A Simple Device for Image-based BRDF Measurement

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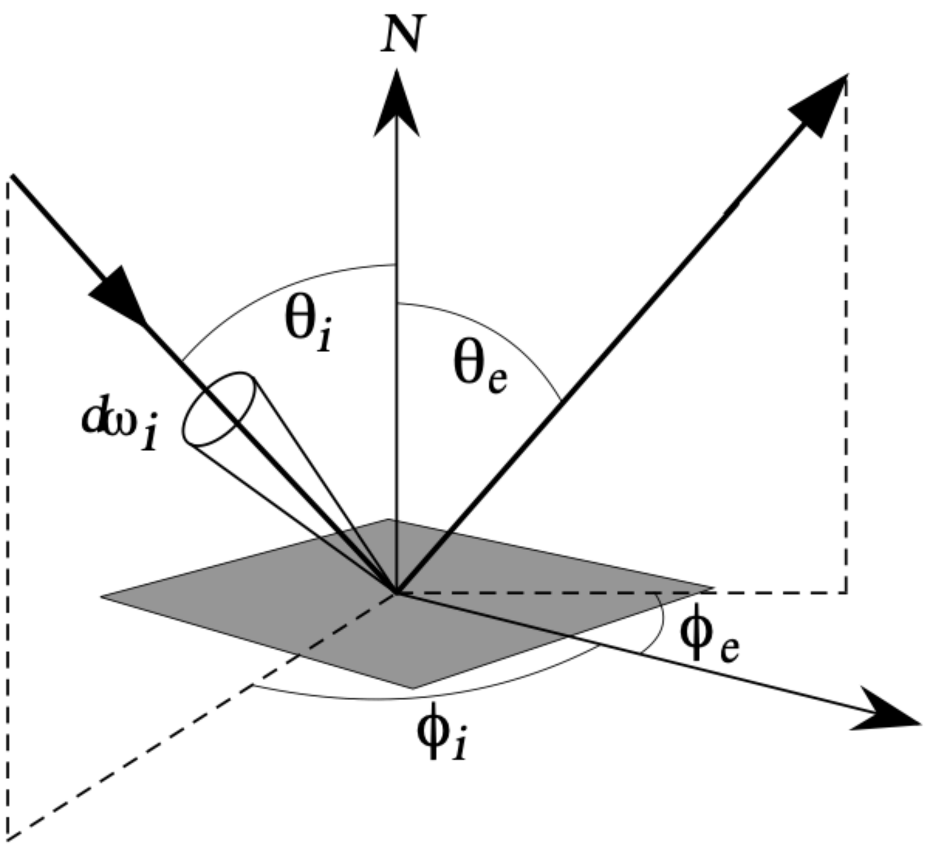
Introduction

For the final project, we conceive a sketch of a small, simple and handy device to measure BRDF(bidirectional reflectance distribution function).

