmented Reality

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Abstract—**Providing experience with registering virtual objects into real world, applications of Augmented Reality become more and more popular. The time performance of recognizing and tracking markers is one key point to attract users. In this paper, for improving the performance of recognition and tracking of markers, QMarker, a new kind of markers is proposed, being advantage at eliminating unwrapping marker image when recognizing. The identifier of marker depends on the number of circular regions on catercorners of the square marker. Experiments show that compared with ARToolKit markers, the speed of recognition improves greatly. In conditions of different scale and orientation the validity of QMarker is testified and shifting of virtual objects is also solved.**

Keywords- Augmented Reality; mark recognition; marker tracking; marker unwrapping

I. INTRODUCTION

Augmented Reality (AR), also known as Mixed Reality, aims to combine virtual and real scene together to achieve that virtual ones are belong to the real world. Being characteristic of integration of virtual and real scene, many applications of Augmented Reality are emerging, such as in field of education, medical treatment and entertainment [1, 2, 3] etc.

Tracking of camera position in real world for registering virtual objects is main technology in Augmented Reality. By presetting known markers in real scene the position could be quickly located. Therefore marker-based tracking is one popular method used in Augmented Reality systems. According to methods of design and recognition of markers, image template matching and image code-decoding are two different methods[6]. Marker image is matched with templates stored in system one by one for recognizing the identifier of marker in former one. The latter one codes marker image in 0 or 1 by dividing the internal region of marker into black or white multi-squares and then decodes them when recognizing. The common points among them are detecting and recognition of graphic regions. Image unwrapping is necessary in that condition because square marker images could not keep square after projecting. However image unwrapping occupies a lot time resource which affects the time performance of AR application. For improving marker detection and recognition, QMarker, a new kind of makers without being unwrapping is proposed. By replacing recognition of graphics regions with detection of number of them, the identifier of markers could be acquired quickly. In addition, as obvious character easily being detected, we set special graphics regions on two catercorners to further improving the time performance.

In Section II, main idea of two methods of marker detection and recognition is introduced. The recognition and tracking of QMarker is discussed in Section III. In Section IV, Experiments are given to show that compared with ARToolKit markers, the speed of recognition improves greatly. In conditions of different scale and orientation the validity of QMarker is testified and shifting of virtual objects is also solved.

II. TWO METHODS OF MARKER DESIGN AND DETECTION AND RECOGNITION

One method is image template matching and another one is image code-decoding. Markers in those two methods are square and constituting of black thick border and black graphics within its white internal region. The advantage of using black and white color is to separate marker from background in grabbed frame easily. Internal region of a marker marks identifier of it. In term of projective geometry, square markers in real world could not be square after projecting onto image plane, in other words, internal graphics in markers often display in distortion. When recognizing them, image unwrapping is necessary. The procedure of unwrapping image is shown in Fig.1.

Figure 1.   Procedure of unwrapping marker image to find ID

The calculation of marker unwrapping could be described as follow: $(x_{c_i}, y_{c_i}), i = 1,2,3,4$ as four corners of a marker are acquired after detecting grabbed frame. Positions of four corners are known in the real world as $(x_{m_i}, y_{m_i}), i = 1,2,3,4$. Homography matrix H could be calculated in (1). By H points in internal region of marker could be unwrapped to formal one.

$$\begin{bmatrix} hx_c \\ hy_c \\ 1 \end{bmatrix} = H \begin{bmatrix} x_m \\ y_m \\ 1 \end{bmatrix} = \begin{bmatrix} N_{11} & N_{12} & N_{13} \\ N_{21} & N_{22} & N_{23} \\ N_{31} & N_{32} & 1 \end{bmatrix} \begin{bmatrix} x_m \\ y_m \\ 1 \end{bmatrix} \quad (1)$$

After that, unwrapping image are used to match templates in matching method or decode in code-decoding method respectively. ARToolKit[4] is typical of matching method. To acquire an ID of marker template matching is executed twelve times at least in four directions and three light conditions, which consumes further time resource. ARTag[5,7] is typical of code-decoding method. Although it needs not match templates, unwrapping image is essential. As result, for heavy burden of calculation in image unwrapping these two methods could not fit applications well with need of high real-time performance.

