Lighting and Compositing for Project Hero

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LIGHTING AND COMPOSITING FOR PROJECT HERO

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Fine Arts
Digital Production Arts

by
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May 2014

Accepted by:
Dr. Timothy Davis, Committee Chair
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ABSTRACT

With tragedies such as the shooting at Sandy Hook Elementary on the rise in the last few years, brainstorming ideas that would prevent that type of violence in schools has become necessary. One such scenario involves a teleoperated robot, manned by local police, which would track down and subdue an intruder until police could arrive at the location.

This thesis follows the process of creating a computer-generated robot and compositing it seamlessly into a real environment for the production, *Project Hero*. This project is a short film that shows a scenario in which a robot would be used to subdue a perpetrator. The production required the robot to appear photorealistic to convince the viewer that it was part of the live-action footage. The main components to accomplish photorealism included surfacing, lighting and compositing the robot.
ACKNOWLEDGMENTS

I would like to thank my committee members, Dr. Davis, Dr. Gilbert, and Dr. House for their assistance and support while I was at Clemson. Thank you to my classmates that gave great feedback during this process always helping to improve my work. Thank you to my family who believed in my dream from the beginning. Their never-ending love and support has driven me for the last seven years. Finally I would like to thank Patrick for his love and all his patience while I pushed through my last year of school.
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CHAPTER ONE

INTRODUCTION

Safety in schools has become an issue of growing importance in recent years. With recent advances in technology, a solution to protect schools and lives should be in development. Project Hero is a concept that arose after the shooting at Sandy Hook Elementary School in Connecticut. With such tragedies on the rise in the last few years, brainstorming ideas that would prevent that type of violence in schools has become necessary. One such scenario involves a teleoperated robot, manned by local police, which would track down and subdue an intruder until police could arrive at the location. Teachers would be equipped with devices to alert the police of a suspicious person. Once the police are notified, they can use Boo B. Trap, a robot equipped with three 360-degree cameras, a battering ram and a non-lethal stun baton, to locate the intruder within the school.

This thesis follows the process of creating a computer-generated robot and compositing it seamlessly into a real environment for the production, Project Hero. This project is a short film that depicts a scenario in which a robot would be used to subdue a perpetrator. The production required the robot to appear photorealistic to convince the viewer that it was part of the live-action footage. The main components to accomplish photorealism included surfacing, lighting and compositing the robot.

When designing Boo B. Trap, a variety of different robots were considered. The final design of Boo was inspired by Boston Dynamic’s “Big Dog” robot, which has four
legs to allow the robot to remain upright in many scenarios and on different terrains. Images of different materials were collected to inform the surfacing of the robot. Old golf carts and Star Wars robot R2-D2 were used as references for the general wear and tear of the robot’s surface. The appearance of Boo B. Trap was also required to match the environment of an elementary school. On its surface, Boo B. Trap displays a few hidden gems that give the robot character. Location filming for the live-action element was performed at an elementary school in Anderson, South Carolina. The school provided permission to film an intruder walking around the hallways and then running from Boo B. Trap. Footage, reference images and light probe images were taken while on location to help with the lighting and compositing of the computer-generated robot. These processes are further explained in Chapters 3 and 4.

This thesis discusses the process and challenges of creating a 3D object for live-action compositing. Chapter 2 of this thesis includes a summary of the software and methods used in the production. Chapter 3 explains the process used throughout production to achieve the desired results, while Chapter 4 displays the final results. To conclude Chapter 5 summarizes future work for this project.
CHAPTER TWO
BACKGROUND

This production relied heavily on lighting and compositing to create a seamless transition between computer-generated objects and live footage. Ray tracing in combination with image-based lighting provided the best lighting method to reproduce photorealism, while final gathering provided the soft shadows needed for the interior scene. Since many crevices were incorporated on the robot’s surface, ambient occlusion was used to create those dark shadows associated with such surfaces. Finally, techniques to effectively composite the computer-generated image sequences in live-action plates were analyzed and implemented.

2.1 Ray Tracing

[Rade97] states “Ray tracing is a technique for rendering three-dimensional graphics with very complex light interactions.” Figure 2.1 depicts a simplistic version of ray tracing in which a single object interacts with a single light source. Rendering starts with a view plane that contains a predetermined number of pixels dictated by the height and width desired for the final image. A ray is fired through a pixel in the view plane and followed until it intersects an object in the scene. From that intersection another ray is fired towards the light source. Using the properties of the material and the light contribution, a final pixel color can be calculated. For instance, if a ray intersects an object, but is blocked from the light source, a shadow is created.
If an object’s material is reflective or transparent, more rays may be fired to determine the light and color of that pixel. This process is performed for each pixel in the original view plane. For this project photorealism of specular highlights and shadows was important since they needed to match the existing live-action footage. The goal was achieved in Maya using the mental ray renderer for ray tracing.