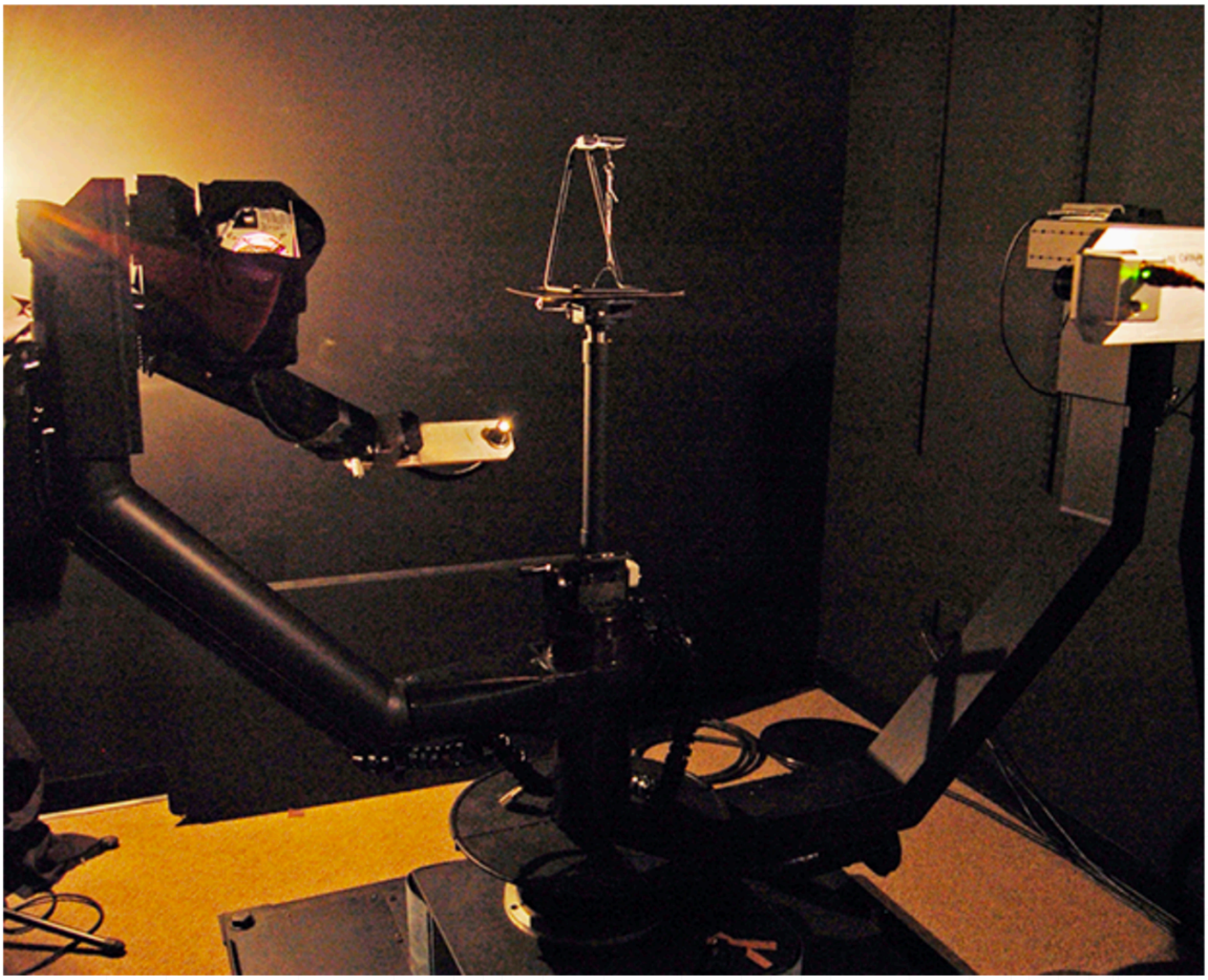
The bidirectional reflectance distribution function is a function used to describe how different materials interact with light source spatially. BRDF is usually written as

$p_{bd}(\theta_i, \phi_i, \theta_e, \phi_e, \lambda)$, which is the ratio of the radiance exiting the surface in a given direction to the incident irradiance of a particular wavelength λ from an incident solid angle $d\omega_i$ about a given illumination direction:

$$p_{bd}(\theta_i, \phi_i, \theta_e, \phi_e, \lambda)= dL(\theta_e, \phi_e) / dI(\theta_i, \phi_i)$$



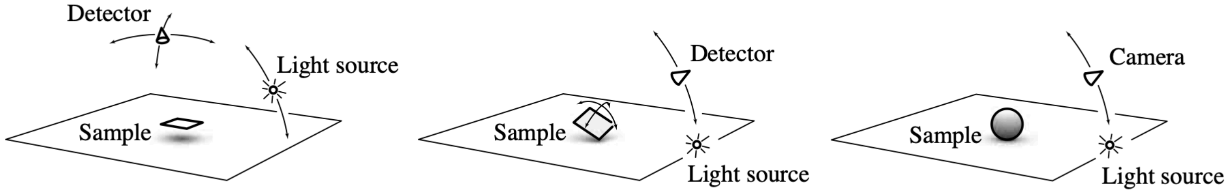
BRDF is of great importance in graphics, because the function depicts the visual effects of different materials' appearances. However, before [1](#), BRDF could only be measured by a complicated and expensive device named gonioreflectometer shown below:



Spherical gantry at UCSD

Apparently, we need 5 degrees of freedom to measure it. As color is processed in 3 channels (RGB) in computer, λ can be discretized. Furthermore, when we measure isotropic materials, only the difference bewteen ϕ_1 and ϕ_2 matters instead of their values. So we can rewrite BRDF as $p_{bd}(\theta_i, \theta_e, \phi_{diff})$. Even if the degrees of freedom are reduced to 3, the full BRDF measuring process can be several hours. The difficulty of building and using such devices like gonioreflectometer makes accurate measurements notorious. Besides, gonioreflectometers are also normally limited to measuring flat samples, and the measurements of curved ones are desirable.

To deal with the problems above, [1](#) gives a measuring method based on images of curved samples such as a sphere or a cylinder. Different parts of a curved object have different normal vectors. Therefore, the 3 angles related with p_{bd} vary inside a single image. So instead of rotating the detector(camera) or the sample shown in (a) and (b), we can simply measure different parts of the surface by analyzing corresponding pixels in an image. In our device, the two dimension of the image itself substitute for the two degrees of freedom of sample or detector rotation.