III. DESIGN AND TRACKING OF QMARKER

A. Design and Recognition of QMarker

The main design idea of QMarker is to eliminate heavy calculation mentioned above. By replacing recognition of graphics regions with counting number of graphics regions recognition could be quickly realized. QMarker consists of black background and white circular regions located along two catercorners of it. Reasons for that are: (1) markers with black and white color could be separated easily from background in grabbed frame. (2) as obvious feature of a square marker two catercorners could be detected quickly. For eliminating to distinguish direction of a marker, one bigger white circle is set on a catercorner closest a corner of marker. This corner is named as Corner1, and in a clockwise direction, other corners of the marker are Corner2, Corner3 and Corner4. ID of marker depends on the number of white circle regions. For example, catercorner1 standing for line between Corner1 and Corner3, catercorner2 between Corner2 and Corner4. ID is assemble digits with number of circle regions on catercenter1 and another number on catercenter2. ID of markers are 42 and 24 respectively in Fig. 2.
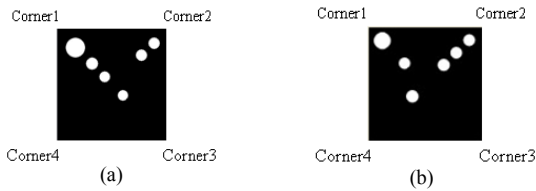

Figure 2. (a)ID of marker is 42; (b) ID of marker is 24

B. Tracking and Register of QMarker

When detecting QMarker, four corners of marker could be acquired by CFD method[6]. After recognition virtual objects which would be registered are known. And then camera position relative to marker should be calculated.

The registration of a virtual object into the real world based on a size-known square marker depends on the relationship between the marker coordinates and the camera coordinates which can be demonstrated in the Fig. 3(a).
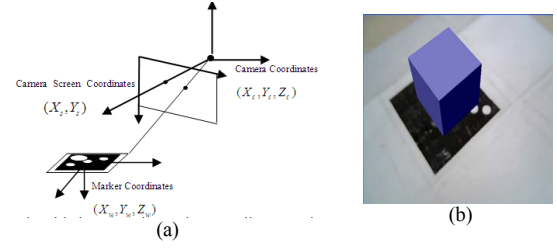

Figure 3. (a) Relationship between the marker coordinates and the camera coordinates. (b) QMarker with virtual cube registering on.

Three coordinate systems are camera coordinates, camera screen coordinates and marker coordinates. The transformation between camera coordinates and camera screen coordinates is described by (2), P is the internal parameter matrix of the camera which can be obtained by camera calibration.

$$\begin{bmatrix} hX_s \\ hY_s \\ h \\ 1 \end{bmatrix} = P \begin{bmatrix} X_c \\ Y_c \\ Z_c \\ 1 \end{bmatrix} \quad P = \begin{bmatrix} p_{11} & p_{12} & p_{13} & 0 \\ 0 & p_{22} & p_{23} & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (2)$$

The relationship between the marker coordinates and the camera coordinates is represented by a transformation matrix T_{cm}, a key to the registration of a virtual object into the real world, which is described as (3).

$$\begin{bmatrix} X_c \\ Y_c \\ Z_c \end{bmatrix} = \begin{bmatrix} V_{3\times3} & W_{3\times1} \\ 0^T & 1 \end{bmatrix} \begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix} = T_{cm} \begin{bmatrix} X_w \\ Y_w \\ Z_w \end{bmatrix} \quad (3)$$

T_{cm} falls into two components, which are rotation component and translation component (shown in (4)).

$$V_{3\times3} = \begin{bmatrix} v_{11} & v_{12} & v_{13} \\ v_{21} & v_{22} & v_{23} \\ v_{31} & v_{32} & v_{33} \end{bmatrix} \quad W = \begin{bmatrix} w_1 \\ w_2 \\ w_3 \end{bmatrix} \quad (4)$$

Based on the coordinates of the marker's four vertexes extracted in the process of marker detection and identification, the transformation matrix T_{cm} from the marker coordinates to the camera coordinates can be calculated. The process of transformation matrix calculation will be presented in the following sections.

