A Novel Marker System in Augmented Reality

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***Abstract*-In augmented reality systems, the three dimensional registration technology based on artificial markers has been widely used. The registration algorithm based on artificial markers is divided into two steps: (1) marker detection and recognition, (2) estimation of camera pose. In this paper, a novel marker is designed based on projective invariants principle, such as collinearity between points and cross-ratio. Compared with the markers used in the ARToolkit, our new marker can greatly reduce the storage space of marker templates. And based on this marker, a new detection and recognition algorithm is proposed. By using the algorithm, the registration in AR system still can be successfully completed even when the marker is occluded by 62.5%, which greatly improves the robustness of the registration algorithm. The experimental results show that the marker and the algorithm posed in this paper are effective.**

Keywords-Augmented reality; three dimensional registration; artificial marker; marker recognition; marker occlusion

I. Introduction

Augmented Reality is a variation of Virtual Reality , which allow user to see the real world, with virtual objects superimposed upon or composited with the real world. Azuma professor defined AR as system that have three characteristics 3D registration, combines virtual and real, interactive in real time[1]. In registered technology based on visual tracking, it is mainly divided into the tracking registered method based on artificial markers and registered method based on natural features. At present most AR systems use the first method above to meet systems of real-time and robustness requirements.

An artificial marker is placed in a scene in order to supply a reference frame. As square markers can provide at least four coplanar points, it can be used for estimating camera pose accurately and assessment tasks based on vision-driven. Although natural features have been shown satisfactory results in some applications, they still have some shortcomings, for example availability and distinctiveness limit their broader use, in addition, their accuracy depends on the location and matching method. Due to these reasons, artificial markers are still be widely used.

ARToolkit[2] system is a secondary development kit which uses image correlation to differentiate markers. It can meet most real-time augmented reality applications. But simple template matching method leads to higher false positive rate, and ARToolkit can't be occluded. Therefore some advanced methods are introduced, for example the ARTag[3], which is relied on error-correction binary codes and can improve occlusion problem. But the images of markers are not imagery and counter-intuitive which limit their usable range. ARSTudio[4] solves occluded problem by using angular point information, but how to design more different markers becomes an unsolved problem.

In 2011, Filippo Bergamasco[5]introduced a novel visual marker system, which adopts the cross-ratio and other projective invariants to make possible both detection and recognition. The proposed approach can complete registration when the marker is occluded by 40%. But detecting and recognizing multi-markers simultaneously is unsolved.

Therefore, in this paper a novel visible marker system is introduced, by using cross-ratio as markers templates, it greatly decreases the storage space of markers templates. At the same times, the detection and recognition algorithm is proposed, which can solve the occlusion problem in AR system. Further, the registration can still be successfully completed even when the marker is occlude by 62.5% and realizes the multi-marker recognition.

II. Theoretical Basis of Markers Design

A. *Projective invariants*

In this paper, we adopt projective invariants principle. Due to machine vision based on visual invariants is easier close to the visual function, it is easy to overcome the changes of machine vision caused by the changes of observer angle[6]. So by using elliptic invariance, collinearity invariance and cross-ratio, the marker detection and recognition can be achieved.

The proposed marker is made up of circular dots, due to the imaging process of camera can be regarded as a projective transformation, so they appear as ellipses. And

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circle center generally does not correspond to ellipse center. But no matter how viewpoint changes, circle always appear as elliptic class[7]. As circular coordinates on imaging plane are not easy to calculate, so in marker detection and recognition stage, we should firstly fitting elliptical curve, and then calculate elliptic coordinates. For a given point set, the collinearity under projective transformation is that a line is transformed again to a line under perspective. Likewise, the angular ordering of coplanar points is still maintained under any projective transformation that looks down to the same side of the plane[2].

