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INCORPORATION OF SHUTTLE CCT PARAMETERS IN COMPUTER SIMULATION MODELS

Final Report

NASA/ASEE Summer Faculty Fellowship Program - 1990

Johnson Space Center

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Date Submitted:	August 10, 1990
Contract Number:	NGT-44-005-803

Abstract

Computer simulations of shuttle missions have become increasingly important during recent years. The complexity of mission planning for satellite launch and repair operations which usually involve EVA has led to the need for accurate visibility and access studies. The PLAID modeling package used in the Man-Systems Division at Johnson currently has the necessary capabilities for such studies. In addition, the modeling package is used for spatial location and orientation of shuttle components for film overlay studies such as the current investigation of the hydrogen leaks found in the shuttle fleet.

However, there are a number of differences between the simulation studies and actual mission viewing. These include image blur caused by the finite resolution of the CCT monitors in the shuttle and signal noise from the video tubes of the cameras. During the course of this investigation the shuttle CCT camera and monitor parameters are incorporated into the existing PLAID framework. These parameters are specific for certain camera/lens combinations and the SNR characteristics of these combinations are included in the noise models. The monitor resolution is incorporated using a Gaussian spread function such as that found in the screen phosphors in the shuttle monitors.

Another difference between the traditional PLAID generated images and actual mission viewing lies in the lack of shadows and reflections of light from surfaces. Ray tracing of the scene explicitly includes the lighting and material characteristics of surfaces. The results of some preliminary studies using ray tracing techniques for the image generation process combined with the camera and monitor effects are also reported.

INTRODUCTION

Geometric properties such as visibility from a given vantage point and clearance for movement are adequately modeled with the PLAID package currently used in the Man-Systems Division at the Johnson Space Center. This modeling package uses engineering drawings and sketches to build a full three-dimensional database of objects based on polygons. This database can then be used to display a filled polygon view from any viewpoint. Clarity of the image is only limited by the spatial resolution of the display device, which is typically 1024 rows by 1024 columns. In an actual mission scenario, the display device resolution is lower and camera effects such as noise are inherent in the imaging process. This study investigates the correction of the computer generated images for degradation during the imaging process.

Surface material properties and lighting characteristics also have an effect on the image generation process. There is a dynamic relationship between the camera iris settings and the relative brightness of surfaces in a scene. Strong variations in lighting can be caused by strong reflective surfaces such as satellite shrouds, as well as shadows due to payload occlusion of light sources. Incorporation of these properties into the PLAID database structure and image generation process is another major component of this study. Preliminary results from some shuttle scenes are also reported.

IMAGING SYSTEM EFFECTS

Finite monitor resolution and camera noise characteristics can be modeled using parameters specified by the manufacturers. The blurring caused by the lower display device resolution can be modeled as a point spread function. In other words, a point in the actual scene is displayed as a blurred circle on the monitor. This process of blurring is illustrated in Figure 1, where Figure 1(a) shows the original intensity of the point in the scene as a narrow peak and Figure 1(b) shows the same point after spreading on the monitor. The classical point spread function derived using the

Fourier transform would be a sinc. This is an expensive function to apply to an entire image and the same visual appearance can be obtained using a Gaussian or triangle point spread function. The original image is resampled using the horizontal and vertical resolution supplied by the manufacturer for the display monitor.

