Source Modeling for Illumination Design

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ABSTRACT

As computation speeds have increased dramatically over the last decade, we can now trace enough rays in a short enough time to use ray tracing to predict the performance of an illumination system. The biggest obstacle, however, to accurately model, and thus design, illumination optics is in developing an accurate source model[3]. In the past, sources were simplistically modeled as very basic geometrical shapes such as points, spheres, or cylinders. Some illumination design software now allows an engineer to create a more complex theoretical model of the source that could include multiple geometrical shapes to more closely approach real source properties. These models, however, are time consuming to create and still fall short of the goal to accurately model the system.

Rather than to build up a source model based on a (combination of) geometric shape(s) with some assigned output distribution based on either measured or theoretical data, the authors will demonstrate a new technique for developing and applying source models based on careful, consistent and general measurements. The measurement system consists of a CCD camera mounted on a 2-axis goniometer that allows images of the source to be captured over variable polar and azimuth increments. These source models produce accurate results even when optical surfaces are placed near the source.

Keywords: Illumination, source, reflector, lamp, ray-trace

1. TRADITIONAL SOURCE MODELING

Source models have previously been based on either basic geometrical shapes, or possibly a combination of geometrical shapes. More recently, some source models were created from measured data, such as polar intensity maps, or source radiance from a single view. Below is a discussion of each of these techniques, their advantages and short-comings.

Point sources (uniformly radiating)
Point source models are very limited in application and value. They only produce reasonable accuracy when the source is very small relative to the distance of the optical elements[1]. They are also only useful in modeling sources that radiate nearly uniformly in all directions. Very few real sources approach either of these conditions.

Point sources (variable radiant intensity)
This model is typical of the far-field illuminance used by lighting designers. This model is good for predicting the illuminance on a surface at a distance of 20 times[2] the size of the source. But, it is still not valid for systems where optical elements are placed near the source.

Spatial intensity map (single view) uniformly radiating
A spatial map of the source radiance at least takes into account the physical dimensions of the source, and improves on the model accuracy. This model can be quite accurate for predicting system uniformity when the optics only collect light emanating from the source over a relatively small solid angle. This is usually true because the source radiance usually is fairly constant over a small angle of view. However, most

efficient illumination systems must collect light over a large solid angle. If the source radiance changes as a function of angle, the model is no longer accurate. It is also not possible to accurately predict overall system efficiency since the true radiance of the source is not known over 4π steradians.

Spatial intensity map (single view) with variable radiant intensity

The spatial map of radiant intensity can yield good results when modeling systems that collect over a small solid angle. By knowing the radiant intensity at each view angle, the system efficiency can be calculated from the relative radiant intensity for all uncollected solid angle. But if the illumination system collects light over a large solid angle, and the source radiance changes as a function of angle – which is almost always the case – the single spatial map is not valid over the majority of solid angle. Therefore, this model cannot accurately predict performance when optical elements are placed close to the source and light is collected over a large solid angle.

Complex geometrical models:

Complex geometrical source models can be described from a combination of basic geometrical shapes such as cylinders and spheres. A detailed model can approximate the variable source radiance as a function of view angle. But to create a reasonably accurate model, one must take very careful measurements of all the lamp geometry including the filament and bulb walls.

There are still several deficiencies in this technique, however. These models typically don't account for all the vignetting that occurs within a lamp, such as when a coiled filament blocks light emanated from some other portion of the filament, or when support wires or glass envelope tip-offs vignette light in certain directions. They also don't account for the variations of filament temperature that exists at different locations on a filament. Small changes in temperature can have a large effect on the radiation generated by the filament.

Arc lamps can also be vignetted by trigger wires, and some portion of the arc is even blocked or reflected by the electrodes themselves at some view angle. But arc lamps pose an even greater challenge to creating an accurate theoretical model; the size of the arc and radiance at each location of the arc are not known unless actual measurements are taken. This is further complicated by the three dimensional volume of the arc, which causes the radiance at each location of the arc to vary as a function of view angle.

Because of the complexity of a typical source, even if some of these physical characteristics can be carefully measured and incorporated into the theoretical model, it can easily take days or even weeks just to create a reasonably accurate geometrical model.