Cross-ratio is the most basic projective invariants of projective geometry. Suppose four collinear points A, B, C and D(see Fig.1), and the corresponding image points A', B', C' and D' are still collinear under projective transformation. A function can be defined that is not affected by such transformations, so this function is called cross-ratio and is defined as:

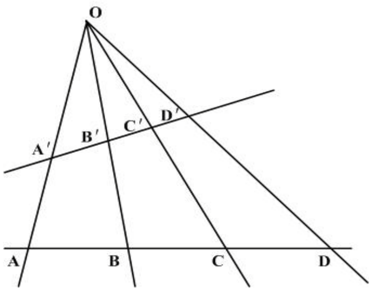

Figure 1. Cross-ratio of four points is invariant to projective transformations.

$$Cross(A,B,C,D)=Cross(A',B',C',D')=\frac{|AB|/|BD|}{|AC|/|CD|}=\frac{|A'B'|/|B'D'|}{|A'C'|/|C'D'|} \quad (1)$$

Where |AB| denotes the Euclidean distance between points A and B. The cross-ratio does not depend on the direction of the line ABCD but depends on the order and the relative positions between the points.

Therefore, the main idea behind the design of the proposed marker is that every adjacent four points on each side have an equal cross-ratio, and each side of the marker share the same cross-ratio. By using connectivity completes marker detection, and template library, namely cross-ratios, different markers are distinguished.

B. The design of the marker

At present, most of artificial markers are made of shapes, which are regular and easy to recognize, such as square, circle etc. Feature points of regular shapes, such as four angular points of square, which can calculate external reference of camera. While the middle of the pattern used to distinguish among different markers. Therefore, tracking markers usually use this as basis, such as ARTookit, ARTag, ARSTudio(see Fig. 2).

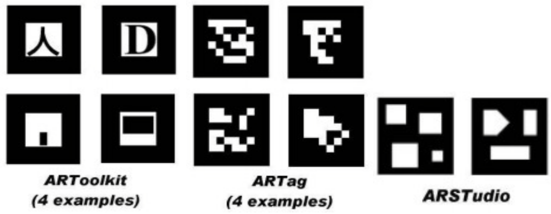

Figure 2. Examples of tracking markers

The proposed marker, which we named CoP-Tag(Connected Points Tag), is a very simple design(see Fig 3). It is made up of exactly 16 dots with connected region of the square, each side has five dots and a straight line through center of the circles, angular dots A, E, I and J are shared by each pair of four sides. Every four adjacent circular center on each side has an equal cross-ratio, and adjacent sides share one cross-ratio, namely Cross(A,B,C,D)=Cross(B,C,D,E)=Cross(A,F,G,H)=Cross(F,G,H,I), the main diagonal of the marker (the red dashed line shown in Fig.3) as basis setting direction of the markers. Moreover, different markers have different values of cross-ratio. These features provide CoP-Tag with a fast, accurate, simple detection and recognition method .

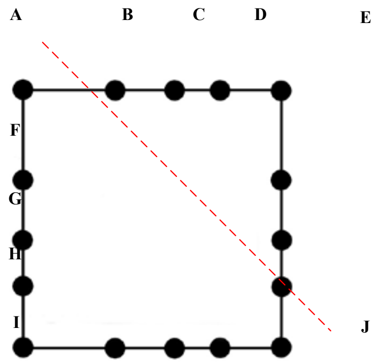

Figure 3. CoP-Tag

III. MARKER DETECTION AND RECOGNITION

According to connectivity and a unique value of cross-ratio, the design of the CoP-Tag can identify different markers.

In the detection process(see Fig.6), firstly we adopts gradient threshold method for binary image processing to extract the edge of the whole image, and further extract image markers of connected region. The connected region on the 640*480 video frame is shown in Fig 4.

