An Illumination Modeling System for Human Factors Analyses

James C. Maida
Space Human Factors Laboratory / Flight Crew Support Division / NASA Johnson Space Center / Houston TX 77058 / 281-483-1113 / James.Maida@jsc.nasa.gov

ABSTRACT

Seeing is critical to human performance. Lighting is critical for seeing. Therefore, lighting is critical to human performance. This is common sense, and here on earth, it is easily taken for granted. However, on orbit, because the sun will rise or set every 45 minutes on average, humans working in space must cope with extremely dynamic lighting conditions. Contrast conditions of harsh shadowing and glare is also severe. The prediction of lighting conditions for critical operations is essential. Crew training can factor lighting into the lesson plans when necessary. Mission planners can determine whether low-light video cameras are required or whether additional luminaires need to be flown. The optimization of the quantity and quality of light is needed because of the effects on crew safety, on electrical power and on equipment maintainability. To address all of these issues, an illumination modeling system has been developed by the Graphics Research and Analyses Facility (GRAF) and Lighting Environment Test Facility (LETF) in the Space Human Factors Laboratory at NASA Johnson Space Center. The system uses physically based ray tracing software (Radiance) developed at Lawrence Berkeley Laboratories, a human factors oriented geometric modeling system (PLAID) and an extensive database of humans and environments. Material reflectivity properties of major surfaces and critical surfaces are measured using a gonio-reflectometer. Luminaires (lights) are measured for beam spread distribution, color and intensity. Video camera performances are measured for color and light sensitivity. 3D geometric models of humans and the environment are combined with the material and light models to form a system capable of predicting lighting conditions and visibility conditions in space.

Keywords: Modeling, ray tracing, luminaires, reflectivity, gonio-reflectometer , luminance, illuminance, human factors, human modeling.

INTRODUCTION

The Space Human Factors Laboratory has been actively involved in computer aided human factors analyses for many years. Using the multi-disciplined resources within its facilities, the integration of workspace modeling and human modeling has been successful in performing evaluations of humans working in a space environment. Virtual workspaces or environments are created from three dimensional computer models of the exterior and interior of the Shuttle Transportation System (STS), International Space Station (ISS), a wide variety of payloads and advanced concept vehicles and habitats. These models also include luminaires (lights), cameras (video and film) and color and reflective properties of the major visible surface areas. Virtual humans are created from statistical data and include range of motion and eye points for both suited and unsuited conditions. The computer modeling software is an integrated system of software modules and packages called PLAID (not an acronym). The virtual workspace components are created using commercial software (and some in-house), while the virtual humans and their virtual workspace or environment are create using mostly in-house developed software. The illumination model uses a combination of in-house software and RADIANCE, a public software tool developed at Lawrence Berkeley Laboratory [1].

Within the Space Human Factors Laboratory, the Lighting Environment Test Facility (LETF) and The Graphics Research and Analysis Facility (GRAF) work together to develop and use the illumination modeling system.

Lighting Environment Test Facility (LETF)

The Lighting Environment Test Facility (LETF) measures the color and reflective properties of materials and the illumination performance (beam spread distribution and intensity) of luminaires or lights. Color and reflectivity are measured using a colorimeter, a gonio-reflectometer and a total reflectance meter. Beam spread distribution and intensity (illumination) are measured with a footcandle meter (lux meter). Brightness and contrast ratio are measured with a foot-lambert meter (brightness meter). This information is used as an empirical basis for modeling and for verification and validation of the modeling output when needed [2].

Figure 1. Devices used to collect the surface reflectivity and color properties of materials as well as spectral and beam spread distribution and intensity of lights.