(a) (b) (c)

For the last degree of freedom, we can either move the camera or the light source. If we assume the material is anisotropic, we can rotate them both.

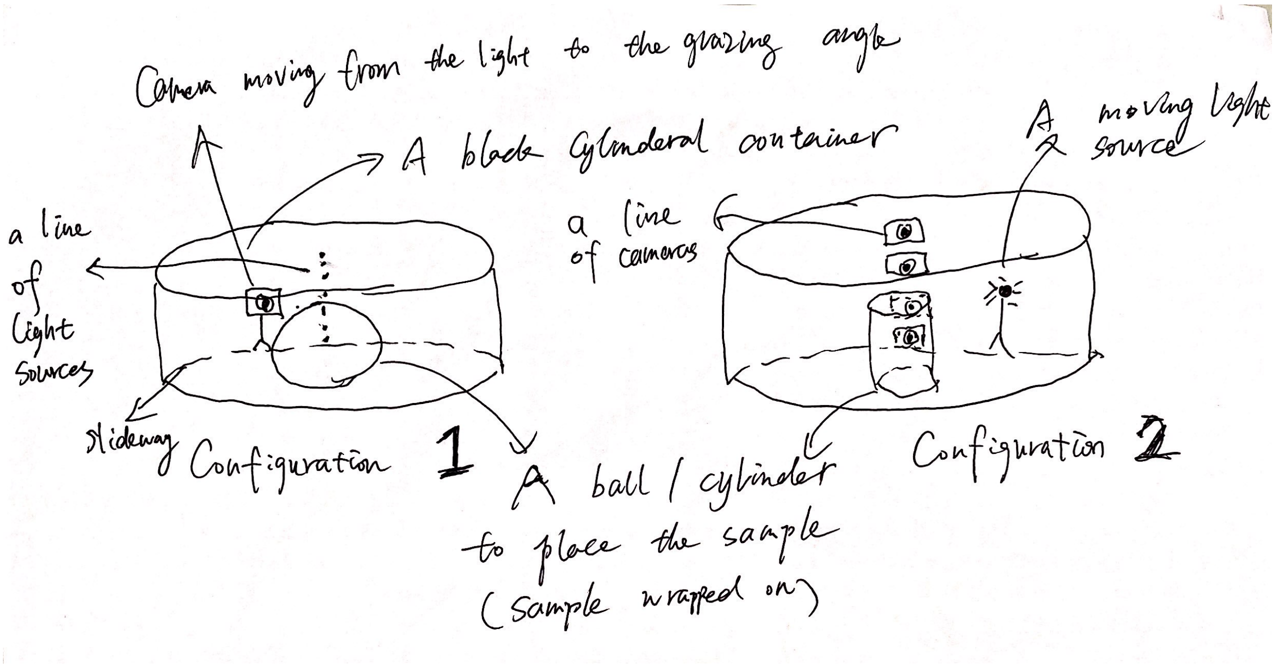
Related Work

Except for 1 discussed in the last part, we also found 2 useful. 2 is an implementaion of the theory in 1. And the device we are going to build is exactly an implementaion of the idea in 1, too. So 2 is of great help to us, which I will talk about in detail in part 3. Other work in this field such as 3 and 4 provides some mathematical tools(to expand the BRDF in certain kinds of series in general) which make the sampling fast. To be honest, I have not dived in articles like 3and 4. So I certainly have no idea to what extent they accelerate the sampling process. I will read them detailly if I have time. 5 includes information on how to set up a gonioreflectometer and what hardware we should use.