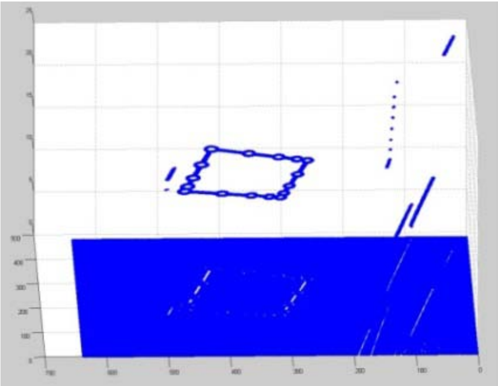

Figure 4. Connected region analysis on video frame

The purpose of adopting connected region is not only can distinguish a set of marker candidates, but also can eliminate noise in the image. By using 8-connected region recursive method, all edge pixels belong to the same connected region are labelled as the same ID(different markers are labelled as different ID, which to distinguish multi-marker). But the straight line of the marker for detecting ellipses is profitless, so the next step is to remove lines. The specific step as following: in the process of image preprocessing, by recording gradient directions of the marker peripheral points, we get a histogram of oriented gradient(HOG for short)(see Fig.5). Each peak in histogram corresponds to a straight line of the marker, thus straight lines of marker can be removed. But in this process, some edge points which gradient directions same with edge points of straight lines are also removed, so that ellipses are divided into multiple circular arc. In this paper we use least square method presented in [7] applied to the image for elliptic curve fitting, elliptic curve foundation is defined as:

$$F(x, y) = x^2 + axy + by^2 + cx + dy + e = 0 \quad (2)$$

Take n edge points(x_i, y_i)(i=1,2,…n)of elliptic curve into the curve equation to achieve the minimum value of $S = \sum_{i=1}^{n} F^2(x_i, y_i)$, so as to define the values of a, b, c, d, e in equation(2).

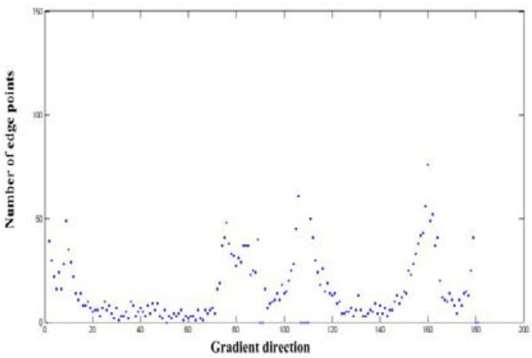

Figure 5. gradient direction histogram of Marker edge points

According to the method presented in [7], the centroids of ellipses can be obtained which ID are same on the same marker, thus we can find all centroids of dots belong to a tag and then process them respectively.

A. *Marker recognition under the condition of fully visible*

After all points of the marker are detected, marker recognition (see Fig.6)is firstly to iterate all the unordered pairs of points, for each pair, checking if they are likely to be two corner points. This check is satisfied only if exactly three other dots can be lying closer to the straight line connecting the candidate corners than a fixed threshold. After identifying one side of the marker, the known corner points should be kept. And then by computing respectively the distance between intermediate points and angular points, a cross-ratio can be obtained. The next step is to iterate over all the points left, and checking if each one forms one side with one of the known angular points, thus two sides can be detected. The fourth corner points can also be obtained with the same method. The final step is to compute the average between two or four cross-ratios and compare it with all value from database, if the value is below a fixed threshold, the marker is successfully recognized.

In practice, most of the first recognized candidate side often leads to a correct recognition, as the false value of cross-ratio will stop the recognition process at the second step.

B. *Marker recognition under the condition of occlusion*

If the marker is occluded, there are two possibilities:

The first case is that there is only one visible angular point on both adjacent sides(see Fig.7(a)). Compared with Fig.7(b), angular points E, I and H are occluded. Recovery algorithm is as follows: with known dots A, B, C, D and formula(1), we can obtain $Cross(A, B, C, D)$. As the value of cross-ratio on each side of marker is unique, we can obtain:

$$\begin{aligned} &Cross(A,B,C,D) = Cross(B,C,D,E) \\ &= Cross(A,F,G,H) = Cross(F,G,H,I) \end{aligned} \quad (3)$$

According to formula (3), the coordinates of occluded points E, I, H are obtained.

