Real-Time Estimation of Illumination Direction for Augmented Reality with Low-Cost Sensors

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Abstract. In recent years, Augmented Reality has become a very popular topic, both as a research and commercial field. This trend has originated with the use of mobile devices as computational core and display. The appearance of virtual objects and their interaction with the real world is a key element in the success of an Augmented Reality software. A common issue in this type of software is the visual inconsistency between the virtual and real objects due to wrong illumination. Although illumination is a common research topic in Computer Graphics, few studies have been made about real time estimation of illumination direction. In this work we present a low-cost approach to detect the direction of the environment illumination, allowing the illumination of virtual objects according to the real light of the ambient, improving the integration of the scene. Our solution is open-source, based on Arduino hardware and the presented system was developed on Android.

Keywords: Augmented Reality, Illumination, Real-Time, Arduino, Android, Unity3d, Human Computer Interaction.

1 Introduction

Augmented Reality (AR) is the combination of real and virtual elements to augment the real world, improving people's senses and skills. Realistic appearance of virtual objects and their proper interaction with the real world is of high interest in entertainment, design, medicine, education and many other applications areas. In the last years, mobile devices like smartphones and tablets became part of our everyday life. Due to their computational power and integrated camera, they can act like a window into an augmented real world ([1]).

As virtual objects share the same scene with real objects in real lighting conditions, a common issue in AR is the appearance inconsistency between the virtual and real objects due to wrong illumination. The illumination of the virtual objects has to change in the same way as the illumination of the real scene. In order to achieve this consistency, the estimation of the illumination direction is required.

To properly align the simulated virtual object with the real world scene and produce a consistent simulation, an AR system must track the position and orientation of the camera respecting to the real world. This is typically performed by using AR markers with known shapes or textures ([2]). Recent development using feature extraction and recognition provides a new approach for AR tracking without needing any marker, however, this approach is still under development ([3]).

Tracking and alignment is required to provide overlay information. To improve the user experience, the system must provide a realistic blending between the virtual objects and the real world. The ability to properly simulate the illumination condition of the real world is still limited, mainly due to the difficulty of estimating the illumination conditions of the real environment.

Another important aspect of an AR system is portability ([4]). An AR system with high portability would give the user a greater degree of freedom during the interaction with the augmented environment. Based on the positioning of the display, there are two categories of AR systems with high degrees of portability: head-worn AR and hand-held AR ([5]). From these two categories, the hand-held AR systems are currently considered to be the best for introducing AR to the mass market due to its low production cost and ease of use ([5]). The proliferation of smartphones that could be used as hand-held AR systems also helps the ease of adoption by potential users. Similarly, head-worn AR is a viable option nowadays since there are many virtual reality headsets on the market.

In this work we present a low-cost approach to detect, in real time, the light source origin using portable devices, like Android and Arduino. Our work allows the AR developer to illuminate virtual objects according to the real illumination of the ambient, improving the integration of the scene.

The rest of the paper is organized as follows. Section 2 provides background information about previous works. Then, in Section 3 and 4, we describe the proposed system for real-time calculation of illumination, followed by an experimental application to show the features of the system. We conclude in Section 5 with a brief discussion on limitations and advantages of our approach and future work.

2 Previous Works

Several methods were proposed and developed to estimate the illumination conditions and create coherence between virtual and real objects in an AR system ([6,7,8,9]). Some progress has been made towards detecting the illumination direction by using image processing algorithms ([10,11,12,13,14,15]). Liu *et al.* ([10]) proposed an approach for tracking outdoor illumination variations by analysing feature points extracted from precomputed video frames, based on GPS coordinates and local time. Clements *et al.* ([11]) built a model of the sun-earth system to determine all shadows possible at a given approximate latitude, and compare shadows within a query to those possible under the model to determine illumination and camera orientation. The points of interest of each frame are described manually by user interaction. Jachnik *et al.* ([12]) presented an algorithm for real-time surface light-field capture from a single hand-held camera, which is able to capture dense illumination information from general specular surfaces. They divided the light-field into diffuse and specular components, showing that the specular component can be used for estimation of an environment map. That allowed a convincing placement of an augmented object on a specular surface, with realistic synthesised shadow, reflection and occlusion of specularities as the viewpoint changes. However, their method is computationally expensive since the intensity of the shadow is calculated as a brute-force approach. Xing *et al.* ([13]) proposed a method to insert virtual objects into a sample photograph of an outdoor scene, simulating the environment illumination and the shadow casting between virtual objects and real scenes. Arief *et al.* ([15]) proposed a method for real-time illumination direction estimation for mobile AR systems, using analysis of shadows produced by a reference object. The method could estimate the direction of a single light source in a controlled environment with a good accuracy. However, the estimation takes within 15 seconds and the method is not good at estimating the distance to the light source. Even though these approaches showed good results, their image processing algorithms are not capable of running in a mid-range smartphone in real-time due to their high computational cost. Furthermore, some of them only work with one frame at time and the user interaction is required to configure or calibrate the system.

