STUDENT SUMMER INTERNSHIP TECHNICAL REPORT

3D Visualization

DOE-FIU SCIENCE & TECHNOLOGY
WORKFORCE DEVELOPMENT PROGRAM

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ABSTRACT

The virtual reality field has recently been the focus of many of the technology monopolies and now can easily be introduced in the Department of Energy Office of Environmental Management workplace. The project of making a 3D visualization model of the contaminated Plutonium Fuel Form Facility Building 235-F at the Savannah River Site in order to develop work procedures and train workers for potential hazards requires the latest technology available. In order to help with the development of this environment, new technologies had to be explored such as head-mounted displays (Oculus SDK), 3D workstations (zSpace), and virtual reality software (Visionary Render) to really encapsulate the hazards in the scene.

The main research was done on how textures and light reflectivity correlate to one another. Bump, normal, and displacement map properties had to be explored as well as the differences in increasing/decreasing ambient, diffuse, and specular properties in 3D models. These react differently with shadows of objects and sometimes have to be used together on one model to create a realistic experience. Once that is achieved, training workers in these environments will be that much better.

Training in a 3D scene without the photorealistic graphics can still prove to be worth the time. Airplane pilots use similar technology to simulate piloting an aircraft vehicle. Specifically, the Search and Rescue Training Unit (SARTU) at Royal Air Force (RAF) Valley, which had a 20 percent fail rate on their individual sections of their course, adopted 3D visualization simulations in order to train their pilot students. The percentage of the pilots' in-training failing rate dropped to 5 percent after these were introduced.

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1. INTRODUCTION

Currently, Building 235-F at the Savannah River Site is undergoing deactivation procedures in order to remove radiological contamination. The current contamination within Building 235-F is plutonium-238 in a very fine powder state. This has spread within the facilities which was previously used to mill down the plutonium-238 into this powder state and insert it into fuel pods for NASA. One of the cleanup challenges is that if equipment is developed to further the deactivation process, it would have to be disposed of as waste if it does not work as intended. This can be a costly procedure as it would have to be repeated multiple times in order to make upgrades to the equipment and send workers to work in the environment.

In order to train workers effectively and develop work procedures that could be applicable within Building 235-F, a 3D visualization model for virtual interaction is in the process of being developed. With 3D modeling tools such as CAD and Pro/Engineer, three-dimensional models can be created to represent real-world objects. These objects can then be imported into a virtual reality (VR) environment, which will allow for interaction of objects in the environment as well as real-world tracking of a user. Multiple users can be in a virtual environment at once, allowing collaboration for team-related tasks and planning.

For the training in a virtualized environment such as Building 235-F to be truly effective, trainees need to believe they are in the environment itself and fooled that the consequences may be real. An immersive environment makes a user forget that they are in a simulation, making choices and acting as if they were in a contaminated facility. This can be done with improving on the finer details of the environment, such as adding realistic textures to surfaces instead of the solid, bland colors that come from modeling software. While textures are developed, they can be saved for future use when working again with common objects such as chairs or walls that will most likely be seen in other virtualized environments.

As important as textures are to the real world, reflectivity is also another factor while working to create an immersive experience. A common example is the reflectivity on materials that have plastic surfaces versus metallic surfaces. This would affect the angle a user is viewing an object along with a light source such as a headlamp or dangling lamp. Of course, with light sources come the shadows they cast. The fine lines of shadows casted can be increased or decreased but the tradeoff with this added detail is the memory usage when performing tasks.

Presently, the technology for making virtual reality environments is on the rise and there are only a handful of companies commercially selling their software. For the development and implementation of Building 235-F's environment, Visionary Render was used. This software has built-in features for tracking users that wear the tracking set of glasses but is fully compatible with head-mounted displays (HMDs) and special 3D workspaces created specifically for working on the finer details of 3D environments. HMDs are helmets a user can wear which will project the virtualized scene onto their entire field of view and track head movements such as looking down or from side-to-side. This compatibility feature is built-in with the idea that the field of VR has recently taken a spike in the market. This will help in shortening development of the virtualization of other sites similar to Building 235-F that are hazardous for even trained workers of the Department of Energy.