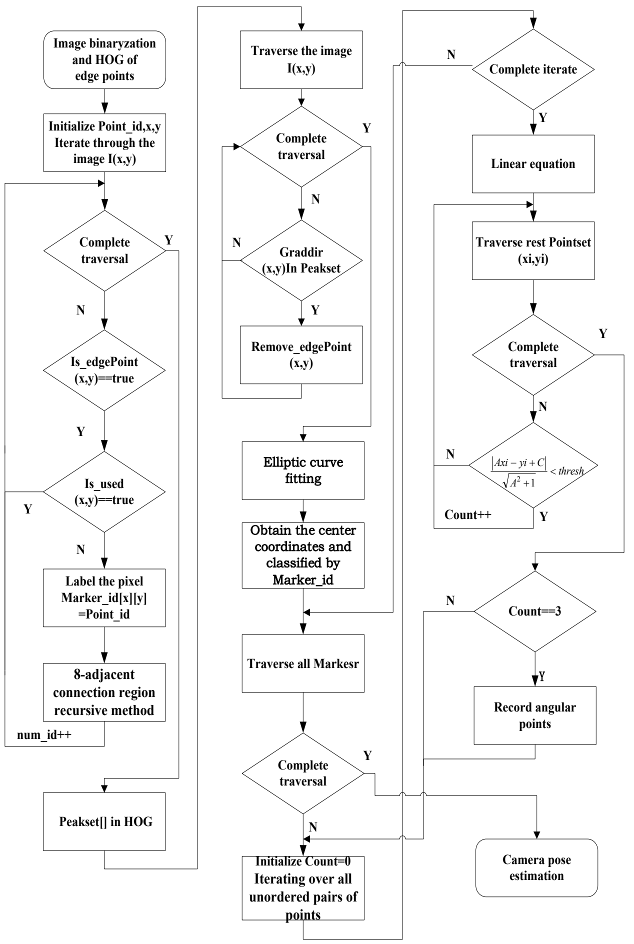

Figure 6. Flow charts of marker detection and recognition

As two parallel lines intersect at infinity point under perspective projection, namely an infinity point on one visible line also locates on the other one pair of parallel. So with another known point on the parallel line, an equation of straight line can be obtained.

Set The centroid coordinate of dot A as (X_A,Y_A), the centroid coordinate of dot F as (X_F,Y_F), and the centroid coordinate of dot B as (X_B,Y_B).

The slope for point A and F is $K_{AF}=\dfrac{Y_F-Y_A}{X_F-X_A}$, and the slope for point A and B is $K_{AB}=\dfrac{Y_B-Y_A}{X_B-X_A}$, thus the equation of straight line AF is

$$Y-Y_A=K_{AF}(X-X_A) \tag{4}$$

Define a point at infinity location of line AF as $P(X_p,Y_P)$, and the equation for the centroid coordinate of dot E (X_E,Y_E) and point P is

$$Y-Y_E=\frac{Y_E-Y_P}{X_E-X_P}(X-X_E) \tag{5}$$

The equation for line AB is

$$Y-Y_A=K_{AB}(X-X_A) \tag{6}$$

Define a point at infinity location of line AB as $O(X_O,Y_O)$ and the equation for the centroid coordinate of dot I (X_I,Y_I) and point O is

$$Y-Y_I=\frac{Y_I-Y_O}{X_I-X_O}(X-X_I) \tag{7}$$

With equation (5) and (7), the fourth occluded angular point can be obtained(see Fig .7(b)).