2. RADIANT IMAGING SOURCE MODELS

An alternative to these conventional source models is to characterize the actual source by careful measurement of the source radiance.   To do this, Radiant Imaging has built a specialized two axis, computer-controlled goniometer on which a CCD camera is mounted (figure 1).   The source is placed at the center of rotation, and images of the source are captured by the CCD camera from view angles over a full 4π steradians. These images of the source are then stored in a database on the computer. The source model thus consists of a series of bitmaps each one giving the relative radiance distribution at the source for a particular polar and azimuth direction.   Radiant has characterized many different sources using this technique such as tungsten halogen lamps, xenon arc lamps, LEDs, compact fluorescent lamps, metal halide lamps, and strobe lamps (figure 2 & 3).

Figure 1 Goniometer

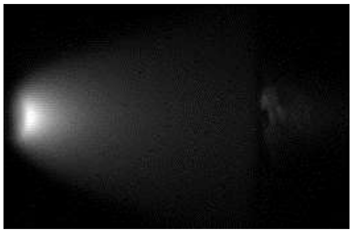

Figure 2 Image of a xenon lamp

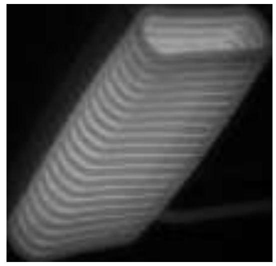

Figure 3 Image of a tungsten halogen lamp

To model an illumination system with this measured source data, rays are traced from the source at various locations and at various angles. The origination angle of the ray determines which source image to use. The originating location of the ray at the source determines the amount of flux assigned to each ray, and is based in the intensity (gray value) of the source image at the point of origination.

Rays from such sources can either be generated at regular intervals or stochastic (random) ray-tracing may be employed. The authors have found the latter method eliminates the risk of aliasing artifacts in the calculated irradiance distribution.

3. REAL-WORLD EXAMPLES

To illustrate the application of these new source models in real-world examples, two optical systems were modeled, and measured. Illuminance was measured using Radiant Imaging's ProMetric™ photometric measurement system. The sources for these systems were characterized using the technique described in this paper, and the illuminance was modeled using Radiant Imaging's ProLight™ illumination design and analysis software, which can utilize the characterized source model. The results are described below.

HPL Lamp in ellipsoidal reflector:
In this example, an ANSI HPL 575W lamp (figure 4) is placed in an ellipsoidal reflector. The HPL lamp consists of four coils placed concentrically about the lamp center. Support wires are located on each side, outside the coils.

A 25mm aperture was placed at the second focus of the ellipse, and the lamp was adjusted to maximize the flux through that aperture. A diffuse surface was placed 1.5m from the aperture and an image of the output was captured using ProMetric. The image is shown in figure 5.

ProMetric analysis showed there were a total of 6780 lumens incident on the measurement surface.

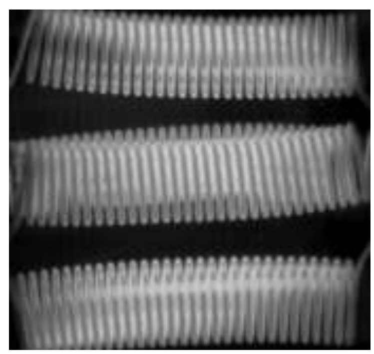

Figure 4 Image of HPL lamp

The source was characterized using the technique described in this paper. However, since the lamp is nearly symmetrical over four quadrants, it was only characterized over ninety degrees in the polar direction. The optical system was then modeled using ProLight and the predicted illuminance at the measurement surface is shown in figure 6. ProLight indicated a predicted output of 6890 lumens, which agrees within 2% of the measured lumens. The illuminance distribution agreed quite well with the actual measurement with one exception. The vertically oriented dark bands on the measured image are both curved toward the right, while the upper vertical band on the modeled image is curved toward the left. This is due to only capturing one quadrant of the lamp, which required ProLight to assume perfect symmetry, which was obviously not exactly the case.