2. EXECUTIVE SUMMARY

This research work has been supported by the DOE-FIU Science & Technology Workforce Initiative, an innovative program developed by the US Department of Energy's Environmental Management (DOE-EM) and Florida International University's Applied Research Center (FIU-ARC). During the summer of 2015, a DOE Fellow intern (Jorge Deshon) spent 10 weeks doing a summer internship at the Savannah River National Laboratory in Aiken, South Carolina under the supervision and guidance of Research and Design Engineer John Bobbitt. The intern's project was initiated on June 1, 2015, and continued through August 7, 2015 with the objective of developing a catalogue of textures and their reflectivity properties within a virtualized environment to create an immersive experience in addition to helping develop the logic that comes with user interaction in the environment.

3. RESEARCH DESCRIPTION

In order to create realistic textures within Visionary Render, memory usage and user interaction should be kept in mind. Rendering textures with too much detail can result in a scene crashing; a rule of thumb needs to be established on which textures to edit. However, leaving one object with bland coloring and another with a natural surface will not help with making the scene appear realistic to a user. This is where the understanding of bump, normal, and displacement maps applies to memory control.
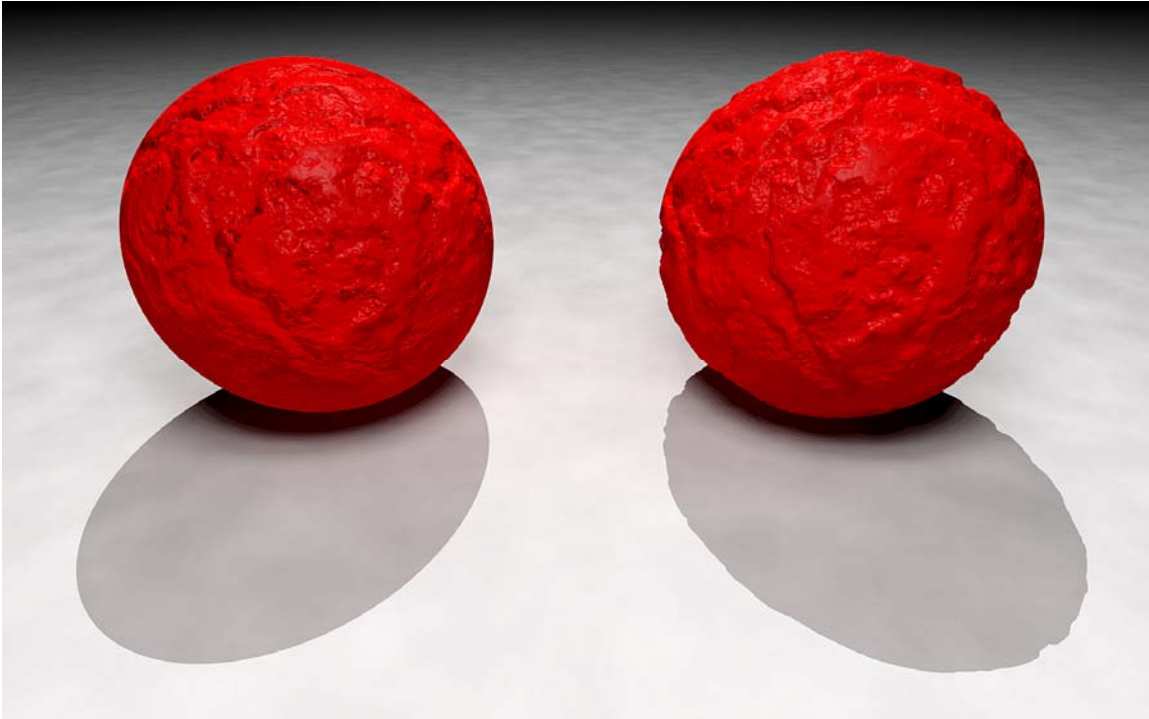

Figure 1. Bump versus Displacement Mapping.

