Estimation of Multiple Illuminants from a Single Image of Arbitrary Known Geometry*

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Overview

- Assumptions
  - Lambertian object of arbitrary known geometry
  - Directional light sources

$$\boxed{\mathbf{L = a \cdot I \cdot n}}$$

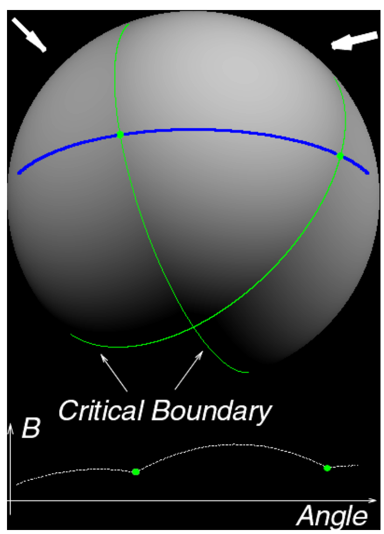
- Advantanges
  - Single image
  - No need for particular calibration objects
  - Robust to noise
  - Use of global information more suitable to Lambertian surfaces

Related Work

- Critical Points & Occluding Boundaries:
  Yang et al., CVPR'91 [20]
  Zhang et al., CVPR'00 [21]
  - Sensitive to noise. Needs calibration object
- Convolution
  Basri et al., ICCV'01 [1]
  Ramamoorthi et al., SIGGRAPH'01 [15]
  - Can not compute exact positions of directional light sources on Lambertian Surfaces
- Specular Sphere
  Debevec, SIGGRAPH'98 [3]
  - Interacts with environment. Need calibration object

Basic Definitions

- Critical Point
  - A point in the image is called a critical point if the surface normal at the corresponding point on the surface of the object is perpendicular to one of the light sources.
- Critical Boundary
  - All critical points corresponding to a real light will be grouped into a cut-off curve which is called a critical boundary.
  - Circle of maximum circumference on the sphere.

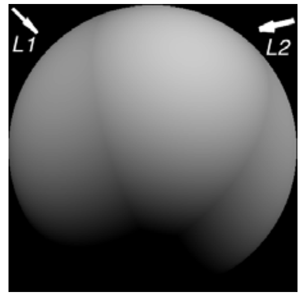


- 2 Light Sources

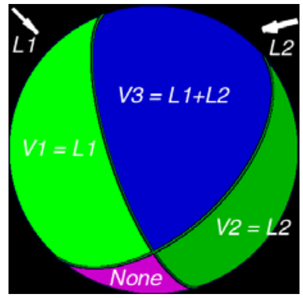
Real Light Source Detection

- Virtual Light Patch
  - Critical boundaries will segment the whole sphere image into several regions. Each segmented region corresponds to one virtual light that minimizes $\Sigma_i(Ii - L \cdot Ni)^2$. Each region is called a virtual light patch.
- Intuitively, the difference between two virtual lights is caused by a real light source, e.g.,

v3-v1 = (L1+L2)-L1 = L2



- Input Image

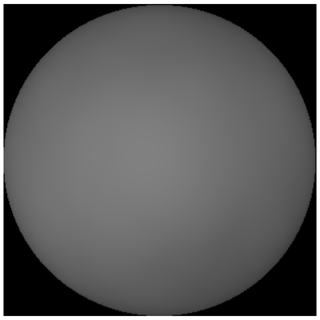


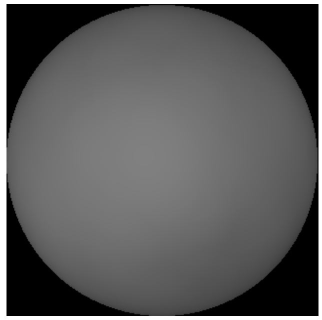
- Segmented Image

Our Algorithm

1. Detect critical points.
2. Find initial critical boundaries by Hough transform.
3. Adjust critical boundaries. Adjust every critical boundary by moving it by a small step, and a reduction in the least-squares error indicates a better solution. Update boundaries using a "greedy" algorithm to minimize the total error.
4. Merge spurious critical boundaries. If two critical boundaries are closer than a threshold angle (e.g.5 degrees), they can be replaced by their average.
5. Remove spurious critical boundaries. Test every critical boundary, and remove it if the least-squares error does not increase. Test boundaries in increasing order of Hough transform votes (first test boundaries that are not as trustworthy).
6. Calculate the real lights along a boundary by subtracting neighboring virtual lights.