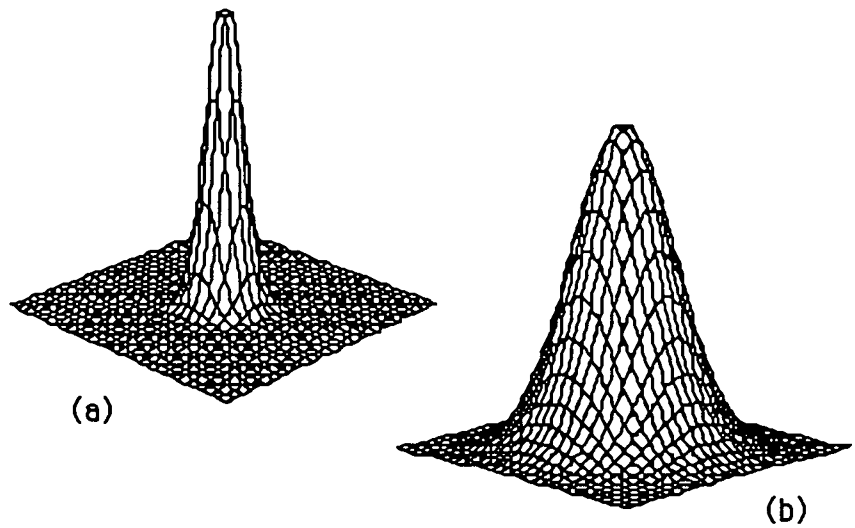

Figure 1. Point spread process caused by monitor phosphors

System noise is the other source of degradation in the imaging process. Noise manifests itself in the camera videotube and in the connecting electronics and wires. Since it is extremely difficult to measure the noise characteristics of the connecting wires, only the videotube noise will be included in the correction process. If the tube is in good calibration, noise will appear randomly throughout the field of view. The amount of noise will depend on the settings of the camera iris, since an iris setting that is narrow in a low light setting will lead to a much greater degradation of the image. The auto-iris setting of the camera causes this to happen most frequently when there are extremely bright objects such as shroud covered satellites in the scene. The iris will close down in this situation with the result that areas in low light are extremely noisy.

Apart from iris effects, a Gaussian white noise process can be used to model the degradation caused by the camera system. The intensity of points in the image as sensed by the camera system are randomly modified by sampling from a uniform Gaussian distribution, whose width can be derived from the signal to noise ratio (SNR) for the camera system. Once again this is information that is supplied by the manufacturers of the system. This process is equivalent to adding or subtracting a percentage of the intensity of the actual image point for point in a random manner. Generally the noise level of the camera system is plus or minus ten percent. The next section discusses extensions to the monitor and camera degradation processes.

SCENE EFFECTS

There are a number of possible extensions to the present model. First, depth of field effects appear as blurring, dependent on relative distance of objects in the scene from the camera. This blurring must be part of the image generation process and can not be added with post-processing. Second, the diffuse and specular components of surface materials will have a direct impact on the overall appearance of the scene. Finally, the effects of limited lighting conditions or directional light will cause shadows in the scene, which can obscure objects of interest. Two methods can be used to add these extensions to the present model. These are ray tracing and radiosity.

Ray tracing is a technique that recursively follows a light ray from the observers' viewpoint throughout the scene to any light source. This process traces the light ray path as it is reflected off of surfaces or transmitted through transparent surfaces such as glass. A ray is spawned for each picture element or pixel in the final image, which is typically on the order of 1024 rows by 1024 columns. Since there are typically thousands of objects in a scene, this is a computationally intensive task. As such, with the present generation of computer hardware, it is not a real-time image generation process such as that used in the present PLAID system. However, single images can be generated using the present computer hardware in about nine hours.

Radiosity is a technique that is based on thermal heat transfer methods applied to light transmission. This method calculates the light transferred between every pair of surfaces in the scene. As mentioned previously, this is typically on the order of thousands of surfaces. A set of simultaneous linear equations which is equal to the number of surfaces is set up and solved using any of the common techniques. This process is then followed by an image generation step such as ray tracing. What is gained in the radiosity step before ray tracing is the inclusion of the diffuse component of scattered light from light sources, such as that cast from the Earth into the shuttle bay.

Ray tracing was the method that was decided upon for the preliminary investigations in this report. The shading model that was used for the rendering portion of the ray tracing process was that of Phong. This model includes ambient, diffuse and specular components of the reflection process. It can be expressed as:

$$I = I_a k_a + \frac{I_0}{k+r}[k_d(\vec{N}\cdot\vec{L}) + k_s(\vec{R}\cdot\vec{V})^n] \tag{1}$$

where I_a is the ambient intensity, I_0 is the intensity of the light source, k_a, k_d and k_s are the ambient, diffuse and specular coefficients, and n is the specular power factor. The various vectors depend on the geometry of the surface, viewer and light source as shown in Figure 2.

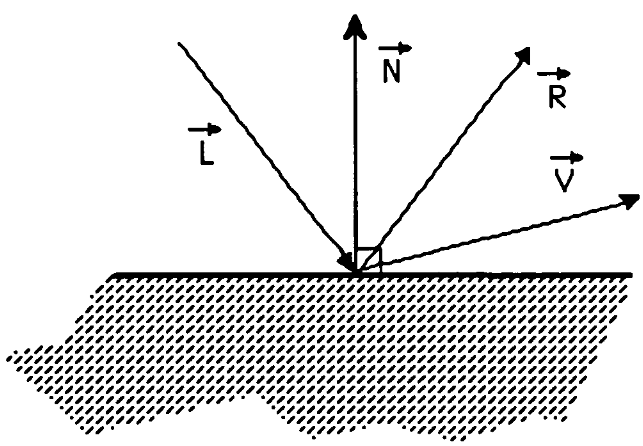

Figure 2. Scene geometry for surface shading.

