Robust Outdoors Marker-Based Augmented Reality Applications: Mitigating the Effect of Lighting Sensitivity

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Abstract. Marker-based AR is widely used in outdoors applications enabling the augmentation of physical objects with virtual elements. However, the diversification of lighting conditions may severely affect the accuracy of marker tracking in outdoors environments. In this paper we investigate the effectiveness of geolocative raycasting, a technique which enables the real-time estimation of the user's field of view in outdoors mobile applications, as a complementary method for enhancing the robustness of marker-based AR applications, thus mitigating the effect of lighting sensitivity.

Keywords: Augmented Reality · Marker-based · Marker identification Vuforia · Occlusion · Field of view · Raycasting · Lighting sensitivity

1 Introduction

Recent advancements in mobile computing have enabled the diffusion of mobile Augmented Reality (AR) applications. Two popular paradigms for implementing outdoors AR are marker-based AR and sensor-based AR. Marker-based AR is based on vision tracking and relies on the placement of fiducial markers in the real world, which are then tracked by the built-in camera of mobile devices. While experiencing marker-based AR, users perceive the real world through the camera feed, superimposed with virtual elements, based on the location of the tracked fiducial markers [1]. On the other hand, outdoors sensor-based AR applications utilize multiple commodity sensors, commonly integrated in smartphones, to estimate the device's rotation and direction. This information allows the appropriate positioning of virtual elements on top of the real world, which are typically projected through the user's camera feed. Outdoors sensor-based AR also utilizes GPS, to acquire user location and provide accurate placement of the virtual elements which are often associated with real locations [2].

Outdoors sensor-based AR applications require only a limited amount of the user's field of view (FoV) to be superimposed with computer-generated graphics, while the rest of the user's view perceives the physical world [3]. The augmentation of the

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physical world by virtual elements provides the user with a better sense of her location and surroundings, thus improving her overall perception. In typical urban settings, though, the to-be-augmented physical spot is often hidden from the user's FoV due to surrounding buildings. This effect is known as *occlusion*. In such cases, the projection of virtual elements meant to augment the occluded physical spot has been found to compromise the depth judgment of users, thereby resulting in misconceptions and wrong pursuance of tasks assigned to them [13]. Moreover, GPS and sensors used in outdoors sensor-based AR applications have limited accuracy, hence, they fall short in accurately positioning virtual elements, occasionally resembling a directional hint rather than an overlay matched to an exact location [8].

Outdoors marker-based AR applications are far more accurate than their sensor-based counterparts. In marker-based AR the virtual elements are visually attached to specific identified parts of the fiducial markers; the latter are commonly created using photographs of physical items which are to be augmented (e.g. the photograph of the side part of a building could serve as a fiducial marker). When the user aims her camera towards a physical item (whose photograph is registered as a fiducial marker), the item is detected and subsequently augmented, as the AR 'engine' matches common feature points of the fiducial marker image and the real image (as captured by the user device's camera) [2]. However, the accuracy of the matching process depends heavily on the actual lighting conditions on the real environment; even slight differences in the environmental lighting conditions (among the time that the fiducial marker's photograph was taken, and the time the user's camera captures the physical item) may severely affect the ability of the AR application to detect the fiducial marker and project virtual elements upon it. In fact, experimental tests have revealed that the sensitivity to environmental lighting conditions increases during nighttime, presumably due to the high variance of artificial lighting in urban environments [5].

The work presented herein attempts to enhance the robustness of outdoors AR applications through mitigating the effect of lighting sensitivity on marker-based AR. Our approach enables -by default- a 'standard' marker-based AR framework to detect registered physical items and accurately superimpose AR content upon them. In the event that marker tracking fails due to improper lighting conditions, we propose the complementary use of a FoV estimation technique (normally used in sensor-based AR apps); the FoV estimation algorithm detects whether the physical item is indeed within the user's FoV and then attempts to project AR content as accurately as possible. Our approach borrows research results from two relevant works recently undertaken by the authors. The first work involved the development of an efficient geometric technique, aiming at assisting developers of outdoors sensor-based AR applications in generating a realistic FoV for the users. The second work involved the evaluation of an outdoors marker-based AR application to annotate and promote architectural heritage in urban environments.

The remainder of this article is structured as follows: Sect. 2 presents previous research related to our work. Section 3 details the design principles and technical aspects of a research prototype which implements the above discussed hybrid approach to enhance the robustness of outdoors marker-based AR applications under non-uniform lighting conditions. Finally, Sect. 4 concludes our work and draws directions for future work.