Total Reflectance Meter   Gonio-reflectometer   Colorimeter

Beam Spread Distribution and Intensity   Spectral Information
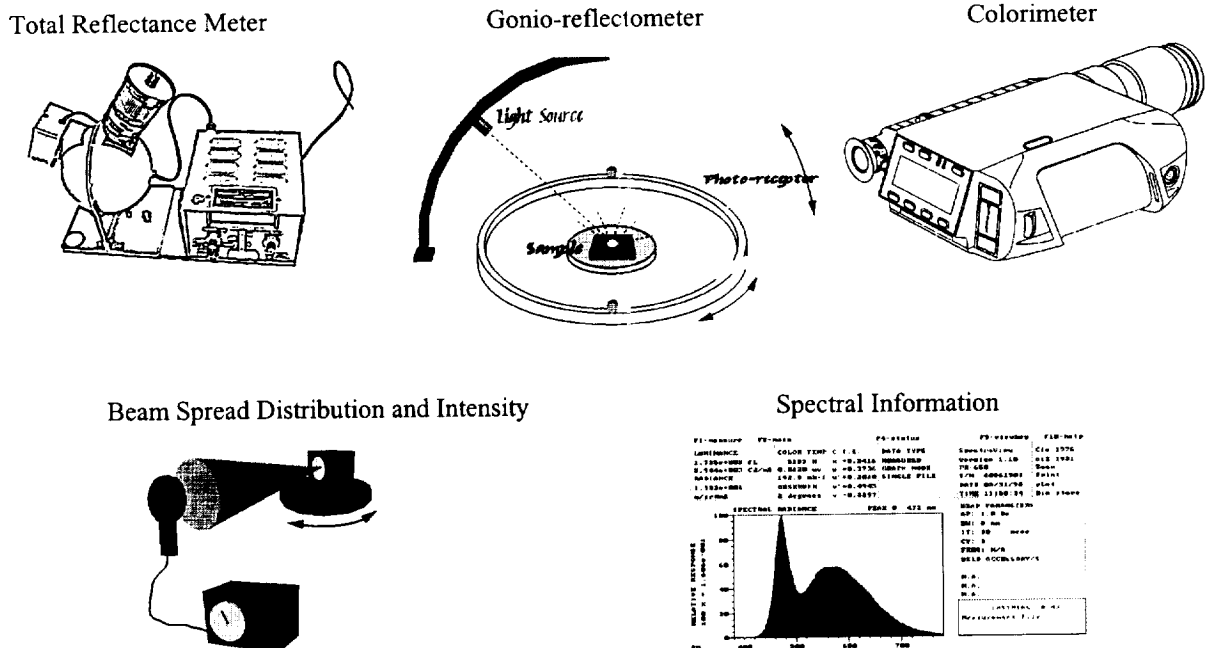
The total reflectance meter uses an integrating sphere with an opening for a light source, an opening for placement of a sample of material and an opening to measure its reflectance. This process is self calibrating, very fast and somewhat more accurate than other techniques. It is used to improve the accuracy of the gonio-reflectometer results.

The gonio-reflectometer measures hemispherical reflectance to determine the specular and diffuse components (the information needed for input into the illumination model) of material reflectivity. It consists of an incident light source, a photo detector for measuring reflected light at one angle, a turntable for rotating the photo detector, and a mount to hold the material sample. A computer interface allows the user to program the motion of the turntable to scan vertical angles between +/- 90 degrees and horizontal angles between +/- 180 degrees in specified increments. After each increment the computer records the vertical (theta) angle position, the horizontal (phi) angle position, the measured bi-directional reflectance (BR) and the calculated bi-directional reflectance distribution function (BRDF). Although much faster and more accurate than a manual process, the device still requires several hours to collect the necessary information for a single material sample.

The colorimeter is used to measure the color of materials and the color and spectral distribution of light sources. The color information can be measured in a variety of color coordinates. Red, Blue and Green (RGB) units is used for input into the illumination model.

The foot-candle meter (lux meter) is used to measure the intensity and beam spread distribution of luminaires. Depending on the access to a luminaire (we must sometimes measure on location) and the size of the luminaire, several techniques are used. Sometimes measurements are made from a projection on a surface, but the preferred method, if possible, is to use the hemispherical approach where the light is rotated relative to the meter (see figure 1). The beam spread and intensity of a luminaire, as well as its geometry are the most important inputs into the illumination model. It is also often the most difficult process and requires additional software to map it properly to the modeling system.

Figure 2. Beam spread and intensity plots for several luminaires (lights). Note that some of the lights are the same but have different intensities. This is the effects of age and use. This is a factor to consider when modeling.
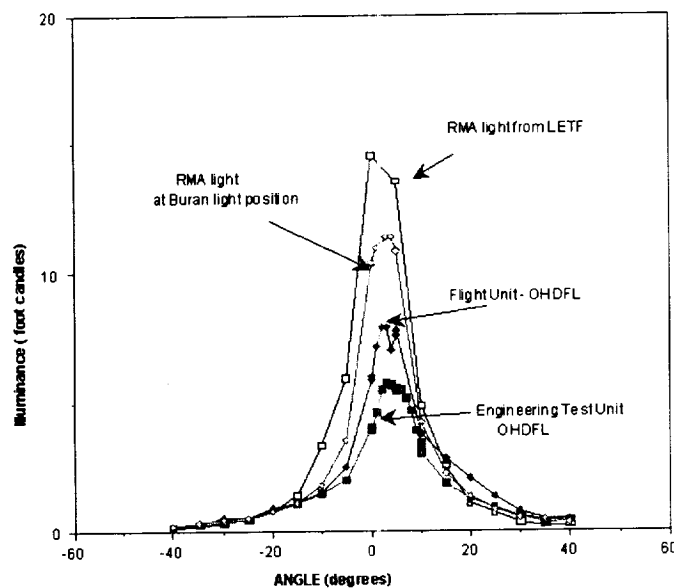
Graphics Research and Analysis Facility (GRAF)

