Realistic Rendering in Mobile Augmented Reality

Johannes Unterguggenberger

Context, Motivation, Approach
Augmented Reality (AR) combines a view of the real world in real-time with computer-generated data. Some mobile applications require a high degree of visual coherence. It is desirable to achieve realistic rendering without additional hardware. Our technique can achieve this goal, requiring only a single commodity mobile device for the steps:

- Capture real world illumination in an environment map
- Prepare the captured illumination information for high quality rendering by computing an irradiance and multiple reflection maps via different methods:
  1. Accurate calculation, 2. MIP-mapping based approximation, 3. Calculation via spherical harmonics
- Rendering an Augmented Reality scene, where virtual objects are shaded via image-based lighting (IBL)

Accurate Calculation
This method for calculating the irradiance and reflection maps computes the accurate results. To calculate the irradiance or radiance of one texel, the algorithm iterates over all other texels in the input environment map and accumulates their contribution weighted by the BRDF.

Bounds optimization:
The quadratic runtime-complexity of this method results in high performance demands. We describe an approach which optimizes the bounds for texture-lookup in the input map to increase the performance for reflection map calculation in exchange for a small quality tradeoff. The higher the specular shininess coefficient is, the narrower the bounds can be chosen.

MIP-mapping Based Approximation
This method strives to maximize the performance of irradiance and reflection maps calculation by creating an approximation to the accurate results. The approximation is calculated by MIP-mapping the input environment map and selecting an appropriate MIP-map level for each reflection map’s specular shininess coefficient which appears similar to the corresponding Phong BRDF-based accurate result.

\[
I_{opt} = I_{max} - \log_{2}(\min(\frac{1}{2}, N))
\]

We select the MIP-map level for reflection maps like shown in equation (3), where \(I_{max}\) is the maximum MIP-map level, \(r\) is the specular shininess coefficient, and \(N\) is the side length of the texture. For irradiance maps, we use the third to highest level, which is sized 4 x 4 pixels.

Calculation via SH Frequency Space
This method transforms the input environment map into its spherical harmonics (SH) frequency space representation by using the SH basis functions. SH basis functions are defined on the surface of a sphere and are arranged in frequency bands which are shown in the figure², where \(I\) is the band index. While SH basis functions on the lower bands capture slow changes over the sphere, functions on higher bands capture finer details of the input environment map. The number of basis functions increases in quadratic relation to the band index and at some level, the computations have to be stopped due to the computational complexity, ignoring all further higher SH bands.

Transforming an input environment map into SH frequency space yields a set of SH coefficients. Using spherical convolution between those and the SH coefficients of the Phong BRDF, irradiance and reflection maps can be calculated in SH frequency space via multiplication which corresponds to a convolution in the spatial domain.

Environment, Irradiance, and Reflection Maps

<table>
<thead>
<tr>
<th>Environment M. store incoming radiance values²</th>
<th>Irradiance Maps store reflected irradiance values</th>
<th>Reflection Maps store reflected radiance values</th>
</tr>
</thead>
<tbody>
<tr>
<td><img src="image1.png" alt="Environment Map" /></td>
<td><img src="image2.png" alt="Irradiance Map" /></td>
<td><img src="image3.png" alt="Reflection Map" /></td>
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Based on a bidirectional reflectance distribution function (BRDF), reflected irradiance and radiance values can be calculated by weighted accumulation of the incoming radiance values. The results are stored in textures and can be used to simplify the rendering equation (1) to the form depicted in (2) when using the Phong BRDF.

The Rendering Equation

\[
L(x, \omega) = L_\text{in}(\omega) + \int_{\Omega} L_i(x, \omega') f_r(\omega', \omega) \cos \theta' d\omega'
\]

Simplification with Phong BRDF-convolved irradiance and reflection maps

\[
L(x, \omega) = L_\text{in}(\omega) + L_\text{em}(\omega) \cdot L_\text{brdf}(\omega, \omega, \theta)
\]

where \(x\) is a point, \(\omega\) a direction, \(L_\text{in}\) the outgoing radiance, \(L_\text{em}\) the emitted radiance, the integral is the sum of radiance received from all directions, and \(\omega'\) is the light attenuation.

Environment Map Capturing
We are using a technique by Kán [Kán, 2015] to capture the full sphere of light in high dynamic range (HDR) with a commodity mobile device.

![Environment Map](image4.png)

The mobile device’s inertial measurement unit (IMU) is used to determine its orientation. Multiple camera images are accumulated to create the full environment map in HDR by using inverse camera response functions and the camera’s exposure time. When a new camera image is merged with the already captured data, feature matching is applied to improve quality. [Kán, 2015]

Visualization

AR rendering result³ using IBL with irradiance and reflection maps generated from the map shown in section Environment Map Capturing, and light mapping.

![AR Rendering](image5.png)

AR rendering results⁴ using IBL for a metallic material using reflection maps of different specular shininess coefficients in each image. The maps were generated from two different light probes with the accurate method.

References


- Adapted from Robin Green, Spherical Harmonic Lighting: The Gritty Details. In Archives of the Game Developers Conference, volume 56, 2003
- Dragon 3D model from the The Stanford 3D Scanning Repository, http://graphics.stanford.edu/data/3Dscanrep/

- Johannes Unterguggenberger

Contact: johannes.unterguggenberger@gmail.com