2 Related Work

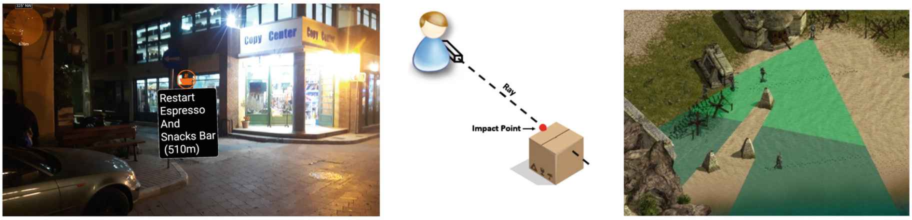
To the best of our knowledge, the problem of inaccurate tracking of fiducial markers has received little interest in the (marker-based) AR literature so far. Existing research [9, 10] has investigated the tracking of custom, barcode-like, grayscale fiducial markers (i.e. not created from photographs) in indoors environments. In particular, Naimark and Foxlin proposed a modified form of homomorphic image processing to eliminate the effect of non-uniform lighting on images [8]. Pintaric introduced an algorithm for selecting adaptive thresholds for fiducial segmentation to cope with generic lighting phenomena, such as shadows or reflections off a marker's surface [7]. Both the proposed solutions have been demonstrated on desktop (rather than mobile) applications. The remainder of this section presents previous works of the authors, the combination of which enables the development of lighting-insensitive outdoors marker-based AR applications.

2.1 FoV Estimation in Sensor-Based AR Applications

Outdoors sensor-based AR applications commonly fail to effectively handle the occlusion effect, thus superimposing virtual elements even when the associated to-be-augmented physical items do not lie within the users' FoV [6]. An example of this issue is illustrated in Fig. 1a, wherein the AR content attached to a venue is projected on the user's camera, although the venue is occluded by another building, thus resulting in misjudgments.

To address occlusion, in classic video games, the visibility of virtual objects is estimated utilizing the raycasting technique. Raycasting refers to the act of casting imaginary light beams (rays) from a source location (typically the point of view of the character or object controlled by the player) and recording the objects hit by the rays [11] (see Fig. 1b). The combination of several rays aiming towards different angles (centered around the characters' current direction) may be used to estimate the user's FoV (see Fig. 1c).

In a previous work [6], we extended this idea to mobile gaming wherein, unlike video games, the game space is not pre-registered and occlusion typically occurs due to surrounding buildings. Our focus has been on determining the user's FoV, whilst satisfying critical requirements of mobile games such as (a) real-time performance; (b) suitability for execution on average mobile equipment; and (c) support of popular map platforms. Along this line, we introduced a geolocative raycasting method which allows mobile game developers to detect buildings (or custom-generated obstacles) in location-based AR game environments, thereby reliably handling the object occlusion issue. Essentially, our method receives inspiration from the raycasting technique utilized in classic video games. It employs an efficient geometric technique generating several ray segments which are derived based on the users' location (as measured by the GPS receiver of the user's device), while their direction is set based on the smartphone's direction (as estimated by its magnetic sensor). Finally, the rays' intersection points with nearby building polygons (deconstructed in sides) are calculated to estimate the users' FoV.



(a) (b) (c)

Fig. 1. (a) Demonstration of occlusion in GPS-enabled sensor-based AR; (b) raycasting in classic video games; (b) FoV determination in classic video games (http://store.steampowered.com/app/6800/Commandos_Behind_Enemy_Lines/).

To test geolocative raycasting we created an outdoors sensor-based AR game for Android smartphone devices, the Order Elimination[1]. In Order Elimination the user has to hunt down a zombie, which moves along a pre-defined route in the real world. To eliminate the zombie, the user has to approach in a distance up to 50 m, and shoot it down while it lies within her FoV, as generated by the geolocative raycasting algorithm (see Fig. 2a and b).

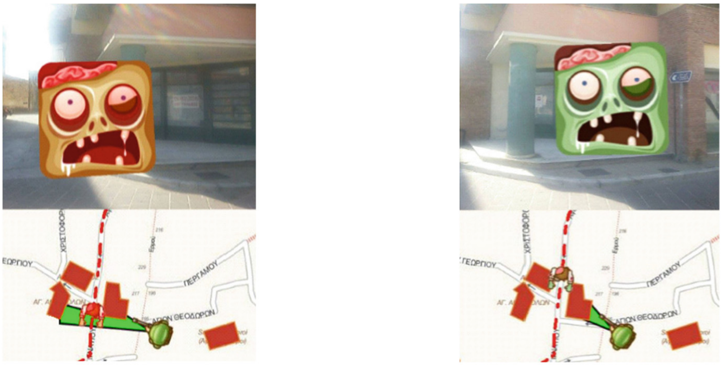
The performance and effectiveness of our method has been thoroughly evaluated under realistic game play conditions by twelve (12) players. The evaluation results have been encouraging as they highlighted the responsiveness and accuracy of the geolocative raycasting technique [6].