The Graphics Research and Analysis Facility (GRAF) integrates the measurements from the Lighting Environment Test Facility (LETF) into its data base of models to be used by the modeling system. The system is then used to execute analyses such as the optimal location and selection of luminaires, as well as, the prediction of on-orbit visibility for direct or indirect viewing (cameras) with existing luminaires and natural illumination. These analyses are computationally intense. To utilize the necessary resources, the PLAID system of modeling tools including RADIANCE reside on a local area network of Unix based workstations with network file sharing. On average, each of 16 workstations are equipped with an R4400 CPU, 256MB RAM and 8GB of disk space. Very large complex scenarios or very dynamic scenarios are distributed over most of the systems during low network utilization periods. However, many of the analyses can be executed in relatively short periods of time (10 minutes per run) during the peak working hours of the day.

Illumination Model

RADIANCE, developed by Greg Ward at Lighting Systems Research Group of Lawrence Berkeley Laboratory, is a public software tool for graphical simulation and analysis of lighting, using backward ray-tracing. Rays from the point-of-view of the eye/camera are traced until they encounter an object. If this object is a light, then the luminance from the light into the eye can be directly calculated. Otherwise the object at the point at which the eye ray strikes generates rays in all directions to "look" for light. If a light is found, then its illumination on the object is determined, and the reflective properties of the object's material is used to determine how much of this light is reflected from the object into the eye. Instead of encountering a light, the new rays may strike another object. The process continues with new rays generated to look for lights. For objects which have specular (mirror like) reflectance, the recursive ray propagation is accurate. However, many surfaces are diffuse reflectors, scattering light in all directions. The number of rays needed to model such a reflectance between many surfaces is computationally prohibitive. As a result, RADIANCE incorporates fast sampling algorithms for diffuse calculations [3][4]. The accuracy and time required for these calculations can be controlled with input parameters.

Previous evaluations[5] of the RADIANCE software show that it is an accurate lighting model which uses techniques for fast calculations of direct and indirect lighting. RADIANCE runs on a variety of platforms (SUN, SGI and a variety of UNIX and Linux based machines) and is used by lighting designers and architects in the commercial world. (see RADIANCE at http://radsite.lbl.gov/radiance/hotlist.html)

Analysis Process

Once measurements have been made and incorporated into the computer modeling data base, lighting analyses are possible. Typically a particular configuration of shuttle payloads or a particular stage of station assembly will be examined. The PLAID system is used to configure the geometry to match the configuration. The data base is organized such that assemblies and sub-assemblies can be easily selected (or not selected) to build the appropriate configuration and establish the appropriate scenario. Depending on the analysis required, eye points, cameras, and luminaires are selected and sunlight positions are determined. Once the scenario is fully defined in these terms, the PLAID system invokes the RADIANCE system to perform the illumination analysis. This process can be repeated many times as the scenario changes within a particular analysis.

Output from RADIANCE is in the form of an energy distribution map at some user definable pixel resolution. This energy distribution map is generated in "nits", a radiometric unit of measure. Foot-lamberts and foot candles can be derived from these units. Using of a variety of tools in RADIANCE and in-house developed software, this information can be used to generate false color images (see figure 3) and synthetic camera images (see figure 4). With this images we can estimate contrast ratios to determine possible glare and estimate light levels for camera selection criteria (low light black and white versus color) or human performance needs (hand held or head mounted lights)[6].

In figure 3, the false color map reveals that two helmet mounted flood lights will provide equal levels of illumination with wider coverage for situational awareness than two fixed lights (labeled CETA in the figure). The option of removing two fixed lights with their high maintenance potential has been identified. In this case, resources have been optimized with the human factor in the equation and at lower cost.

