

Exploring the Performance of Graphically Designed AR Markers

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Figure 1: Markers evaluated in the study, showing the star-rating awarded them by the Vuforia target manager

ABSTRACT

The design of graphical augmented reality (AR) markers requires compromise between the aesthetic appearance and tracking reliability. To investigate the topic, we created a virtual reality (VR) pipeline to evaluate marker performance, and validated it against real-world performance for a set of graphical AR markers. We report that, with the well known Vuforia framework and typical smartphone hardware, well designed 20×20 cm markers can be tracked at distances of up to 68 cm. We note that the number of feature points is particularly important to a marker’s angular performance.

CCS CONCEPTS

• **Human-centered computing** → **Human computer interaction (HCI)**.

KEYWORDS

Augmented reality, AR, aesthetic markers, virtual pipeline, Vuforia

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1 INTRODUCTION AND RELATED WORK

Visual markers are a well-known approach to camera-based augmented reality (AR) tracking, with application examples ranging from books [2, 4] to clothes [3, 7] and games [8]. The markers should

be designed so that they can be reliably tracked from a range of distances, angles and in various lighting conditions, but also, often are required to match to product design aesthetics and user experience. A performance optimized marker may be perceived as technical looking and obtrusive [9], or not fitting to the use context [1].

AR tracking frameworks typically include inbuilt proprietary features to provide guidance on the quality of marker images, e.g. Vuforia’s star rating, which awards 5-stars to images expected to track well [12]. To evaluate the performance of different tracking algorithms, Zhang et al. [13] utilized a physical camera moving relative to a fixed marker to explore the effects of marker size (distance), perspective distortion, blur, and partial obstruction [13]. The use of a virtual reality (VR) pipeline to simulate real-world marker tracking was introduced by Gruber et al. [5, 6], who used photographic images with relatively high numbers of feature points as markers. Findings from the VR environment were validated against a physical setup reporting a consistency 0.74 between detection rates in the two environments [6].

Aiming to provide a more tangible evaluation of marker performance than current framework-integrated ratings, we developed a VR evaluation pipeline for AR markers, and validated it against real-world data. As a contribution, we provide data on the performance of a variety of typical, and low feature point AR markers in the Vuforia AR framework.

2 METHOD

To enable efficient evaluation of the performance of AR markers over a wide range of conditions, we developed a VR evaluation pipeline in Unity 3D. As a proof-of-concept, the commonly used Vuforia AR framework was chosen. As Vuforia expects a physical webcam as an image source, a pipeline was needed to stream the video of a Unity camera to Vuforia as a webcam stream. A plugin [11] was used to expose a Unity camera as a virtual webcam. As this device was not recognized directly by Vuforia, a webcam splitter [10] was added as an intermediary. The video was compressed with highest quality settings at a resolution of 1280×720. The vertical FOV of the virtual camera was 60°. The marker under evaluation

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Table 1: Mean lock probability for markers in the virtual pipeline and real-world test, over the camera-to-marker distance range 32 - 68 cm. Consistency ratio (C) is the ratio of simulated to real data [6]

	AR-Tag	Hiro	Lehner	Brovision	AR Toolkit	Leaves	One Star	Two Star	Three Star	Four Star	Five Star
VR Pipeline	0.30	0.77	0.95	0.95	0.98	0.99	0.45	0.40	0.62	0.79	1.00
Physical	0.31	0.72	1.00	0.89	0.57	0.91	0.06	0.51	0.78	0.86	1.00
Consistency (C)	0.76	0.87	0.95	0.94	0.59	0.90	0.59	0.57	0.77	0.83	1.00

was placed in the virtual environment and the virtual camera was moved to evaluate the effects of distance and angle.

We selected 6 well known AR markers, and created 5 original markers that received 1-5 rating stars from Vuforia’s target manager (Figure 1). The created markers were designed to have the minimum number of feature points (i.e. minimal visual complexity) to achieve each rating criteria. All markers were presented as sprites at their native resolution of 400×400 pixels and a real-world size of 20×20 cm. As the core metric, we used the ‘lock’ flag reported by the Vuforia SDK. This corresponds to a marker being identified and pose information being available. To ensure the measurements were not affected by memory effects within Vuforia, the Vuforia component was deactivated and reactivated between each condition. To account for random variability in marker lock, each condition was repeated 20 times (c.f. [6]), the mean of which resulted in the probability of lock in the condition.