Our Approach

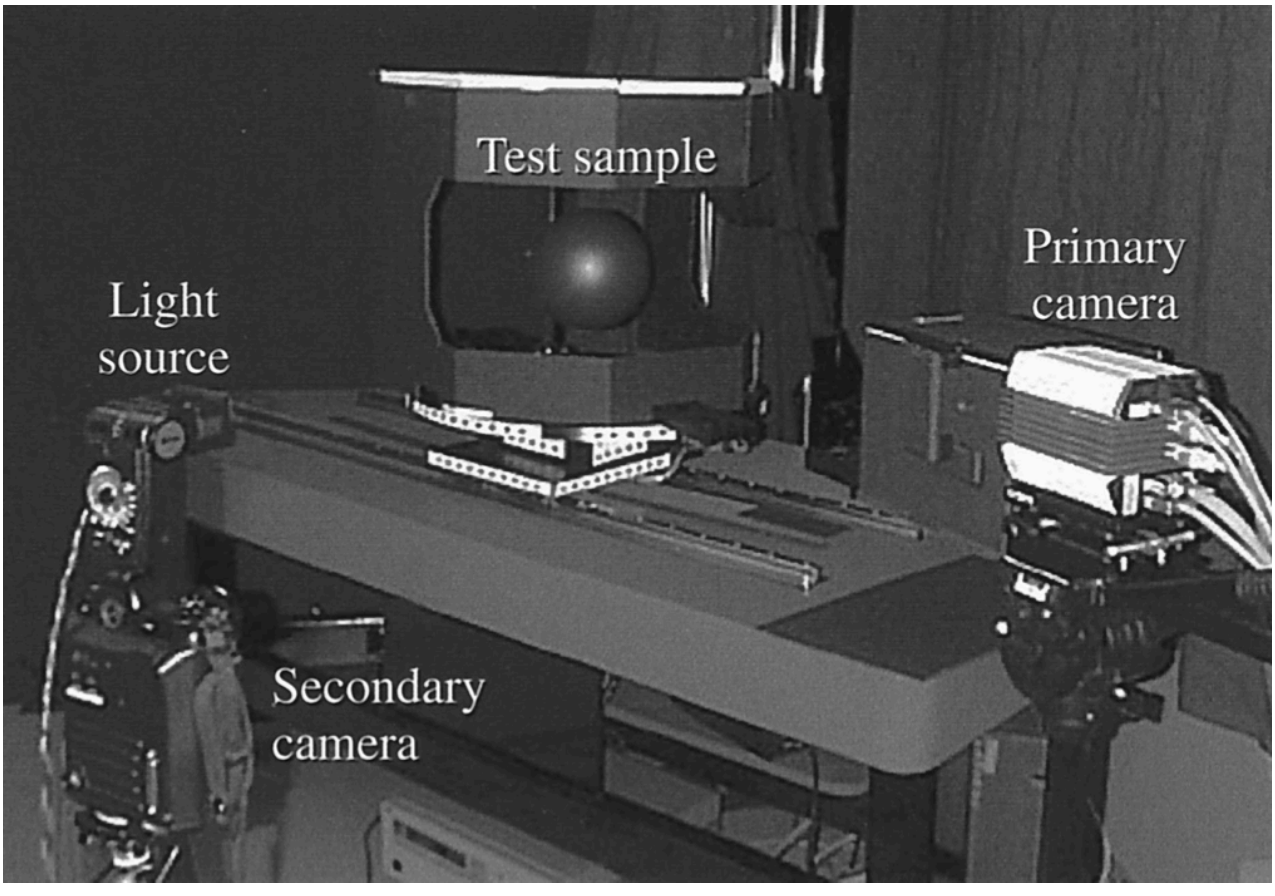
We conceive two configurations for the measurement. Each of them has its pros and cons, so we have not made our minds on a certain one. We expect to measure not only isotropic materials but also anisotropic ones. So we move the camera as well as expand the light source or move the light source as well as expand the camera.

	Configuration 1	**Configuration 2**
Pros	Less cameras, light sources are easier to place on the "wall"	Easy to focus as the cameras are fixed, easy to control the light, efficent use of cameras, large range
Cons	Hard to focus as camera is moving, hard to control the light, waste of the second camera ,small range	More cameras means more cost, cameras are harder to place on the "wall", hard to control the cameras