Specification of surface characteristics relies on knowledge of k_d, k_s and n. These factors can be derived from experimental data collected in the NASA laboratories.

An example of this data is shown in Figure 3, taken from JSC Internal Note 85-SP-1, where orbiter tile reflectance characteristics are plotted vs. degrees off specular angle.

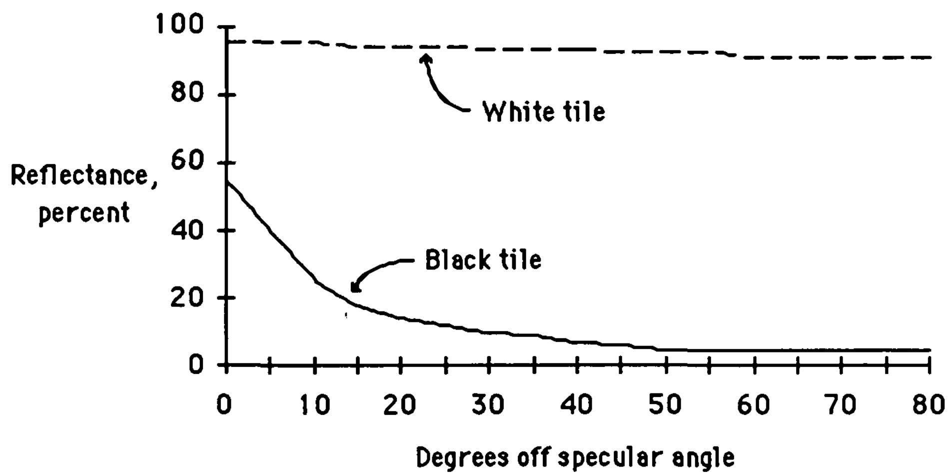

Figure 3. Reflectance vs. specular angle (From C.D. Wheelwright, "Orbiter Solar/Artificial Illumination During STS Flights," JSC Internal Note 85-SP-1).

The reflectance at 80 degrees will be entirely diffuse and this value is k_d. The reflectance at 0 degrees will be a mixture of diffuse and specular, with the specular component being dominant. The dot product term is unity at this angle and the total reflectance is equal to $k_d + k_s$ at this point. Since k_d is already known, k_s can be found directly. With a fixed light source position for the experiment, the only variation expected in the reflectance curve would be due to specular effects. Each experimental point can be then used to find a value of n, the specular power factor, which is then averaged for the value used in the Phong shading formula of Equation 1.

Surface colors and lighting positions are found in NASA documents for the light source intensities and positions in the Phong shading formula. The geometric database needed to derive the surface normals, given by the vector **N** in Figure 2, is taken directly from the PLAID polygon based description of any structure. For example, the PLAID package can be used to build a description of a specific shuttle mission with the appropriate satellites in the payload bay. The vector V in Figure 2 is interactively derived using the PLAID package or can be found in the documented camera mount locations for most NASA structures.

EXPERIMENTAL STUDIES

Experimental studies were done on a planned shuttle mission STS-46, which will carry the Tethered Satellite System (TSS) in 1991. Scene geometry was taken directly from the PLAID database for this mission. The image was generated using the Craig Kolb rayshade package from Yale University (available via anonymous ftp at weedeater.math.yale.edu). Parameters for this preliminary test are (1) diffuse surface materials; (2) image resolution of 512 rows by 512 columns; (3) all shuttle bay lights including the forward payload bay bulkhead light on; (4) shuttle in the dark zone of its Earth orbit; and (5) view position of Camera A on the payload bay forward bulkhead. The result of the ray tracing of this scene is shown in Figure 4. Although specular reflections are not present in the scene, most of the visibility related effects are included, with shadows cast along the length of the payload bay being of primary importance.

Figure 4 shows the scene as it would appear to a human observer through the payload bay forward bulkhead window. Incorporation of the camera and monitor effects is easily accommodated using the techniques described in the beginning of this report. Application of the point spread function and the Gaussian white noise distribution to Figure 4 gives the image seen in Figure 5. The point spread function is derived using the published CCTV monitor resolution of 300 rows by 400 columns. Detail on the TSS is lost in this view due to the blurring.

