ARTTag: Aesthetic Fiducial Markers based on Circle Pairs

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(a) (b) (c)

Figure 1: *Examples of ARTTag, in which circles are seamlessly integrated. (a) Zebra motif markers with two circles as eyes. Left eye in right marker is 8% larger than in left marker. (b) Cat motif markers with multiple circles in cloth texture. One circle is 5% larger in right marker. ARTTag can assess difference between left and right markers in (a) and (b), which is hardly perceptible to human observation and undetectable by NFT. (c) shows identification and calibration results of cat motif markers in (b).*

Abstract

In this paper, we present ARTTag, an aesthetic fiducial marker system, of which the design development can be performed with any color, texture, shape, or other features as long as circle pairs are integrated. By utilizing the projective properties of circular features, ARTTag is appropriate for detection, identification, and camera-based registration in augmented reality (AR) applications.

Keywords: augmented reality, fiducial markers

Concepts: **• Computing methodologies ~ Computer vision tasks;** *Scene understanding;*

1 Introduction

For practical AR applications, many artificial fiducial markers have been proposed, e.g., Kato et al. 1999, Rekimoto et al. 2000, Naimark and Foxlin 2002, and Bergamasco et al. 2011. These fiducial markers exhibit several advantages that lead them to be widely adopted in applications for camera-based registration. One of the advantages is the simplicity and robustness these approaches offer. Another is that the set of markers are crafted in a similar pattern and appearance as to be easily identified by humans; thus, users would not be confused about which target to interact with. Also, any member in the set of markers is uniquely identified by applications.
However, these fiducial markers have strictly restricted designs or binary coded patterns and are explicitly attached in everyday environments, so they usually reduce the user experience or can be visually unappealing. Some approaches have been proposed for this problem, e.g., Tenmoku et al. 2007 and Korondi et al. 2012, to achieve balance between visual elegance and robustness. To extend the common use of fiducial markers in everyday contexts, where aesthetic considerations are as much important as efficiency of application, we propose an aesthetic marker system that can be integrated into everyday environments and that still maintains high levels of robustness and accuracy with the help of circle pairs. Since circles are one of the most common and natural design features in artwork and illustrations. They have projective properties that can be used to simplify detection and camera calibration processing. In this paper, we present two main accomplishments:

1. Aesthetic fiducial markers designed in any color, texture, shape, or other design features integrated with circle pairs.
2. An efficient algorithm for handling this kind of fiducial marker by utilizing the properties of projected circle pairs.

2 Versus NFT

Natural feature tracking (NFT) methods are becoming more common and important as they are also less obtrusive and provide a more natural experience; however, these methods are still too immature to achieve robust and accurate registration. Also, the algorithms of these methods need to have enough distinguishable visual features; thus they are unable to uniquely identify similar patterns and appearances in a set of markers for practical use.

3 Algorithm for detection and calibration with ARTTag

Instead of depending on any other visual features or design patterns in fiducial markers, our processing workflow mainly involves circle pairs and is described as follows.

3.1 Registration of fiducial markers

For circle pairs for every member i in a set of fiducial markers, only radius r_i of one circle in the pairs is distinct with from other markers (**Figure 1**). Let the symmetric matrix of coefficients $\boldsymbol{c}_i$

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SIGGRAPH 2016 Posters, July 24-28, 2016, Anaheim, CA
ISBN: 978-1-4503-4371-8/16/07
DOI: http://dx.doi.org/10.1145/2945078.2945116

present the circle, where $x^T c_i x = 0$, c_i is determined by the position and r_i of the circle. In the same form, another circle in the pair can be described as c, which is exactly the same in for every marker i (same position and radius r). The radius ratio, r/r_i, of circle pairs is registered in the system as an index for identifying marker i.

For circle pairs c and c_i, we can calculate a scalar value as *Trace* $(c^{-1}c_i)$ or *Trace* $(c_i^{-1}c)$, which is invariable under projective transformation [Forsyth et al. 1991]. This projective invariant is registered in the system for detection.

For practical implementation to deal with noisy images, we also register visual features between the centers of circle pairs by using binary code to remove pairs that happen to share similar projective invariants and radius ratios of the member in the set of fiducial markers.

3.2 Circles detection and circle pairs filtering

Since circles appear as ellipses under projective transformation, so the projective invariant of ellipse pairs should be the same as circle pairs. We customized the simpleblobdetector class in OpenCV by adding the Taubin method to detect all ellipses in projection images and calculate the matrices of coefficients. Then, the projective invariant of every ellipse pair is calculated and compared with registered values in the system. Since only one parameter r_i has been changed in the c_i of the circle pairs, the projective invariant of all circle pairs in the set of fiducial marks is altered in a relatively small range, which is difficult to use as identification in noisy images. However, ellipse pairs of which the projective invariant is inside this small range are easy and fast to select, and they are the candidates that may be from the circle pairs in the set of markers. Visual features are also checked to remove incorrect candidates.

3.3 Camera calibration and identification

Ellipse pairs in the projection image of two co-planar circles are invariant with respect to the point of view of the camera, and this characteristic allows for an easy and straightforward rectification of the image plane where circle pairs reside [Chen et al. 2014]. Thus, circle pairs can be reconstructed from ellipse pairs selected from **Section 3.2**; then, the radius ratio can be calculated and compared to registered values in the system for specific identification.

3.4 Occlusion handing

Since our algorithm depends on circle pairs in a marker, it is obvious that the occlusion of other areas of the marker does not affect the algorithm. If there are multiple circles in a marker, more than one group of circle pairs can be registered in the system; therefore, the approach can also be robust to occlusions of circles as long as one pair of circles is visible.

4 Results

Figure 1 (c) shows an experimental image taken by iPhone 6. The numbers indicate the identification results. A 3D coordinate system and teapot model are displayed according to the camera calibration results. **Figure 2** shows results obtained when occlusions occurred.

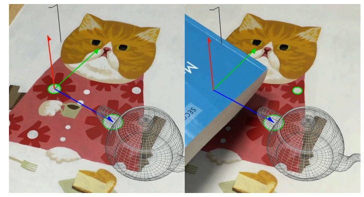

Figure 2: *Experimental image that demonstrates occlusion handing results.*

5 Conclusion

We presented ARTTag, a novel design for fiducial markers, which is based on circle pairs. Experimental images showed the results of our approach for AR applications in the context of an everyday environment. One of the limitations of our approach is the undesirable characteristic of a small number of identifiers.

Acknowledgements

We thank Kensuke Ito and Kenji Suzuki for their original design artwork for ARRTag.

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