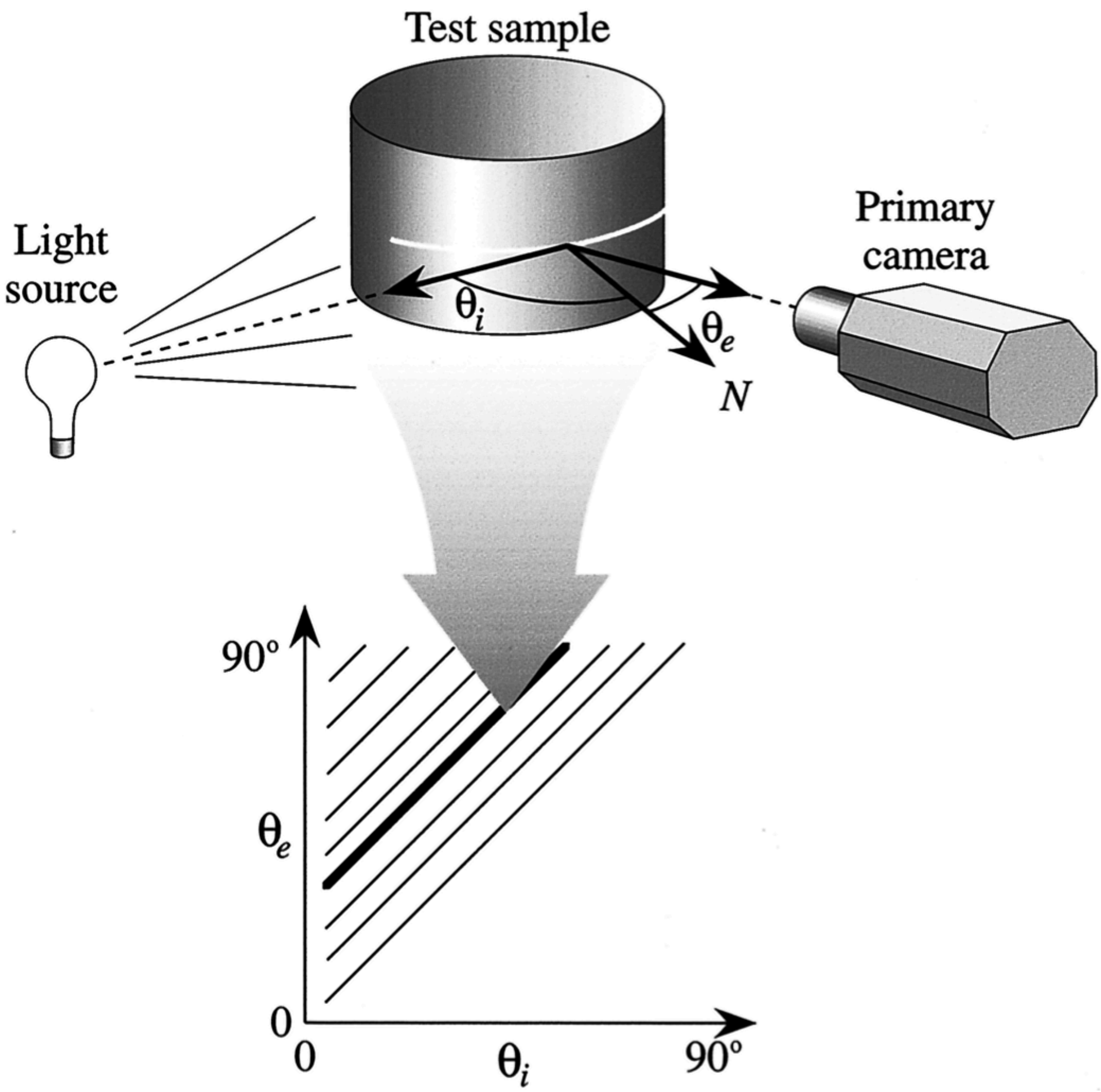


The height of the configuraions shall be 10 centimeters, and radius of the bottom circle shall be 25 centimeters or more. The rather big radius makes the camera easier to focus. The interior of the cylinderal container shall be painted black so that there is no light source caused by reflectance. The top of the container is a lid. You can open it to set up the light, the sample and the camera.

The difficulty of configuration 1 is how to control the light. The primitive plan is to use electric relay outside of the container. We control the light manually. The alternative plan is to control the lights using arduino or raspberryPi, and the circuits are inside the container, which will cause no leak of the light.



The difficulty of configuration 2 is how to let the camera on at the same time. The inpiration of configuration 2 comes from 2. Their device is shown above. The light source is moving. And a camera is attached to the light source. Through a calibration image taken by this camera, we are easy to know the accurate postion of the light source. However, they only have 1 camera except for the one attached to the light. We have a line. I do not know whether we can use OpenCV camera calibration to start them at the same time. The primitive plan is to start them one by one.



Another problem worth attention is that the camera should not change the light field. So the camera should be set up behind or at least aligned with the light source. Therefore, we can see the configuration 2 is more reasonble with cameras on the wall. And it allows larger range, because the initial included angle between the light and the camera can be very small.

For data processing, we can calculate the angles, radiance and irradiance from the image by OpenCV camera calibration.

Timeline

- Oct. 10th Finish reading relative paper and decide the final blueprint
- Oct. 17th Finish buying all the hardware needed
- Nov. 1st   Finish writing controlling code for the hardware and setting up the hardware
- Nov. 8th   Finish processing data
- Nov. 10th Presentation

Reference

[1] https://www.graphics.cornell.edu/pubs/1999/MLW+99.pdf

[2]http://www.graphics.cornell.edu/pubs/2000/MWLT00.pdf

[3]https://link.springer.com/article/10.1007/s11263-008-0151-7

[4]https://dash.harvard.edu/handle/1/4238987

[5]https://silo.tips/download/automated-three-axis-gonioreflectometer-for-computer-graphics-applications