Other approaches use special hardware to generate a 3d reconstruction of the scene ([16,17]). Thus, by knowing the location of the objects and the light sources, they can estimate the illumination of the virtual objects. Rohmer *et al.* ([16]) presented a differential illumination method obtaining a consistent illumination of the inserted virtual objects on mobile devices. They use multiple HDR video cameras in a predetermined scenario. Gruber *et al.* ([17]) presented an approach for real-time light estimation and photorealistic rendering in AR. They use a Microsoft Kinect to reconstruct the scene geometry. These approaches still do not work in real-time scenarios and expensive hardware is required.

3 Proposed System

Direction and colour of the illumination source are two important and necessary properties to simulate a proper illumination effect. Moreover, experiments by Slater, Usoh, and Crysanthou in [18] showed that the existence of shadows could improve the spatial perception of the user. We therefore focused on detecting directional illumination sources in order to simulate realistic shadows for a mobile AR system. To achieve this, real-time estimation of the illumination condition of the environment surrounding the mobile device is required.

In this paper we present an illumination direction estimation method to simulate illumination on mobile AR systems in real-time. A low-cost sensor was built in order to detect the illumination of the real environment. Since no image processing method is used, our method is affordable for any smartphone capable of running an AR application. A PC application is required to transmit the information from the sensor to the smartphone.

3.1 Sensing Illumination

In order to estimate the light source direction, we need to estimate the angle of incidence from the light source to a certain point in space. Hence, we can obtain an approximation of the light source rotation and therefore, estimate its direction. A photo-resistor or light-dependent resistor (LDR) is a very common and low-cost sensor which decreases the current resistance according to the light intensity detected on its surface. A semi-sphere shape sensor was built to sense illumination from different angles. This semi-sphere has an array of 8 LDRs along its surface in order to estimate the incident angle of the light source in the yaw rotation axis, each one separated by 45 degrees. Also, one last LDR is located on the top of the semi-sphere. The location of the LDRs can be seen in Figures 1 and 2. Together with the other LDRs, the angle of incidence of the light source in the pitch rotation axis can be estimated. The sensor is shown in Figure 3.

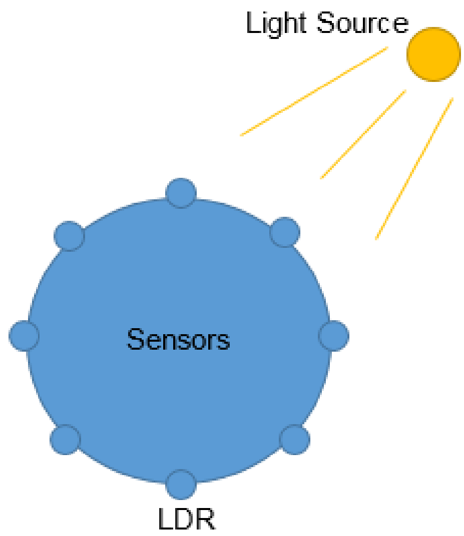

Fig. 1. Sensor top view. The array of eight LDRs is distributed around the sensor, each one separated by 45 degrees.

As Rohmer *et al.* proposed in [16], the computation of the system is distributed between the smartphone application and a PC application. Hence, the calculation of the direction of the light is done in the PC, allowing the smartphone application to focus only on the processing of the AR application. A local wireless communication is established between the smartphone application and the PC application. The PC application calculate the illumination source position in the space, and send that information to the smartphone application. An Arduino UNO Microcontroller[1] was used to gather the information from the sensors, sending it to the PC application.

The yaw rotation of the light source is calculated as follows. First, the eight LDRs around the sensor are numbered from 0 to 7. Then, the LDR detecting more light is considered. For instance, the LDR 3 in Figure 4. As each LDR is separated by 45 degrees, the angle of incidence of the light would be the number of the LDR detecting

[1] https://www.arduino.cc/

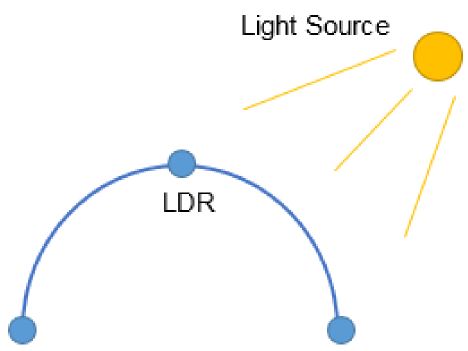

Fig. 2. Sensor sectional view. One last LDR is located on the top of the sensor.

Fig. 3. The semi-sphere shape sensor showing the position of the LDRs.

more light, multiplied by 45 degrees. In Figure 4, the angle of incidence of the light would be 135 degrees.

A second approach is proposed in order to get a better approximation. In this approach, not only the LDR detecting more light is considered, but also the others immediately next to it. Thus, the yaw angle is calculated as an interpolation of those three measures. Similarly, the pitch rotation of the light source is calculated as an interpolation between the LDR detecting more light and the LDR on the top.

