Image Based Relighting
TNM083 – Image Based Rendering
Jonas Unger, Stefan Gustavson, Joakim Löw
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1 Introduction

Lighting plays a key role in the realism and visual interest of computer generated objects. This has led to research and development of many techniques for simulating complex illumination for computer generated scenes. Designing a virtual lighting environment for simulating the illumination in a real world scene is often a very difficult task. By using omni-directional high dynamic range images of real world illumination, light probes, it is possible to render synthetic objects under real world illumination. Light probes can be captured in a variety of ways, e.g. photographing mirror spheres, using fish eye lenses etc. Using traditional light probes, the light incident onto a single point in space is captured, i.e. the plenoptic function is sampled at a single point in space at one single instant in time. This lighting information can then be used to illuminate synthetic objects with real world lighting.

To achieve maximum realism it is often convenient to use an image based approach also on the model side, i.e. use an image based method to estimate the reflection properties, BRDF \(^1\), and how it varies over the surfaces of the object to be rendered. This type of image based approach is convenient to use when the material properties are complex. Image based methods are among other things used for rendering high quality faces where it captures things such as self shadowing and sub-surface scattering within the human skin.

This practical is about image based relighting of such reflection data. Here we use a generated Light Stage data set of a face.

2 Light Stage Data

A Light Stage, see Figure 1 for a schematic, is a usually spherical structure or computer controlled arm with calibrated light sources attached to it. The subject is placed in the

\[^1\]BRDF stands for Bi-Directional Reflectance Distribution Function, and describes how a material, as viewed from any specified direction, reflects the light incident from any direction on the hemisphere.
center of the stage and illuminated by the computer controlled light sources, (usually), one at a time. For each light source an image is captured. The Light Stage configuration is then changed such that the illumination is coming from another direction and a new image is captured. This process is repeated until the entire sphere of incident illumination is sampled at some resolution. If the subject is stationary during the capture the final data will contain an estimation of how incident illumination is reflected at each point from the set of directions from the light source positions to the center of the Light Stage. Figure 2 displays five images, from the full set of images, illuminated from different directions.

2.1 Reflection Functions

The Light Stage data can be stored as the separate images, where each image describes how the entire object reflects light incident from a certain position on the sphere, see Figure 2. Another representation that sometimes is more convenient is to for each point on the object generate a reflection function that describes how light is reflected from all sampled directions in that object point.

The reflection function is usually stored in a longitude latitude map, i.e. each entry corresponds to a spherical direction. The directions are given by the configuration of the light sources in the Light Stage. The values in the reflection function are the value of the pixel of interest from each image in the sequence and describes the BRDF at the point of the object given by the pixel location.

This representation is often used when the data is used for things where the entire
Figure 2: displays six images illuminated from different directions. The five images are taken from the full set of images.

BRDF per object point is needed, e.g. solving for normal directions on the object surface.

3 Relighting

Relighting is the process of rendering the captured reflection data as illuminated by some novel lighting environment. This can be done using high dynamic range light probe images or purely virtual light sources such as spotlights, directional lights and area light sources. Here we will focus on relighting using light probe images.

Relighting of the sequence of images $I_i$ can be described by the following equation:

$$I = \sum_i^N I_i \int_{\phi_i - \Delta\phi}^{\phi_i + \Delta\phi} \int_{\theta_i - \Delta\theta}^{\theta_i + \Delta\theta} E(\phi, \theta)\sin(\theta)d\theta d\phi$$

the sum of the each image $I_i$ in the sequence scaled by the integral of the lighting environment $E$ over the solid angle corresponding to the $ith$ lighting direction.
Here we approximate the above equation by a linear combination of the images \( I_i \) and the mean of the lighting environment \( E_i \) over the solid angle scaled by the relative area of the solid angle projected onto the unit sphere \( W_i \)

\[
I \approx \sum_{i}^{N} I_i W_i E_i
\]  

(2)

For a more in depth explanation of how the weights \( W_i \) are calculated and what the values are for our data set in this practical see the document Sample Scaling in latitude-longitude maps that can be found on the home page. There you can also find the mapping between image number in the sequence and which direction it corresponds to.

If the images in the sequence are simply added together and scaled correctly, i.e. \( \{ E_i = 1, i = 0, 1, 2, \ldots \} \), the result is a diffusely\(^2\) lit rendering of the object.

4 Matting

In order to put the rendered object into the scene in which the illumination was captured we use a process called matting. To do this we use an alpha mask image that shows where in the data we have the rendered object and where the background should be. Most Light Stage-like apparatuses has some kind of matting system built in such that the alpha mask can be captured during the scan. The rendered object is then pasted in to the background using the mask in an ordinary alpha blend operation. The resulting image \( I \) can be described as:

\[
I = a \cdot I_r + (1 - a) \cdot I_b
\]  

(3)

where \( a \) is the alpha mask, \( I_r \) the image of the rendered object and \( I_b \) the background image.

5 Assignments

The data we will use here is not captured in a real Light Stage, but a rendering of a head as illuminated from a set of 30x15 directions on the unit sphere.

Since there are a lot of images in the data set, we have made the choice to use images of relatively low resolution (512x512 pixels). You will not be able to load them all into memory at the same time. Instead, try to loop over the images in your scripts.