Set the center of the marker as the origin of the marker coordinates system. The x-axis of the marker coordinate system is parallel with one pair of the parallel edges of the marker and the y-axis with the other pair. Assume the coordinates of marker's four vertexes in the maker coordinate system to be (x_{w1}, y_{w1}, z_{w1}), (x_{w2}, y_{w2}, z_{w2}), (x_{w3}, y_{w3}, z_{w3}), (x_{w4}, y_{w4}, z_{w4}) and the coordinates in the camera screen coordinate system to be (x_{s1}, y_{s1}), (x_{s2}, y_{s2}), (x_{s3}, y_{s3}), (x_{s4}, y_{s4}). The method of calculating the rotation component has been thoroughly discussed in a paper by [3],

and the same method is applied here to obtain the rotation component $V_{3\times3}$.

After obtaining the rotation component, we need to calculate the translation component which combined with the rotation component composes the transformation matrix from marker coordinates to camera coordinates.

- Combining (2) and (3), we get equations (5-7).

$$p_{11}w_1 + p_{12}w_2 + (p_{13}-u)w_3 = (u-p_{13})w_z - p_{11}w_x - p_{12}w_y \qquad (5)$$

$$p_{22}w_2 + (p_{23}-v)w_3 = (v-p_{23})w_z - p_{22}w_y \qquad (6)$$

$$
\begin{aligned}
w_x &= x_w v_{11} + y_w v_{12} + z_w v_{13} \\
w_y &= x_w v_{21} + y_w v_{22} + z_w v_{23} \\
w_z &= x_w v_{31} + y_w v_{32} + z_w v_{33}
\end{aligned} \qquad (7)
$$

- Substituting the variables in the equation (5) and equation (6) with camera screen coordinates of the four vertexes and their corresponding marker coordinates, we get a equation group consisting of eight equation. Transform the equation group to a matrix equation as follows in (8-10).

$$M_{8\times3}W_{3\times1} = C_{8\times1} \qquad (8)$$

$$
M_{8\times3} = \begin{bmatrix}
p_{11} & p_{12} & p_{13}-x_{s1} \\
0 & p_{22} & p_{23}-y_{s1} \\
p_{11} & p_{12} & p_{13}-x_{s2} \\
0 & p_{22} & p_{23}-y_{s2} \\
p_{11} & p_{12} & p_{13}-x_{s3} \\
0 & p_{22} & p_{23}-y_{s3} \\
p_{11} & p_{12} & p_{13}-x_{s4} \\
0 & p_{22} & p_{23}-y_{s4}
\end{bmatrix}
C_{8\times1} = \begin{bmatrix}
(x_{s1}-p_{13})w_{z1}-p_{11}w_{x1}-p_{12}w_{y1} \\
(y_{s1}-p_{23})w_{z1}-p_{22}w_{y1} \\
(x_{s2}-p_{13})w_{z2}-p_{11}w_{x2}-p_{12}w_{y2} \\
(y_{s2}-p_{23})w_{z2}-p_{22}w_{y2} \\
(x_{s3}-p_{13})w_{z3}-p_{11}w_{x3}-p_{12}w_{y3} \\
(y_{s3}-p_{23})w_{z3}-p_{22}w_{y3} \\
(x_{s4}-p_{13})w_{z4}-p_{11}w_{x4}-p_{12}w_{y4} \\
(y_{s4}-p_{23})w_{z4}-p_{22}w_{y4}
\end{bmatrix} \qquad (9)
$$

$$
\begin{aligned}
w_{xi} &= x_{wi}v_{11} + y_{wi}v_{12} + z_{wi}v_{13} \\
w_{yi} &= x_{wi}v_{21} + y_{wi}v_{22} + z_{wi}v_{23} \\
w_{zi} &= x_{wi}v_{31} + y_{wi}v_{32} + z_{wi}v_{33} \quad (i=1,2,3,4)
\end{aligned} \qquad (10)
$$

- Multiply the two sides of equation (8) with matrix $M_{3\times8}^T$, the equation is transformed to (11).

$$A_{3\times3}W_{3\times1} = B_{3\times1} \qquad (11)$$
$$A_{3\times3} = M_{3\times8}^T W_{3\times1}, \ B_{3\times1} = M_{3\times8}^T C_{8\times1}$$

Theoretically, matrix $A_{3\times3}$ is reversible. Therefore, pre-multiply (11) with matrix $A_{3\times3}^{-1}$, the translation component in the transformation matrix is obtained as (12).

$$W_{3\times1} = A_{3\times3}^{-1}B_{3\times1} = \left(M_{3\times8}^T W_{3\times1}\right)^{-1} M_{3\times8}^T C_{8\times1} \qquad (12)$$

Now that both rotation component and translation component have been obtained, compound the two and form the transformation matrix T_{cm} . Fig. 3(b) shows virtual cube displays on QMarker with identifier 42.