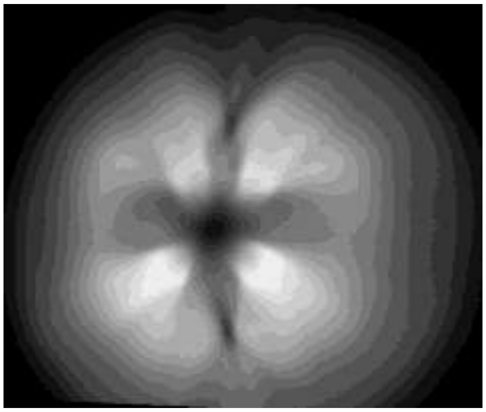

Figure 5 Actual measurement of HPL lamp in ellipsoidal reflector

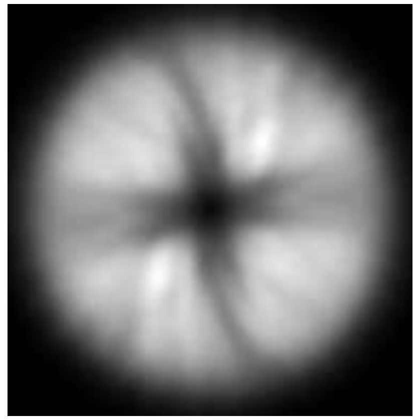

Figure 6 Simulated HPL lamp in ellipsoidal reflector

It should be obvious from the geometry of this system that a simple source model that approximates the HPL lamp as a point, sphere, or cylinder could not have predicted the uniformity patterns above. Likewise, a model that was based on a single view of the lamp would not have been very accurate since this source appears very different at different view angles.

Flashlight:

This source modeling technique can even be applied to complex sources that include optical elements, such as lamps that are potted in reflectors and shipped as a single unit. To demonstrate, this example is based on a simple flashlight that uses a 'V' shaped filament surrounded by a reflector of unknown shape.

The flashlight is placed ten feet from a surface, and ProMetric is again used to capture an image of the illuminance on the surface. This image is shown in figure 7.

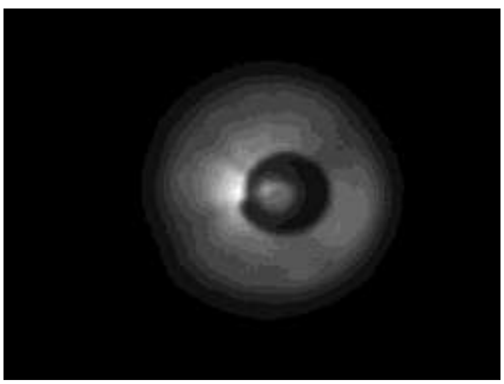

Figure 7 Image of flashlight output

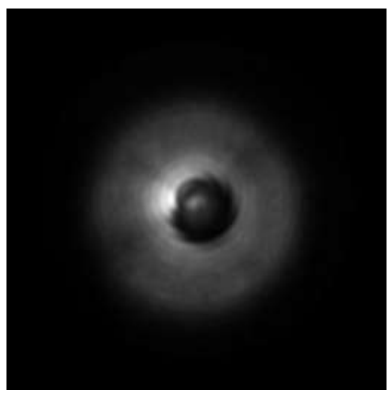

Figure 8 Calculated flashlight image

The entire flashlight was then placed on the goniometer and characterized by taking images of the lamp/reflector. Note that the images captured by the goniometer system were taken with CCD camera looking directly into the head of the flashlight (see figure 9).

The source model – which consists of images of the flashlight head from different view angles – was then utilized by ProLight to predict the illuminance on a surface ten feet away. The calculated illuminance distribution is shown as figure 8. In comparing the two images, all the features of the actual distribution were accurately modeled. This model could be used to simulate the flashlight output at <u>any</u> distance from the source.

It's again important to note that had this "source" been modeled as any simple geometric shape or single view model, ray-trace analysis could not have predicted the structure in the above images. A complex geometrical model may have come close, but that would have required knowledge or careful measurement of the reflector shape, filament size and shape, reflector reflectivity, bulb wall dimensions and thickness, and filament temperature at many location on the lamp filament. This is a difficult, time-consuming, and costly task.

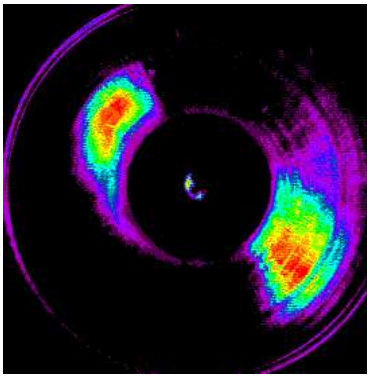

Figure 9 Image looking directly into flashlight

4. SUMMARY & CONCLUSIONS

These source models have been employed with great success on a wide variety of applications and with many types of sources, such as aerospace lighting, fiber optics, camera flash, cinema projection, LCD projectors, and others. These source models are straightforward to use, require minimal effort by the optical designer, and are the most accurate model available. Although presently only the ProLight software can fully utilize these models, many other software vendors are working on adopting this technology as well.

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