5.1 Image Numbers and Related Angles

When doing the renderings, it will be convenient to have a table that maps from an image number to a direction on the sphere. This will be useful in the relighting process, where you will integrate over the portion of the light probe image decided by the direction.

\(^2\)It is rendered as if it was illuminated equally from all directions.
There are 452 images in the sequence. The first image, (0001), is captured from straight below the face, i.e. at $\theta = 180^\circ$, and the last image, (0452), from the top of the sphere at $\theta = 0^\circ$. The top, (0452), and the bottom, (0001), images should NOT be used during the relighting in this lab, since the weighting will not be correct.

The 450 remaining images in the sequence are 15 sub-sequences with 30 images each. For each sub-sequence the light source makes $360^\circ$ one revolution around the y-axis. The angle $\phi$, rotation around the y-axis, varies from $0^\circ - 348^\circ$ in steps of $12^\circ$.

The images are related to the angles $(\phi, \theta)$ in the following way:

<table>
<thead>
<tr>
<th>Image #</th>
<th>$\theta$</th>
<th>$\phi$</th>
</tr>
</thead>
<tbody>
<tr>
<td>0002-0031</td>
<td>174$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0032-0061</td>
<td>162$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0062-0091</td>
<td>150$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0092-0121</td>
<td>138$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0122-0151</td>
<td>126$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0152-0181</td>
<td>114$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0182-0211</td>
<td>102$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0212-0241</td>
<td>90$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0242-0271</td>
<td>78$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0272-0301</td>
<td>66$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0302-0331</td>
<td>54$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0332-0361</td>
<td>42$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0362-0391</td>
<td>30$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0392-0421</td>
<td>18$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
<tr>
<td>0422-0451</td>
<td>6$^\circ$</td>
<td>0$^\circ$ - 348$^\circ$</td>
</tr>
</tbody>
</table>

Note that $\theta$ goes in the opposite direction compared to the description in the document Sample Scaling in latitude-longitude maps. Here we have changed the order to be consistent with the definition of the angles in the light probe images.

Write a function that generates the table such that it stores $(\phi, \theta)$ in radians and you can index into the table with an image number to find the related angles.

### 5.2 Sample Scaling

Write a function that generates a latitude longitude map of size 30x15 pixels containing the proper weights $W_i$ depending on the angle $\theta$. See the document Sample Scaling in latitude-longitude maps for information about the correct sample scaling.

This latitude longitude map of weights will be useful in the relighting process, since you can use it as a lookup table to find the proper weighting of the samples in the lighting environment.

### 5.3 Diffuse Rendering

To acquaint yourself with the idea of image based relighting and the data, write a script that generates a diffusely lit version of the head. This is done by simply adding
the images together properly weighted. Use the latitude longitude weight table from Section 5.2.

If you want, you can also change the color of the illumination by multiplying the images with a constant \((R, G, B)\) triple.

### 5.4 Relight With Your Own Lighting Environment

Create a lighting environment of your own in Photoshop or similar software. That is, make an image of size 30x15 pixels where you put some colored dots or lines, for instance a red and a green, on a black background. The colored parts of the image will now act as light sources in the environment.

Load your lighting environment into Matlab and write a script for rendering the Light Stage data set as illuminated by the weighted lighting environment. When you load it you should type cast it from \texttt{uint8} to \texttt{double}. This is done in the following way:

```matlab
image = double(imread('myImage.jpg'));
```

It might also be convenient to normalize it:

```matlab
image = image/max(image(:));
```

Use the table that maps from image number to directions in the lighting environment to find out which coordinates to use in the latitude longitude map for the individual images in the sequence. Remember that it is the spherical angles \((\theta, \phi)\) that is stored in the table, which means that you will have to convert them into texture-coordinates before you do the actual lookup.

### 5.5 Sampling the Lighting Environment

Download the mirror sphere image from the practical home page or, if you want to, download another HDR light probe image from the internet. \texttt{www.debevec.org} has a collection of high resolution light probes you can choose from. Resample the light probe into a longitude latitude map. To do this you can use your scripts from the practical on image warping. You can load the HDR image using the \texttt{ReadPFM} function that can be found on the home page. This script reads floating point images in the \texttt{.PFM} format.

Write a function that given a lighting environment in latitude longitude format computes the mean value, \(E_i\), of the lighting environment over the solid angle for each for each lighting direction \(i\) and stores the values in a latitude longitude map of size 30x15. For a certain direction \(n\) this is done by taking the mean of the values inside a square centered at the direction with side length 12°.

### 5.6 Relight with Light Probe and perform Matting

Load a light probe and compute \(E_i\) as described in Section 5.5. It can now be used for relighting of the data. Write a script that relights the sequence with the lighting
environment described by $E_i$. Before relighting the data set you should pre-multiply the lighting environment with the latitude longitude weight map to get the proper scaling.

Use the alpha mask to add the functionality to make a nice matte with a suitable portion of the original high resolution lighting environment as background. The total field of view of the camera is 30°. Use the field of view to calculate what size the portion of the background image to use. Make sure that the right part of the background image is chosen according to the direction of the camera.

Add functionality to allow the user to choose the rotation of the environment (including the background) around the y-axis.