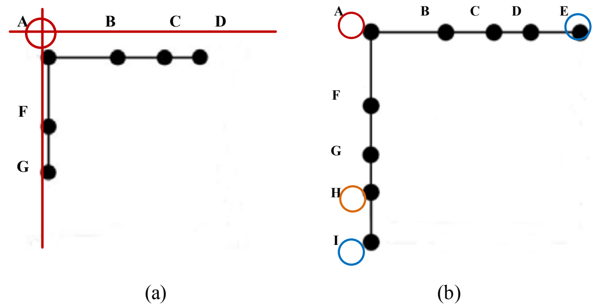

Figure 7. The markers of adjacent sides occluded

The second case is that the relative sides of the marker are visible and one angular point on one of the sides is occluded(see Fig.8(a)). By using angular points detection algorithm, points B, E, F, J can be obtained, in which point F and point J are recognized angular points.

Then, Set the centroid coordinate of dot E and F as (X_E,Y_E) and (X_F,Y_F), the distance between point E and point F can be defined as $d_{EF}=\left|\sqrt{(Y_F-Y_E)^2+(X_F-X_E)^2}\right|$; Similarly d_{EJ}, d_{BF}, d_{BJ} can also be obtained.

With $\min\{d_{EF},d_{EJ},d_{BF},d_{BJ}\}$, the third angular point E can be obtained. According to $Cross(A,B,C,D)=Cross(G,H,I,J)$, the fourth occluded angular point A can be obtained(see Fig.8(b)).

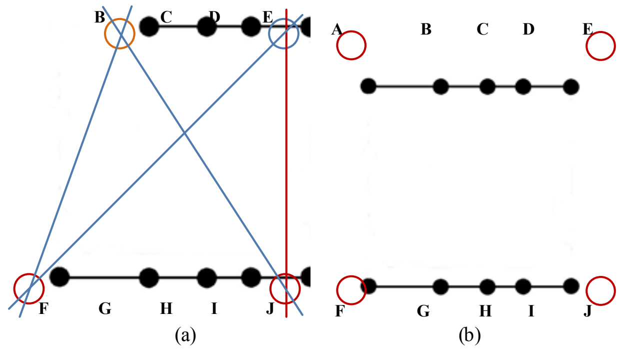

Figure 8. The marker of relative sides occluded

By using the detected&labelled ellipses, it is possible to estimate camera pose. PnP problem is a classic problem in the field of computer vision, projective measurement and even mathematics. And when $n\geq 4$, the problem of coplanar 4 points has a unique solution. So in this paper we use the method based on solving PnP problem to estimate the camera pose.

IV. EXPERIMENTAL RESULTS

In this paper, the detection and recognition method of our CoP-Tag is realized in the environment of Visual Studio 2008, and all the experiments have been performed on a PC equipped with a 2.27GHz Intel Core Duo processor. The camera is a HD camera of Logitech Pro C920. In this section, the performance of CoP-Tag is evaluated.

In the circumstance of 640*480 resolution, an ARToolkit template needs 300KB, while our CoP-Tag only needs 4B, the amount of data compression is 37500 times.

One of the characteristics of CoP-Tag is that it can deal with moderate occlusion. In Fig.9, compared with the result of ARToolkit, the precision of CoP-Tag is still quite reasonable even when almost 62.5% of the dots are not visible.

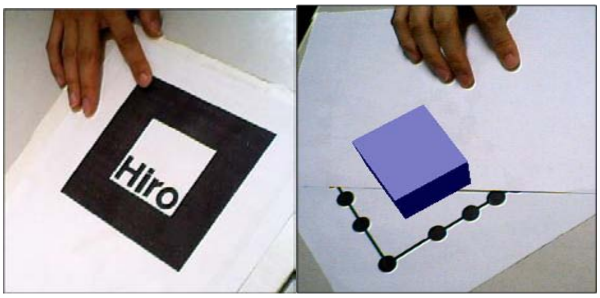

Figure 9. Marker recognition under occlusion

CoP-Tag method gives very satisfactory results even in presence of heavy artificial noise and blur, as shown in Fig.10.