When glancing at both of the object's surfaces in Figure 1, they seem to have depressions and details that will help with drawing in a user to the scene. However, looking closer at the surface shapes, the left figure still seems to have a perfect sphere shape while the right has small indentations. Furthermore, the shadows themselves are what can be easily distinguished. Bump maps change the grayscale image of an object while displacements maps actually indent the surface physically.

Bump maps do not in fact change the physical surface of an image, as can be seen from the left object. They are essentially grayscale images, which only play with the 256 colors that come with white, black, or gray. Pushing bump map values to gray coloring gives the same effect of a 2D image. A value that is closer to white makes the illusion of a surface being pulled while a value closer to black creates the opposite effect that gives the surface more depth. The problem with this method of adding detail is that this illusion can be broken when looking at an object in certain angles since the grayscale values do not actually adjust to a user's point of view.

Displacement maps actually do not use any sort of illusion on the user. What a user sees is what is actually there. These maps are intended more for use when a user directly interacts with an object, such as when trying to grab an object that may or may not fit into a measured container. These maps indent or pull the image but at the cost of memory, which can result in all other images not being created with the detail intended. In addition, shadows conform to this geometry, which has to be considered as well.

The median of bump and displacement maps is normal maps. These do not actually change the physical surface of the object but actually improve upon bump maps method of illusion. Instead of the grayscale values bump maps use, normal maps implement the red, green, and blue color values, more formally known as the RGB values. These are related to the XYZ axis which allows a normal map surface to apply the appropriate shading according to the user's point of view. The advantages of this over bump maps is a more reliable and realistic experience for a user navigating in a virtualized environment and a significant drop in the amount of memory used compared to displacement maps. Compared to bump maps, normal maps do not use much more memory that would make a noticeable difference in a medium-sized environment.

$$I_p = k_a i_a + \sum_{m \in \text{lights}} (k_d (\hat{L}_m \cdot \hat{N}) i_{m,d} + k_s (\hat{R}_m \cdot \hat{V})^{\alpha} i_{m,s}).$$

Equation 1. Equation used for calculating reflectivity off a surface.

The equation above is used in 3D computer graphics to calculate how any surface reflects light and is referred to as the Phong Reflection Model equation. The k_s, k_d, k_a, and α constants represent the reflectivity properties of a texture in the environment. The $\hat{L}_m, \hat{N}$, and $\hat{R}_m$ constants represent how all the light sources are aimed at the texture's surface and their positions. $\hat{V}$ represents which direction the light is going to point to the viewer. This equation applies to all maps. However, normal and displacement have the advantage over the range of colors involved when producing shadows.

The figure below further explains the Phong Reflection model through a diagram of a light source reflecting off a surface. The eye represents a user viewing the surface and how they perceive the reflectivity. The variable H represents the vector that is located in the middle between the normal vector, N, and the light source, L. That is essentially how a user will view a surface that has multiple or single light sources reflecting off it.
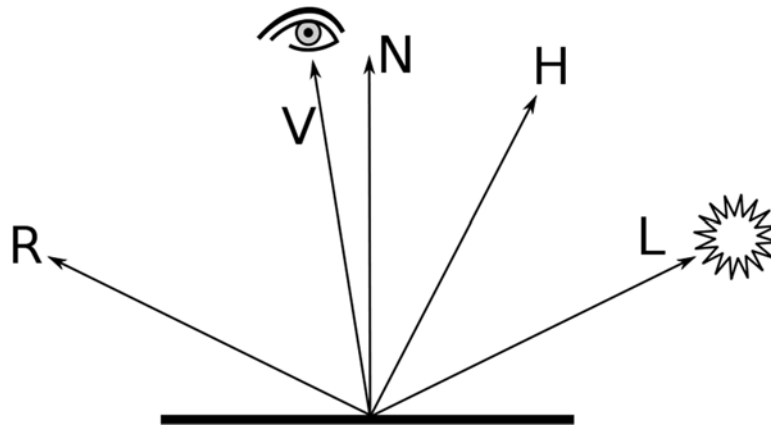
Figure 2. Phong Reflection Model.

