Illumination System Measurement Using CCD Cameras

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Abstract

Accurate measurement of illumination system performance , e.g. efficiency and uniformity, has typically been accomplished using photo detectors at the "image plane". This is a time-consuming task, even when aided by computer-controlled goniometers. A new method of illumination measurement using CCD cameras and specialized software is presented. The method greatly reduces the time required to record measurements, and significantly improves the quantity, quality, and comprehensiveness of the data. It can be applied to both steady-state systems, or transient systems, such as camera flash reflectors. In addition, such a system can be utilized to record accurate, digital images of an illumination source, which can be useful in illumination system design and modeling.

Introduction

Illumination system performance measurement is usually focused on efficiency and incident energy distribution which is compared to some desired distribution pattern. Typically, incident energy distribution is measured by placing the illumination system on a goniometer, and recording incident flux on a single detector. The illumination system is then turned to a new angle, relative to the detector, and a new reading is recorded. An alternative method is to build an array of detectors, that could record flux intensity at several field positions simultaneously.

Goniometer systems are typically expensive, and can require a great deal of time to record a significant number of readings. They are not effective for measuring transient systems, and require a high degree of stability in the source.

Detector arrays can also be quite expensive, and are limited in the number data points they can collect. They are also difficult to calibrate, and maintain calibration, since the sensitivity of each detector can vary.

Both systems suffer from the lack of integrated data analysis, and it is left to the user to post-process the data into meaningful information.

The CCD-based system described solves these problems by recording a large number (in this case 61,440) of data points in a single 1/60 second frame. Integrated software provides quick analysis of the data, providing information such as system efficiency and uniformity graphs.

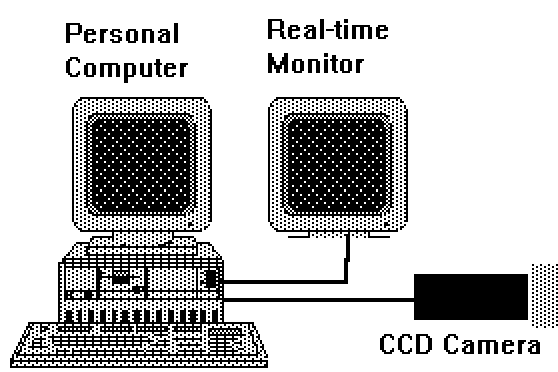

Figure 1. System Configuration

System Components

The CCD-based measurement system consists of a personal computer, a frame-grabber card installed in the PC bus, a real-time monitor, and a CCD camera with appropriate lens, as shown in figure 1.

The PC is used to process and store the data captured by the camera and frame-grabber card. The real-time monitor displays real-time images from the camera, which is useful for aligning both the camera and illumination system, and can also be used as an aid in focusing the illumination system.

System Setup and Use

The system is set up with the illumination system to be measured aimed at a diffuse surface, such as a low-gain projection screen, or flat, low-gain paper. The illumination system is placed with it's axis perpendicular to the screen.

The CCD camera is also aimed at the diffuse surface, and may be off-axis relative to the illumination system. When the camera is set to real-time mode, a live image is displayed on the real-time monitor, which allows quick alignment of the camera.

Once the alignment is complete, a "frame" or single picture can be recorded and transferred to the PC. This data, recorded as a gray-scale image, can be analyzed with integrated software.

Considerations using CCDs

Although CCDs offer much promise in illumination system measurement, they are several important considerations that must be dealt with to achieve accurate measurement.

First, the camera being used must provide output that varies linearly with the energy collected. This can be achieved by using high-grade industrial cameras that optionally can be set to a linear scale, rather than the more common logarithmic output.

Since the camera is directly measuring flux intensity reflected from a diffuse screen and collected by the lens, several potential errors are introduced when relating this data to flux incident on a surface, which is the actual information desired. The lens will typically introduce a cosine-fourth fall-off in addition to possible off-axis vignetting[1]. Additionally, the projection screen used may not be perfectly diffuse (e.g. have a unity gain), which may introduce further off-axis errors.

Because the camera cannot be placed directly on-axis with the illumination system, a keystoning of the image will occur. This effect may be quite significant if the camera must be located far off-axis due to physical setup constraints.

Calibration

To remove the errors described above, and accurately calibrate the measurement system, post-processing of the image is done in software to eliminate these undesired effects.

The calibration process involves the following steps:

1. A diffuse source is placed on-axis to illuminate the screen, which will produce a cosine-squared falloff.
2. Pertinent information is entered into the software including the source distance to the screen, camera distance to the screen, camera off-axis distance etc.
3. An image of the diffuse source is captured and transferred to the PC.
4. Since the camera distance, and off-axis distance are known, the keystone effect can be computed, and removed by mapping the pixels recorded into different locations in a new image.
5. The intensity of each pixel is then compared to a theoretical intensity calculated by cosine-squared falloff. A map of the difference between the theoretical values for each pixel and the actual recorded intensity is created.
6. This map is then applied, pixel-bypixel, to subsequent measurements to adjust the intensity, which compensates for the errors described above.

This method of calibration removes the keystone effects and removes all potential errors introduced by lens cosine-fourth falloff, lens vignetting, and screen gain effects, including local screen defects.