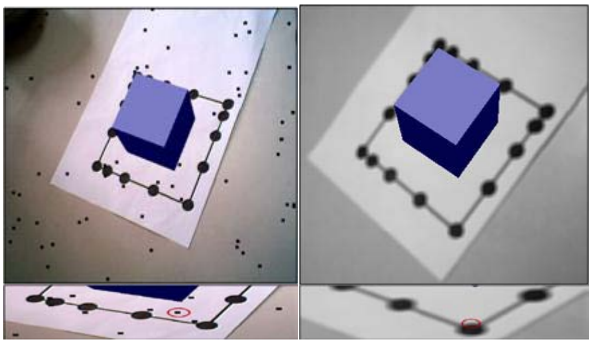

Figure 10. Marker recognition in the environment of artificial noise and blur

At last we show the multi-marker registered effect(see in Fig.11), and the performance is stable and reliable.

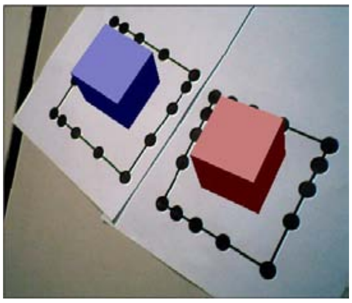

Figure 11. The multi-marker registered effect

V. CONCLUSION

In this paper, The novel marker proposed exploits projective invariant principles which offers a simple, fast, and accurate pose detection. The features of CoP-Tag show very satisfied results in the conditions of artificial noise and blur. And marker design is resilient to occlusion without severely affecting its detection or pose estimation accuracy. We also solve the multi-marker problem in real-time Augmented Reality applications.

Of course there still exist some drawbacks. For example, when the camera position from marker over a certain distance, the marker detector relies on the width of straight lines and the size of the circular points in the image plane. And the range of possible cross-ratio values and specific number of different tags in one AR system application are still need to be researched.

REFERENCES

[1] R.Azuma, "A survey of augmented reality," Teleoperators and Virtual Environments, vol.6, pp. 355-385, 1997.

[2] H.Kato, M.Billinghurst, "Marker Tracking and HMD Calibration for a video-based Augmented Reality Conferencing System," In Proceedings of the 2nd International Workshop on Augmented Reality (IWAR 99), pp.85-94, 1999.

[3] Mark Fiala, "ARTag, a fiducial marker system using digital techniques", In proceedings of the IEEE Conference on Computer Society Computer Vision and Pattern Recognition, (CVPR 2005) pp.590-596, 2005.

[4] S. Malik, G. Roth, and C. McDonald, "Robust Corner Tracking for Real-Time Augmented Reality," Proceedings of Vision Interface (VI)2002, Calgary, Alberta, Canada, pp.399-406, 2002.

[5] Filippo Bergamasco, "Image-Space Marker Detection and Recognition using Projective Invariants," proceedings of International Conference on 3D Imaging, Modeling, Visualization and Transmission, pp.381-388, 2011.

[6] Murphy-Chutorian,E, "Head Pose Estimation in Computer Vision: A Survey," IEEE Transl.J.vol.31, pp.607-626, April 2009.

[7] Yanli-Hong, "Calculation of Image Coordination of Centers of Circles Based on Geometric Invariance Under Projective Transformation," Computer and modernization, vol.9, pp.9-15, 2010.

[8] Fuchao-Wu,Zhanyi-Hu, "A Linear Method for the PnP Problem," Journal of Software,vol.14,pp.682-688, 2003. Survey," IEEE Transl.J.vol.31, pp.607-626, April 2009.

[9] Huijuan-Zhong, Xiaolin-Liu, Xiaoli-Wu, "Study on Augemented Reality System and Key Technologies," Computer Simulation,vol.25, pp.252-255, 2008.

[10] Chen Huang, Yimin-Chen, Sheng Xu," The Research of Wide Range Registration Based on Magnetic Force Tracing in AR System",Computer Science,vol.38,pp.290-292,2012.