Visibility studies using a different camera for this scene can be done by changing the viewpoint. Switching to Camera B mounted on the aft bulkhead of the shuttle bay should give an indication of what the visibility is in the shadowed region of the payload bay. This view is shown in Figure 6, and it can be seen that there is little improvement in visibility with a change in camera position.

Visibility in a region of shadow can be enhanced if the mission is scheduled during the day portion. Substantial illumination is obtained from reflection of sunlight from the Earth.

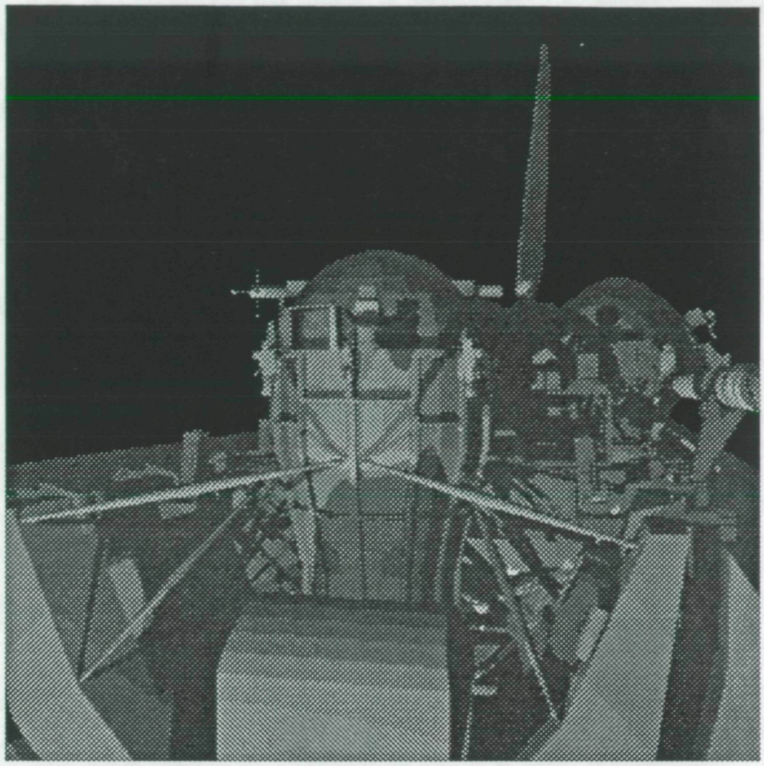

Figure 4. Ray traced image of STS-46 mission

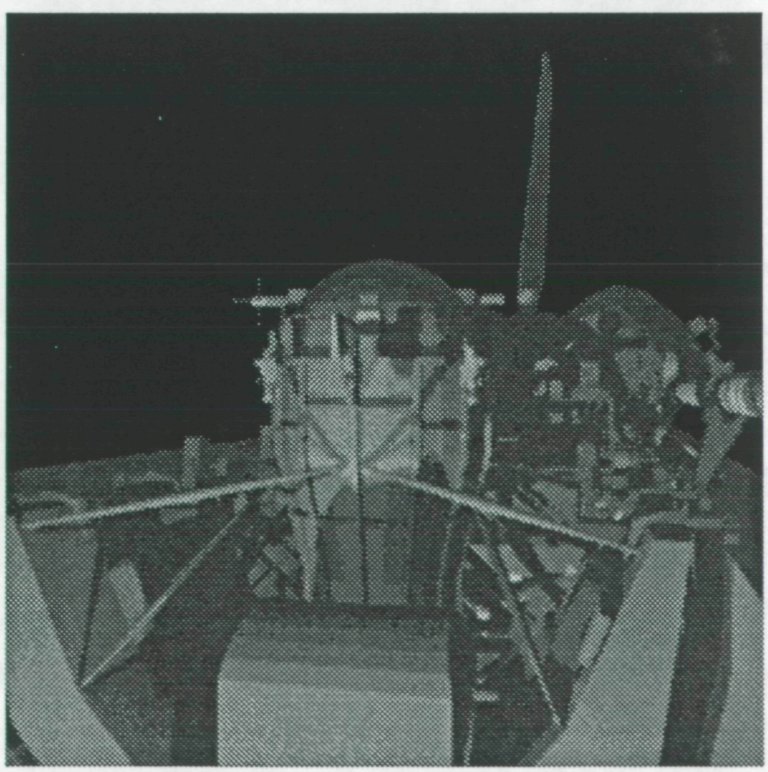

Figure 5. Blurred ray traced image of STS-46 mission

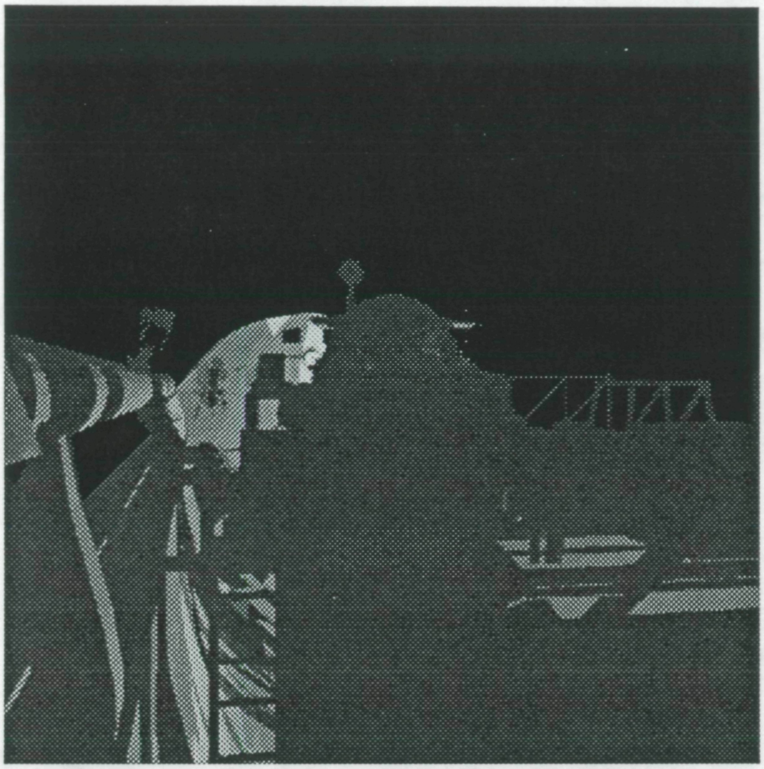

Figure 6. Shadow region ray traced image of STS-46 mission

Figure 7. Earthshine model ray traced image of STS-46 mission

To accurately model this effect would require a radiosity treatment of the imaging geometry. An approximation can be found using a light source that is distributed over a large area during the ray tracing image generation process. A ray traced scene with the same viewing parameters as used in Figure 6 but with a distributed light approximation to the Earth is shown in Figure 7. More of the surfaces of the other payloads can be seen. The distributed light approximation gives an indication of the better viewing conditions and can, with increased time needed for the ray tracing, realistically model the actual scene.

DISCUSSION

The PLAID modeling package used in the Man-Systems Division at Johnson maintains an up-to-date geometric database of NASA structures including the shuttle and Space Station Freedom. The work discussed in this report extends the PLAID system to include image degradation processes in the image generation process. The point spread blurring function and noise characteristics were taken directly from the shuttle CCTV monitor and camera documentation, and integrated into a post-processing step for image rendering.