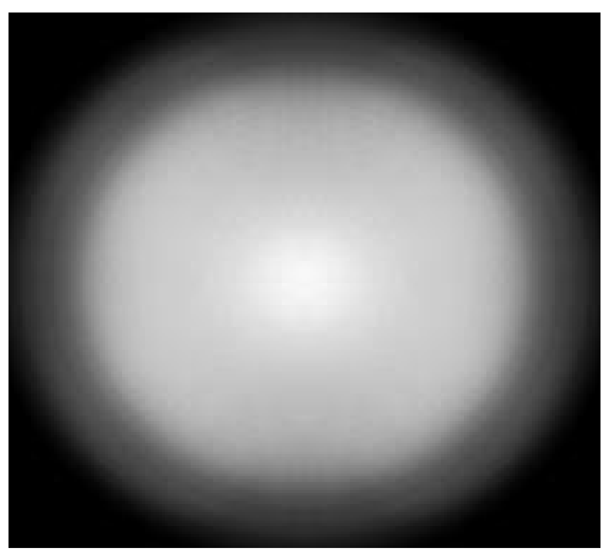

Figure 2. Theater Spotlight Image.

Applications

This system can be used to measure a variety of illumination systems. Figure 2 is the actual image recorded from a theater spotlight. Figure 3 shows the illumination pattern of an automobile headlamp. Figure 4 is a picture of a tungsten-halogen lamp.

The lamp picture is particularly useful for illumination modeling applications. Since the illumination pattern produced by a system is highly dependent on the source size and physical characteristics, an accurate model of the source greatly improves the accuracy of illumination modeling. Such a digital image could be incorporated into a modeling system.

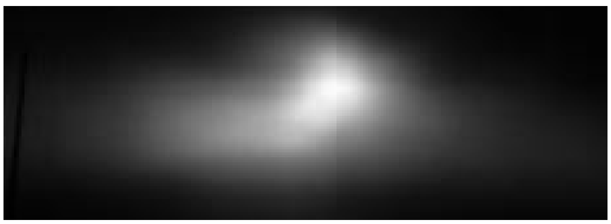

Figure 3. Automobile Headlamp Image.

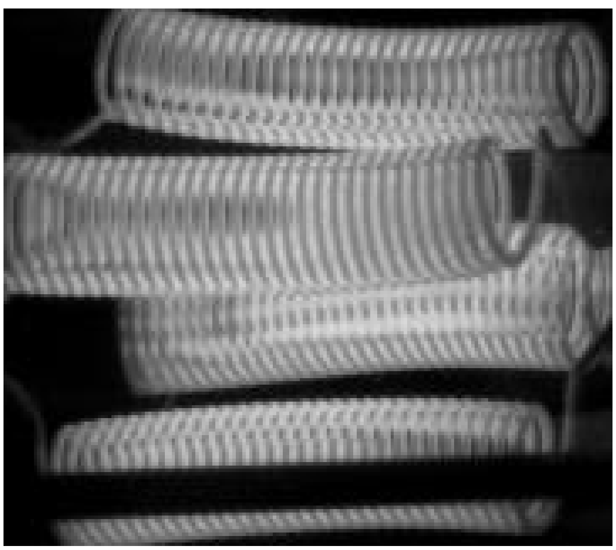

Figure 4. Four-filament tungsten-halogen lamp.

Another useful application is in the measurement of transient systems. For example, this system has been successfully applied to the measurement of camera flash-lamp output. [2]

Analysis

The software accompanying this measurement system provides a variety of information in both numerical and graphical form. For example, integration of the flux intensity at all points measured can be performed to yield total lumens incident on the surface. And if the source lamp lumen output is known, system efficiency can be given.

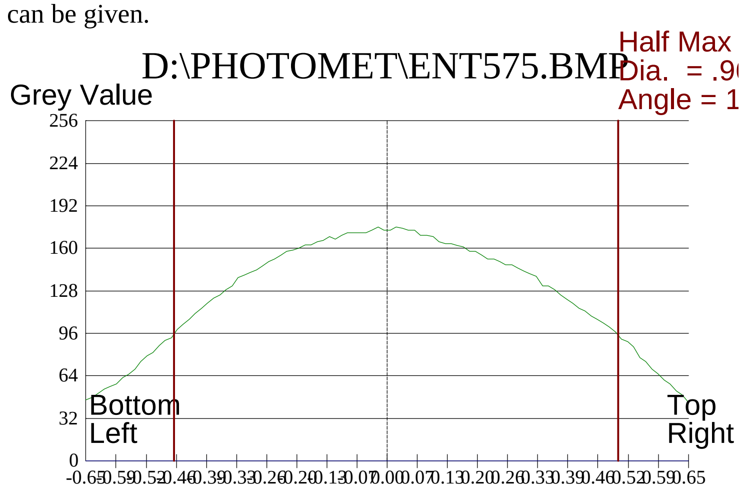

Figure 5. Theater spotlight uniformity

Figure 5 shows the graphic displayed by the software indicating the relative flux intensity as a function of position at the surface. This cross-section plot can be provided for any slice through the image, and may also be given in absolute values such as irradiance on the surface expressed in Ft-Candles or Lux.

Conclusions

A CCD-based illumination measurement system, if properly calibrated, can provide a fast and accurate data capture and measurement for a variety of illumination systems. By integrating specialized software, this data can be conveniently presented as useful information without the need for additional post-processing of the data.

References

1. Warren J. Smith, Modern Optical Engineering (McGraw-Hill Inc., 1990) pp. 144-145

2. Rick Albrect, Eastman Kodak, Rochester, NY (Personal Communication)