Synthetic Sphere – 15 Light Sources

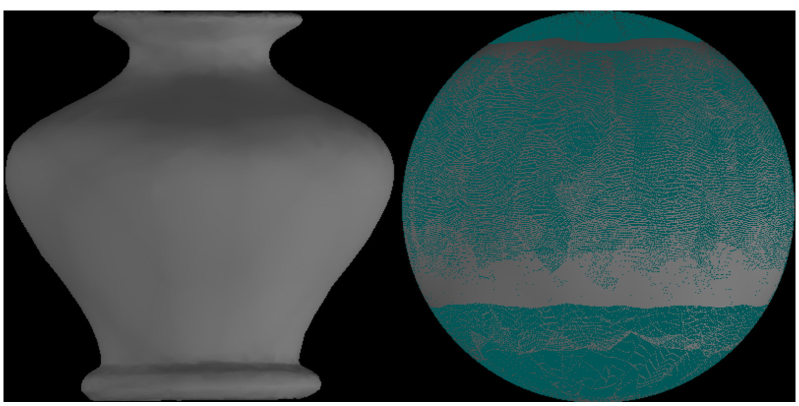




- Original Image
- Rerendered Image
- Virtual Light Patches

- Average Pixel Intensity (0-255 range) Error: 0.42 gray levels

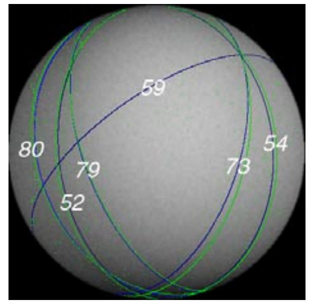
Objects of Arbitrary Geometry



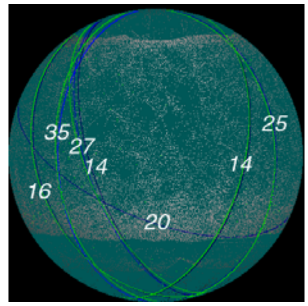
- Normals are mapped to a sphere
- High number of missing data points on the sphere (in green)

Hough Transform

- Use global information to get boundaries.
- Problems:
  - Noise causes fake boundaries.
  - Sparse data cause missing boundaries.
- Solution:
  - Evaluating the Least-Squares error using information from every available pixel inside a region (virtual light patch).