2.2 Marker-Based AR Architectural Heritage Guide Application

A typical application of AR technology in cultural heritage involves the use of the marker-based AR to effectively promote heritage assets through projecting virtual content over physical objects, thereby serving as an attractive interpretation and guidance tool [4, 7, 14]. Our previous work with marker-based AR challenged this narrow view suggesting its utilization as an effective annotation tool; in particular, as a means for (a) spatially correlating archival photos with the current form of a building; (b) annotating particular architectural or decorative elements of a building; (c) facilitating the development of AR content by end users (i.e., citizens and tourists) participating in crowdsourcing campaigns.

To demonstrate this idea, we have developed Flaneur [5], an outdoors marker-based AR application which offers dual operation: the 'projection' mode of Flaneur serves as a 'typical' mobile architectural heritage guide which projects pre-edited content over selected heritage buildings; the 'annotation' mode of the application invites a crowd interested in architecture to wander around a city and actively contribute in highlighting its architectural assets. In particular, the user may use the Flaneur application to capture a photo of a building, register it as a fiducial marker (as long as the building view has

[1] A video demonstration of *Order Elimination* can be found at: https://www.youtube.com/watch?v=iiY5aTasKPg .



(a) (b)

Fig. 2. (a) Zombie lying within the player's FoV; (b) Zombie lying out of the player's FoV (occluded by surrounding buildings).

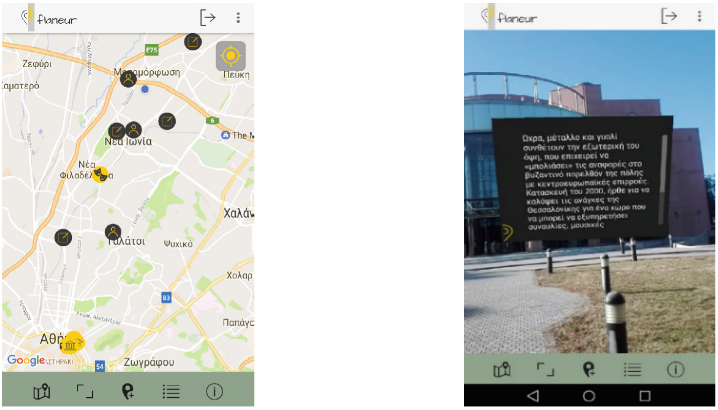
enough identification points) and then accurately position augmented information, such as text, upon the captured image [5]. Thereupon, the annotated building along with the augmentation content are available for end users to retrieve and consume through operating the 'projection' mode of Flaneur (see Fig. 3).

The evaluation of Flaneur by eighteen (18) participants, revealed that the most critical issue which severely affected and caused frustration to end-users has been the failure of the application to track buildings (i.e. fiducial markers) under diverse lighting conditions. For example, the photograph of a real location captured by a user during the morning, and registered as a fiducial marker, could not be detected by other users of Flaneur during the evening. This was mainly due to varying illumination levels as well as lighting phenomena like shadows or reflections off a marker's surface.

3 Supporting Marker-Based AR Applications Under Non-uniform Lighting Conditions

Inspired by the works presented in the preceding section, we have developed a prototype application wherein the geolocative raycasting technique is used to enhance the robustness (i.e. the accuracy level) of outdoors marker-based AR apps under diverse environmental lighting conditions. To validate our solution, we firstly implemented an application for Android smartphone devices based on the Vuforia[2] AR framework (also utilized in Flaneur). As a case study, we have taken photographs (under clear sky, daylight conditions) of two sides of an important cultural heritage building located in Lesvos (Mytilene, Greece); those photographs have been later registered as fiducial markers in the Vuforia cloud service. Figure 4a presents the two building sides along with the locations where the user can stand and aim her camera to display AR content.

[2] https://www.vuforia.com/.



(a) (b)

Fig. 3. The *Flaneur* application: (a) map view illustrating the location of AR-enhanced buildings; (b) identification of a marker (building's side) and projection of AR content.

Figure 4b demonstrates the augmentation of the building side with virtual content upon the successful tracking of the respective fiducial marker by the Vuforia engine. Figure 4c illustrates a 'bad' scenario, wherein the application fails to detect the fiducial marker during a cloudy day, thus preventing the projection of the AR content.

To address this issue, we 'hybridized' the application through incorporating sensor-based AR capability; the latter has been enhanced by our geolocative raycasting implementation so as to accurately detect events wherein the user is indeed in line-of-sight with the registered building's polygon sides. Firstly, we created a custom polygon resembling the cultural heritage building. Figure 4d presents the building polygon, two sides of which have been annotated with the same AR content as in the respective marker-based AR mode of the application. We have confined the overall user's FoV to 4 rays, representing a 4^{o} FoV. This narrow FoV ensures that in order to enable the AR content (through geolocative raycasting), the user should target exactly the same part of the building as in the marker-based version of the application. Finally, Fig. 4e presents the result perceived by the user, when she aims at a building side annotated with AR content. Evidently, the user views the same AR content, as in the marker-based version of the application, even if the lighting conditions are inappropriate for tracking the fiducial marker[3].