IV. EXPERIMENT OF VALIDITY OF QUCIKMARKER

Experiments are compiled in VS2003 and executed in computer with Intel E4500 CPU (Dual-core, 2.2GHZ).

A. Verify the Effects of Scale and Orientation

The major advantage in using number of circle regions other than recognizing multi-regions is that number of circle regions in one marker is invariant to scale and orientation. One hand, the number of circle regions can thus continue to be tracked at a large range of distance from camera. On another hand, it also could be tracked easily for its locating along catercorners when viewing at a sharp angle from camera. Fig. 4 shows that virtual cube could be registered on QMarker in different condition of scale and orientation.
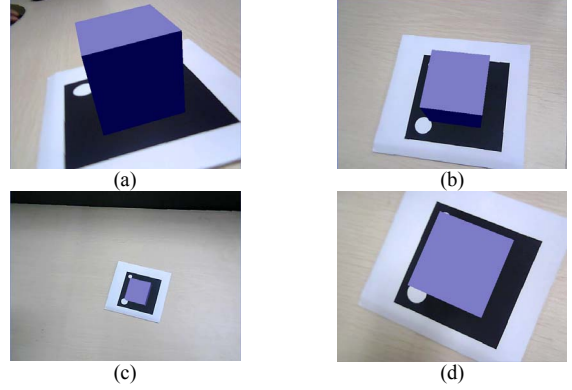

Figure 4. (a)(b)Register under sharp angle and gentle angle; (c)(d) Register under long and short distance.

B. Solution of drifting of virtual objects

Due to heavy calculation of image unwrapping and matching virtual objects often drift over marker when camera and marker move relatively fast. As shown in Fig. 5 a marker moves fast from left to right and then virtual cube could not register well on it in ARToolKit. However, under the same condition, virtual cube could register well on QMarker as a result of without heavy calculation.
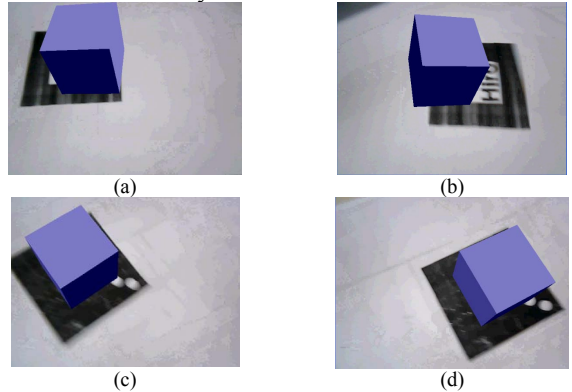

Figure 5. (a)(b)Virtual cube shifts when ARToolKit marker moves fast; (c)(d) Virtual cube registers on QMaker when it moves fast.

C. Verify the validity of time performance between ARToolKit and ARTag

In term of statistics analysis, we choose four different markers in ARToolKit and QMarker for testifying time of recognition in ideal conditions. Every marker is to be recognized in N times, and then the average time of four different markers' are T1 and T2 respectively. Table I shows different values of them according to value N. Speed of recognizing QMarker is as 30 times as the speed of ARToolkit, which shows that the speed of recognizing the new marker is greatly increased[10].

TABLE I. VALUE OF T1 AND T2 UNDER N IS 1000, 5000, 10000 RESPECTIVELY

N（times） T（seconds）	1000	5000	10000
T1	1.640	7.250	15.138
T2	0.051	0.25	0.523

V. CONCLUSION

For improving the performance of detection and recognition of markers, a new kind of markers QMarker is proposed. The identifier of marker is decided by the number of circular regions on catercorners. Due to eliminating heavy calculation of image unwrapping and matching or code-decoding, time performance of recognition and tracking and register improve compared with ARToolKit. In addition, experiment results also show that in condition of different scale and orientation validity of QMarker is testified.

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