4. RESULTS AND ANALYSIS

The results of the research done on textures and how to manipulate the multiple images laid onto them revealed there were three properties to always take in account. These three properties of illumination are what the Phong Reflection Model equation derives its light values from, which are:

Illumination values include:
1. Ambient: a constant value that is produced by various surfaces and gives the atmosphere of a scene
2. Diffuse: the reflection of light in every angle when shined upon a certain point
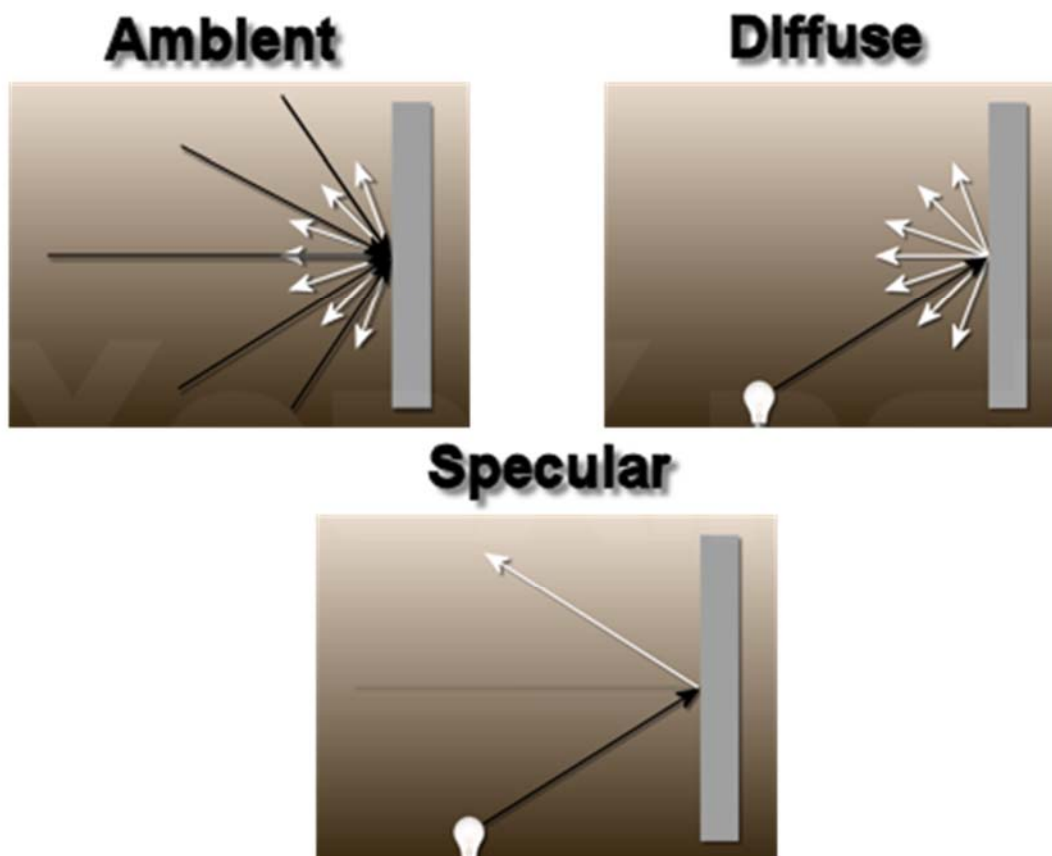3. Specular: the reflection of light from one angle when shined upon a certain point.

Figure 3. Demonstration of Ambient, Diffuse, and Specular Reflectivity.