Figure 3. False Color Image (energy distribution map) of the light distribution on an airlock spur region. The region is a candidate for EVA (extra-vehicle activity) translation activity. Two exterior fixed lights (CETA) are used in the top image. Two helmet mounted flood lights are used in the bottom image. Units are in foot-candles for this application.
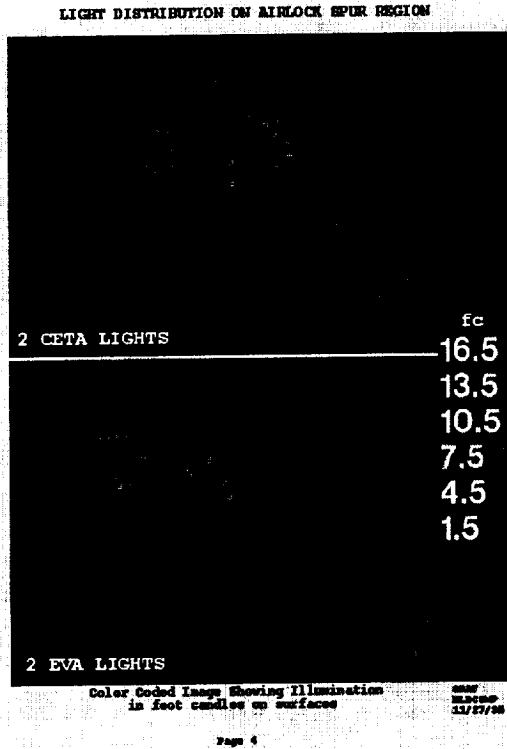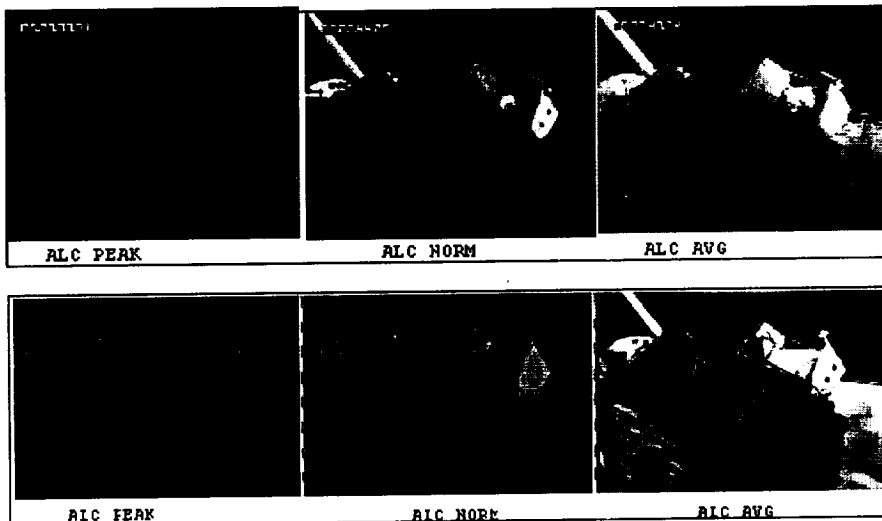

Figure 4. An example of how the energy distribution map can be post-processed to model camera controls and artifacts such as ALC (automatic lens control) and glare. The first line of images is from video stills. The second line is computer generated images from the synthetic camera model.

CONCLUSION

There are many other cases where the illumination modeling system has been valuable in performing human factors analyses. Interior and exterior lighting issues have been, and will continue to be, addressed with this system. The ability to predict visibility conditions for a wide variety of situations has an impact on what goes up in space and where it will be used. Current and future activities are related to real time illumination modeling for dynamic lighting conditions [7].

ACKNOWLEDGMENTS

REFERENCES

[1] Ward, G. J., Rubinstein, F. M. and Clear, R. D. (1988). A Ray Tracing Solution for Diffuse Interreflection. 1988. Computer Graphics, Vol. 22, 85-92.

[2] Maida, J. and Aldridge, A. "Measurement/validation of bi-directional reflectivity of shuttle and station materials". JSC26935, 78-79,1995.

[3] He, X., Torrance, K. E., Sillion, F. X., Greenberg, D. P. (1991). A comprehensive physical model for light reflection, Computer graphics, 25(4), 175-186.

[4] Ward, G. H. (1992). Measuring and Modeling Anisotropic Reflection. Computer Graphics, 26, 265-272.

[5] Maida, J. C., Pandya, A. K. and Aldridge, A. M. (1992). A Comparison and Validation of Computer Lighting Simulation Models for Space Applications using Empirically Collected Data. Research and Technology Annual Report 1992, II8-10.

[6] Maida, J. and Aldridge, A., "Viewing and Lighting Analyses Using Physically Based Modeling and Synthetic Imagery", Johnson Space Center Research and Technology 1995 Annual Report.

[7] Aldridge, A., Maida, J., Novak, J., "Effects of Lighting on Human Performance in Training", Advances in Human Factors and Ergonomics, (HCI 1997 Proceedings) Editors: Smith, M., Salvendy, G., Koubek, R., Elsevier Press 1997, Volume 21B, Design of Computing Systems: Social and Ergonomic Considerations, Pages 877-880.