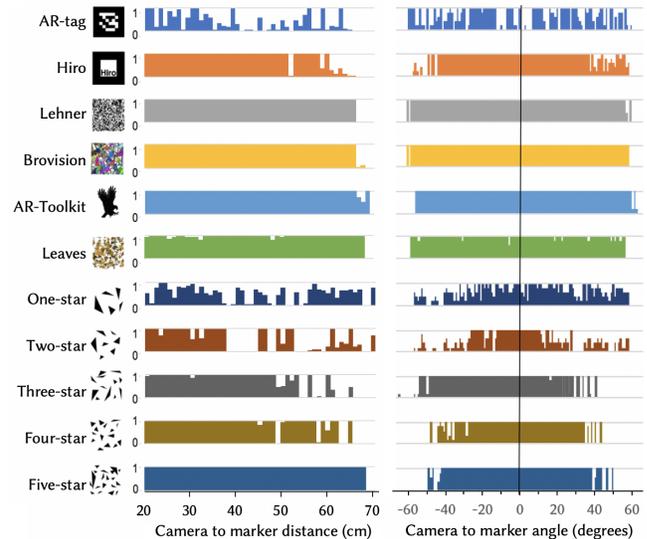
To validate the performance of our virtual pipeline, we assembled a physical setup to accurately control perpendicular camera to marker distance. The setup used the horizontal axis of a large 3D printer, with a webcam (Microsoft LifeCam HD 3000 720p) attached in place of the print head. The vertical field of view (FOV) of the webcam was measured as 31°. Lighting was controlled to minimize the effects of the environmental setting. Identical evaluation software and parameters as in the virtual pipeline were used, except the camera feed was taken from the physical web cam.

3 RESULTS

For each marker in the virtual environment, a dataset consisting of measurements over a range of distances (1200 data points per marker), angles (900 data points) and contrast levels (1700 data points) was collected. In the real-world environment 900 measurements were made per marker over a range of distances.

Figure 2 shows the lock probability of each of the markers in relation to their distance from the camera in the virtual environment. To compare the results against the real-world measurements, the real world distances were adjusted to compensate for the different FOVs of the virtual and real cameras (60° vs. 31°). After adjustment, the real-world measurements were binned to correspond to the nearest virtual measurement position. Table 1 presents the lock probability for each marker over the range 32 - 68 cm from both virtual and real-world systems and the calculated consistency ratio [6]. Overall, our findings indicate a high level of consistency between virtual and real-world across the range of marker types tested, $\bar{C} = 0.80$, $SD = 0.15$.

The best performing markers (Vuforia leaves and Five-star), provided reliable lock up to a distance of 68 cm. Horizontal angle and contrast performance at a fixed distance of 31 cm was measured

**Figure 2: Lock probability vs. perpendicular distance and horizontal angle (at 31 cm)**

in the VR environment. For contrast, all markers performed somewhat similarly, requiring between 10% and 16% opacity to achieve lock. The best performing markers (Lehner, Brovision, AR-toolkit, Leaves) were able to lock at angles of -60° to +60° (Figure 2). There was an asymmetrical performance notable for some markers.

4 DISCUSSION AND CONCLUSION

In general, we were able to validate the results from our VR marker evaluation pipeline against the markers’ real-world performance (Table 1). However, similar to Gruber et al. [6], we noted large differences in consistency between markers. With a 60° vertical FOV camera system (typical in smartphones) and a well designed 20×20 cm marker, reliable lock can be achieved at distances of up to 68 cm. Our findings indicate that the number of feature points is particularly important to angular performance, with maximum functional angles being in the range from 40° to 60°. We acknowledge that our work has focused only on one AR framework, but believe our findings and evaluation pipeline will be generally transferable to other feature-point based tracking frameworks. As future work, extension to include other frameworks is planned.

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