When images of each type are combined, they result in giving proper shading of 3D objects. The specular value, if at a high value, gives a shined effect on a certain spot of the object. The diffuse value covers a more generalized area of the object, giving it an overall color when light is shined on it and where the shadow should end. What determines the whole color of the object is the ambient value but light does not affect this image and in result usually gives a matte look to it. When finally combined, a final result, as shown below, is produced:
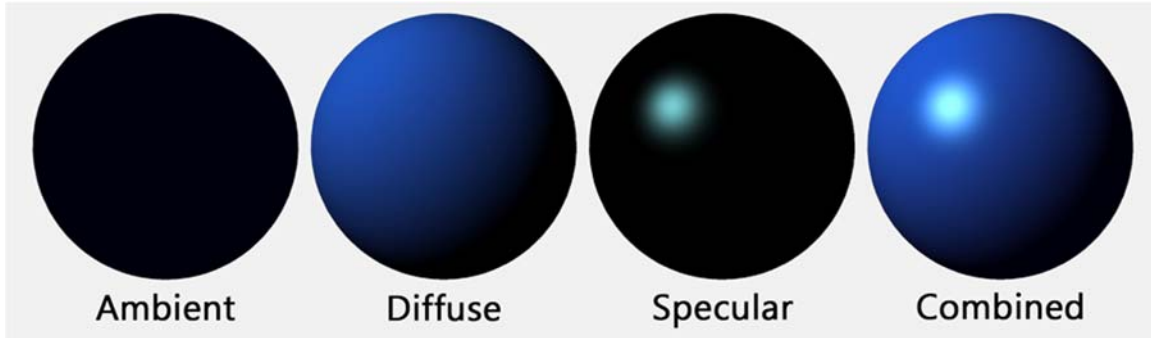
Figure 4. Examples of Ambient, Diffuse, and Specular Images.

In the program used for the 3D visualization model of Building 235-F (Visionary Render), the features to edit these images of objects are built-in. However, to generate higher-quality images for each specific object, programs such as CrazyBump and PixPlant needed to be downloaded. These programs were built just to generate new and improved maps such as the figures above, as well as the bump, normal, and displacement maps. Then any 2D image, such as an image of grass, rusted metal, and a peeling lead painted wall can be turned into a realistic 3D image.

The results of this research was a catalogue of common textures saved as a file in Visionary Render in order to drag and drop them onto 3D objects found in future scenes. Their light properties were adjusted to react accordingly to a situation encountered in decontamination procedures such as a flashlight being shined upon them in the dark or a dim setting. It seemed that since these images were created for dark light settings, when a light was turned on in the scene, the object's textures would still have darker shading. Removing either the ambient occlusion map (a map to help with making an image react properly in the dark) or generating a whole new texture designed to be in a brighter setting would fix this issue.

Figure 5. Visionary Render System with GrayQb Demo.

Figure 6. Oculus Rift Demo.

5. CONCLUSION

The research done concluded that the texture and their light properties for the visualization model of Building 235-F are possible but require much more attention than the scene itself. Pulling in a scene from the 3D modeling tools takes minutes compared to the hours used to develop textures for every object. To speed up the process, a catalogue of textures was created for future use along with a manual written about the experiences of this research while working with Visionary Render. This manual helps to determine what settings are needed for setting the proper lighting in a scene. Patches are still needed for certain situations but the issues occur when developing, not when someone is in the scene itself.

The most important aspect of this technology is the versatility that can be applied to it. Military task forces can use this to simulate a terrorist threat or train individuals in settings that would be costly to transport them to. Technology similar to this has been used previously but is now gaining attention due to other industries exploring its advantages. This increasing attention of VR systems will help with projects funded by the Department of Energy for decontamination efforts.

In the near future, the technology and methods for developing these environments will change drastically but the modeling phase and virtual scene should be kept as two different tasks. The modeling phase is the least demanding as the 3D modeling software commercially available makes it simple to design objects with specified measurements. The realistic texture for each object is the most demanding as it takes a keen eye and deep understanding of 2D maps to apply them to 3D objects. Undeveloped textures do not diminish the goals that can be accomplished with this sort of technology. However, developed texture enhances the effects that VR can bring when training users for a specific task.

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