In addition, this report presents some preliminary studies of the use of ray tracing techniques for image generation. The PLAID model database was extended to include surface material characteristics which were obtained from NASA documentation of experimental studies. Placement and strength of light sources, information which is vital for visibility studies, was also obtained from available NASA documentation. An experimental study of shuttle mission STS-46 was done. Figure 4 in the main body of the report shows an unblurred view of the shuttle payload bay for this mission. After the degradation model is applied, detailed feature observation is difficult, as can be seen in Figure 5. Visibility in shadow regions was investigated using the same mission profile. Figures 6 and 7 show the result of this study, where a night view is shown in Figure 6 and a day view is shown in Figure 7. The models used for the Earthshine phenomena are still in development, but an fairly accurate idea of potential visibility problems can be found in these first studies. The images shown in this report have lost contrast due to the printing process, and can be found in their original form in the videotape *PLAID Graphics Lighting Studies* available as NASA Reference Master 903959 from the Television Office at the Johnson Space Center or from the PLAID Graphics Laboratory in the Man-Systems Division at Johnson Space Center.

Future work will include further extensions of the PLAID modeling framework for faster ray traced previews of scenes. This will be accomplished using a distributed parallel implementation of the ray tracing algorithm. Better modeling of light source geometry will also be studied. With these extensions, the PLAID model database will be a suitable candidate for simulations of visible and range sensor views of scenes in a semi-autonomous robotics environment for NASA development of computer vision algorithms.