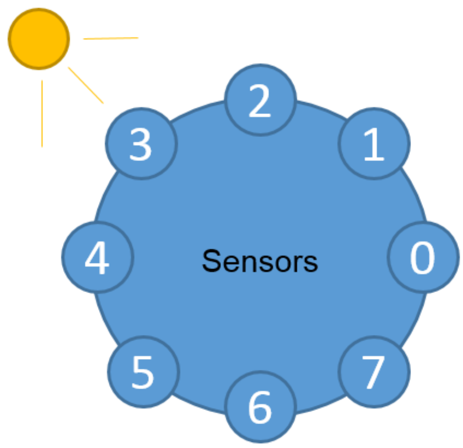

Fig. 4. Illumination example. The LDR 3 is sensing more illumination than the others.

4 Experimental Setup

In order to test our system, an AR application running on an Android device was implemented. Unity3d[2] with Vuforia[3] were used to create the application.

The application consists of an virtual object projected over an AR marker and a virtual directional light source, which rotation depends on the data transmitted by the sensor. The main purpose of the experiment is the comparison between the illumination and shadows projected by a real object and a virtual object. The shadows projected by the real object is produced by the real light source, and the shadow projected by the virtual object is produced by the virtual light source, which orientation depends on the sensed data. Figure 5 shows the experiment where the illumination and shadow of the real and virtual objects can be appreciated. As the position of the light source changes, the illumination and shadows of the virtual object also change in real-time.

[2] http://unity3d.com/es/
[3] http://www.vuforia.com/

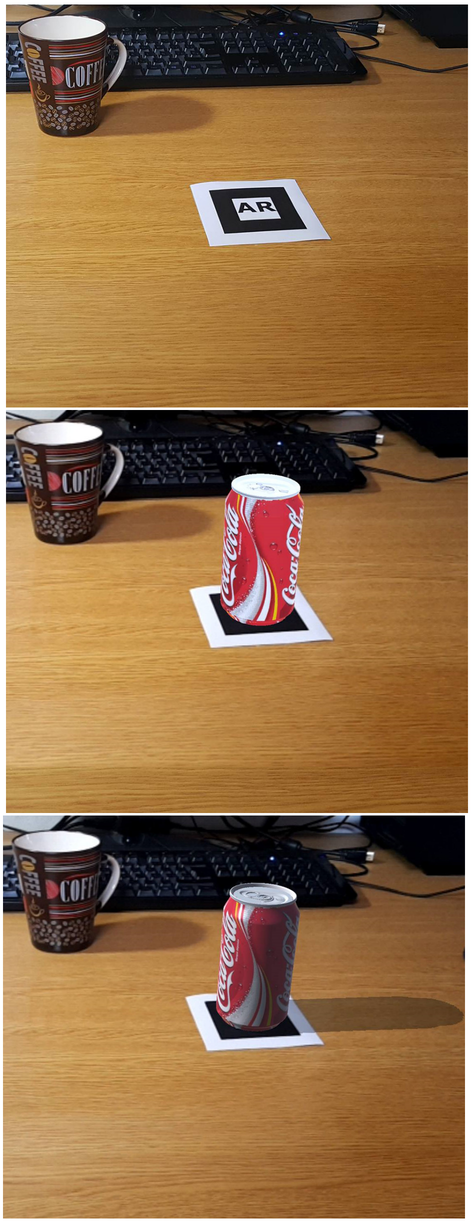

Fig. 5. Complete system working. No virtual object projected (top). Virtual object projected with ambient illumination (middle). Virtual object projected with directional illumination and shadow mapping (bottom).

4.1 Experimental Results

The main purpose of this work was the creation and test of a low-cost sensor to detect the illumination direction of the environment. The gathered information is then used to manipulate a virtual light source in an AR application running on an Android device. In general, our method generated a coherent AR environment, where the virtual illumination resembles the real illumination.

The illumination and shadows comparison between real and virtual illumination can be seen in Figure 5. The results are qualitatively similar to those of earlier studies. For instance, both Liu *et al.* [10] and Arief *et al.* [15] obtained similar results, however they performed image processing algorithms. On the other hand, Gruber et al. [17] also obtained good results, but using very expensive hardware.

The results seem to indicate that this approach is useful in any situation, specially where low monetary and computational cost are required, or the computational core of the system is based on smartphones.

5 Conclusions and Future Work

In this paper we have described a solution for real-time estimation of illumination direction for an AR application. Our approach is based on low-cost sensors and Arduino. We presented an experimental test using Android as a platform for our AR software and a PC to transmit the illumination information provided by Arduino.

The appearance of virtual objects and their integration with the real world is fundamental. A visual inconsistency between the virtual and real objects due to wrong illumination negatively affects the appreciation of the scene. As we have seen, few studies have been made about the estimation of illumination direction in real-time with affordable hardware.

Our results are encouraging and future research must include the development of a PC-free sensor, such as a stand-alone sensor or one physically attached to the mobile device. Such device should be able to interact with the AR software without needing any extra hardware. We must continue investigating new hardware in order to achieve a portable sensor, thus maintaining the low cost of the system. Finally, the detection of multiple light sources and the light color and distance were not considered for this work. In order to accomplish this, further work is planned to extend and improve the sensor features.

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