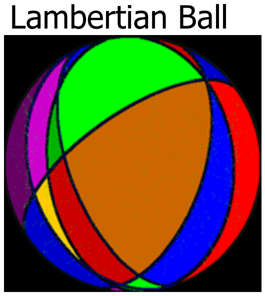
- Lambertian Ball



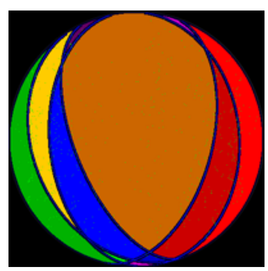
- Lambertian Vase

Virtual Light Patches

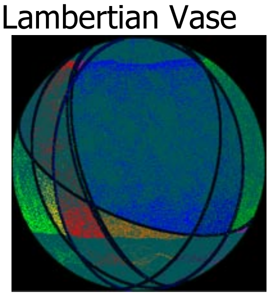
- Lambertian Ball



▪One spurious critical boundary is removed

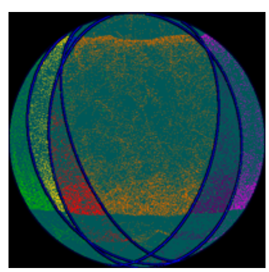


- Lambertian Vase

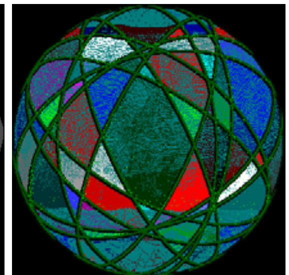


▪One spurious critical boundary is removed

▪Two critical boundaries are merged



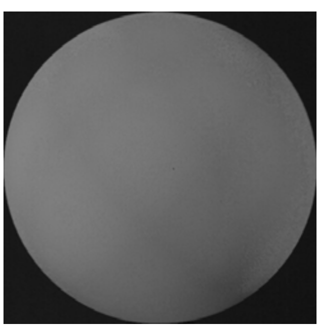
Synthetic Vase – 15 Light Sources

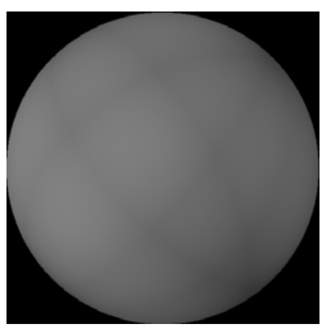


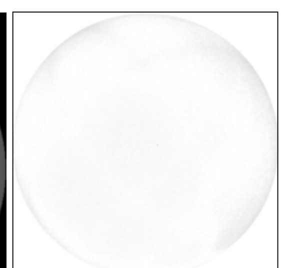
- Original Image
- Rerendered Image
- Virtual Light Patches