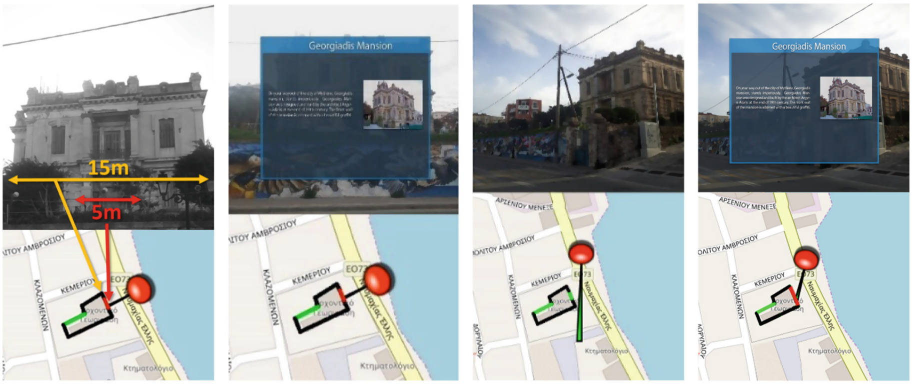
Even though our preliminary field tests revealed that the geolocative raycasting technique can effectively complement marker-based AR application, a number of limitations have been identified. First, the GPS accuracy may affect the accuracy of geolocative raycasting. However, our tests revealed that the 5 m–10 m GPS accuracy, which is common among smartphone devices [12], is acceptable. Users who evaluated the Order Elimination game shared the same view, further supporting this claim [6].

[3] A video demonstrating geolocative raycasting, used to support outdoors Marker-Based AR applications, can be found at https://youtu.be/pYIIEQEtgTc.

Fig. 4. (a) Fiducial markers locations; (b) projection of AR content by means of 'standard' outdoors marker-based AR; (c) marker-based AR under non-ideal lighting conditions: failure to track the marker; (d) the polygon sides of the cultural heritage building; (e) projection of AR content in sensor-based AR, enhanced by geolocative raycasting.

Moreover, considerable attention should be paid when annotating polygon sides with AR content. As shown in Fig. 5b, the user should register the whole building's side photograph as a fiducial marker, and associate it with AR content.

However, when using geolocative raycasting, the polygon side to be tracked (i.e. to be targeted by the rays) should be significantly shorter than the actual building side, and be center-aligned on the building side. This requirement is meant to address the lower accuracy of sensor-based AR applications, which is mainly due to the inaccurate estimation of the device's GPS location. Moreover, it enforces the sensor-based AR mode of the application to resemble its marker-based counterpart with respect to the location wherefrom the user may trigger the projection of the AR content. As shown in Fig. 5a, for example, the total length of the building side registered as a fiducial marker is 15 m, while the respective polygon side length fed into the geolocative raycasting algorithm is only 5 m. Thus, the application correctly enables or disables the projection



(a) (b) (c) (d)

Fig. 5. (a) Adjusted polygon side; (b) AR content correctly enabled based on the user's FoV; (c) AR content correctly disabled based on the user's FoV; (d) AR content erroneously enabled (due to registering a polygon side which matches the actual length of the building's side).

of AR content depending on whether the rays intersect with the narrow (5 m long) building's polygon side (see Fig. 5b and c). On the other hand, if the polygon side matches the full length of the building side (i.e. the 15 m used to create the fiducial marker), the user will be able to view AR content from locations which would be unsuitable for the marker-based version of the application (see Fig. 5d).

4 Conclusion

Outdoors marker-based AR applications commonly fail to track fiducial markers (often created using photographs of real physical locations) under non-uniform lighting conditions. In this work, we propose a hybrid method for enhancing the robustness of AR applications: we use a standard marker-based AR framework to track registered markers; in parallel, we execute an efficient geometric method to detect events where the user actually targets a marker which, however, remains untracked due to inappropriate environmental lighting conditions. This method is based on an existing geolocative raycasting technique which enables real-time determination of the user's FoV in outdoors sensor-based AR applications.

Our preliminary field tests revealed that geolocative raycasting may effectively complement standard marker-based frameworks to counteract their sensitivity to diverse lighting conditions. In the future, we aim at incorporating device inclination in our raycasting algorithm, to enable virtual elements annotation at specific building parts (e.g. interesting architectural details such as decorative elements), apart from building sides.

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