- Average Pixel Intensity (0-255 range) Error: 0.74 gray levels

Real Image of a Rubber Ball – 5 Light Sources





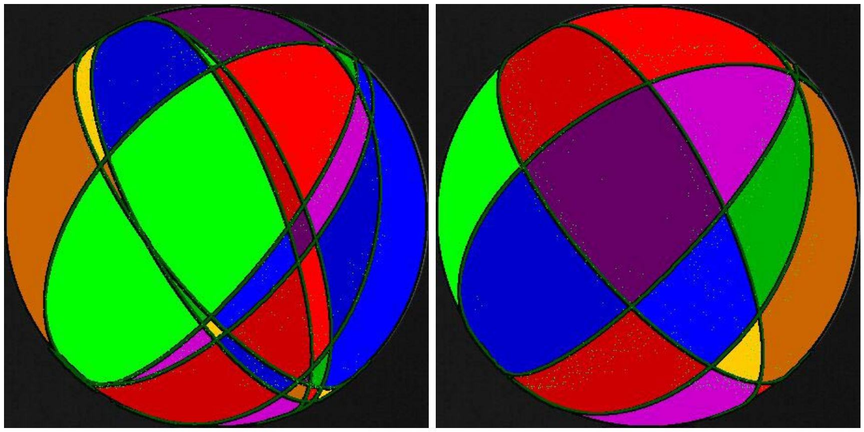


- Original Image
- Rerendered Image
- Error Image

- Average Pixel Intensity (0-255 range) Error: 3.39 gray levels

Real Image of a Rubber Ball

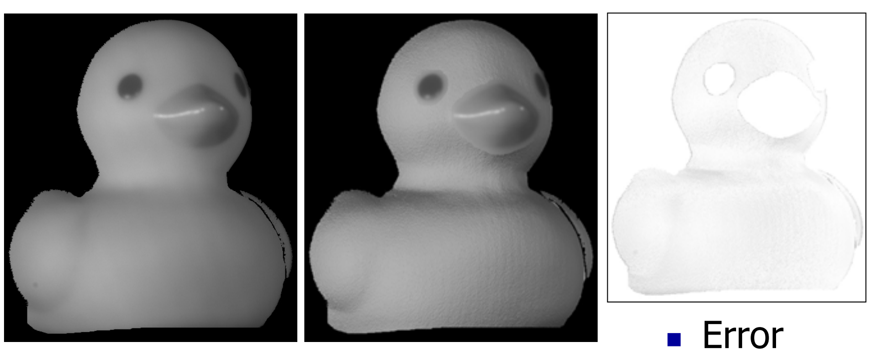
– 5 Light Sources



- Initial and Final Virtual Light Patches

Real Image of a Rubber Duck

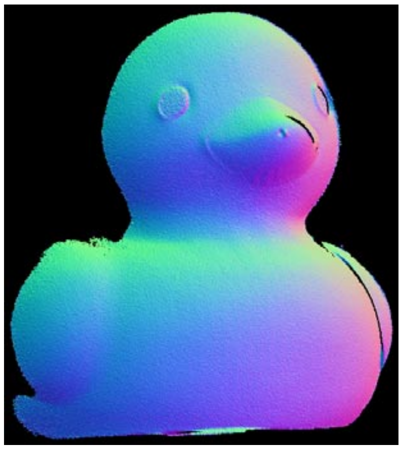
– 4 Light Sources

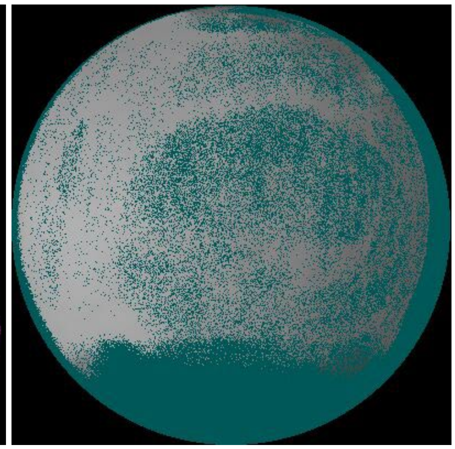


- Original Image
- Rerendered Image
- Error Image

- Average Pixel Intensity (0-255 range) Error: 6.55 gray levels

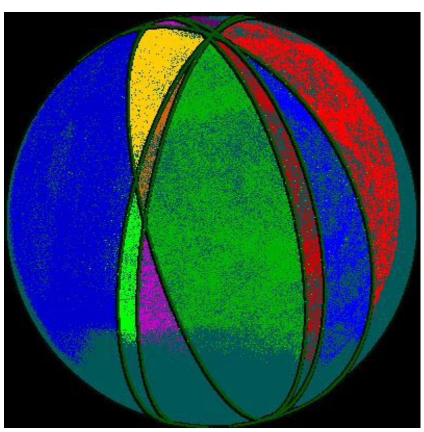
Real Image of a Rubber Duck
– 4 Light Sources

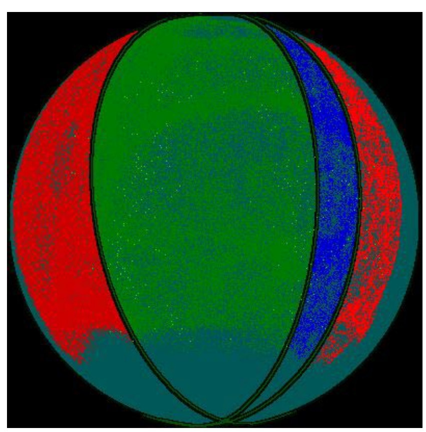




- 3D Shape
(Noise in acquisition)
- Sphere mapping

Real Image of a Rubber Duck
– 4 Light Sources





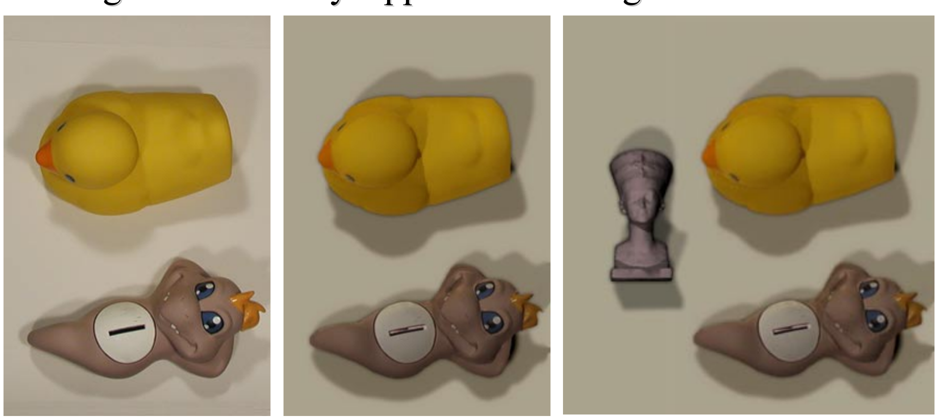
- Initial patches
- Final patches

Future Work

- Study of the properties of arbitrary surfaces, so that we can avoid the intermediate sphere mapping.
- Speed up of the least-squares method.
- Extend the method to non-Lambertian diffuse reflectance for rough surfaces.
- Explore combinations of our method with shadow based light estimation methods and with specularity detection methods.

Future Work (Preview)

- Augmented Reality Application– 3 Light Sources



- Original Image
- Rerendering with one light switched off
- Superimposing an object