2.2 Image-Based Lighting

Image-based lighting uses a high dynamic range image (HDRI) to light the scene. HDRI is a method used to capture the greatest possible range of lights and darks of an image. Often, a light probe image is acquired by using a chrome sphere to capture the complete lighting in the environment [Debe08]. In Maya, a sphere is placed in the scene around the objects that are to be rendered. The light probe image is then projected onto
the sphere. In ray-traced rendering an initial ray is sent from the camera to a point in the scene. The color at that point is then calculated based on the object color and incoming light from the light probe image. Once the radiance is calculated, it can be used to identify the light reflected towards the camera based on the object’s material properties. Together, image-based lighting and ray tracing created photorealistic renderings almost identical to the original footage. Figure 2.2 shows an example of objects lit by two different light probe images.

![Image-Based Lighting Example](image)

**Figure 2.2 Image-Based Lighting Example [Deba08]**

### 2.3 Final Gathering

Final gathering is a fast and effective way to render natural light realistically by providing a degree of diffuse inter-reflections. Objects in the scene become ray-emitting light sources that “influence the color of their surroundings” [Maya14]. When a ray hits an object, final gathering rays are emitted to sample the surrounding area and compute the illumination. The red shadow on the left side of the rear cube in Figure 2.3 is an example of final gathering.
2.4 Ambient Occlusion

Ambient occlusion is a render pass that adds shadows in areas that are difficult for light rays to reach [Dera12]. Again ray tracing is used to shoot rays from the camera into the scene. When a ray hits an object, more rays are created at the intersection and shot in semi-random directions across the surface of an enclosing hemisphere. If rays hit another object within a specified distance, the intersection is shadowed. Figure 2.4 is an example of ambient occlusion. Since the pass is grayscale, it is easily combined with the image using multiplication. The gray and black pixels darken the original render while the white pixels allow areas of the original image to remain unchanged [Dera12] (Figure 2.5).
Figure 2.4 Ambient Occlusion Example

Figure 2.5 Original Image (top) and Image with Ambient Occlusion (bottom)
2.5 Render Layers and Render Passes

In Maya, render layers and passes are used to efficiently render image sequences. According to [Maya10], “Render layers are intended for decomposing scenes at the object level and for overriding properties, while render passes are intended to decompose data at the shading level.” Multiple render passes are associated with each render layer and are efficient because they are rendered simultaneously. The data is stored in a frame buffer and then separated by passes selected by the user [Maya10]. Examples of render passes include diffuse, specular, reflection and shadow; however, many more passes are possible depending on the final film’s output demands. Multiple render passes can be stored in a single EXR file that can then be separated and edited in compositing software. Since every pass is separated, making changes to alter the look of the final composition is facilitated. For instance, if the reflection on a surface is too bright, it can be fixed in compositing without re-rendering the entire image sequence.

2.4 Basic Compositing and Nuke

Once all layers are rendered, they can be imported in a compositing software package, such as Nuke. Compositing software is classified as one of two types: layer-based and node-based [Lani10]. Layer-based programs import images or image sequences and display them on a timeline where each has its own filters or transformations. Layers are stacked and composited bottom to top. Nuke, on the other hand, is an example of a node-based program. Here, images or image sequences are imported as a singular node. The output of a node can then be connected to the input of
another node, such as a color-correcting filter. Nuke implements essentially three different types of nodes: special effect filters, input and output controls, and viewers [Lani10]. A node can only accept a limited number of inputs; yet the output can be connected to any number of nodes. The structure of nodes is termed as a node network, tree graph or node tree. Arrows in such structures point in the direction that the data follows. Nuke allows the artist to combine multiple layers that are all computer-generated or the artist can combine computer-generated, layers with live-action footage. Generally when compositing computer-generated layers with film, depth of field, film grain and color must match closely. For this project compositing was heavily used to match the color and lighting of footage acquired on location.
Production for *Project Hero* began with gathering inspiration for the robot’s design. Once that was established, the live-action elements at the school were then filmed and 3D models were created. Lighting and compositing the 3D model focused on developing photorealism and integrating 3D elements with live-action footage.

3.1 Inspiration for Boo

Boston Dynamics, in conjunction with DARPA, has designed a four-legged walking robot, Big Dog, which can navigate through a variety of different mediums such as snow, water, mud and ice. Further, it is capable of righting itself if overturned and can carry up to 340 pounds [Raib08]. These types of features were a good starting point for Boo B. Trap. In addition, Boo B. Trap is equipped with three cameras such that the officer controlling it would be able to see the environment around the robot. One camera is positioned on top of the robot, one underneath and one in the middle of the robot’s body, with all cameras able to rotate 360 degrees. This strategy of camera placement prohibits an intruder from blinding Boo B. Trap. Additionally the robot is equipped with a battering ram that is able to remove any obstacle, such as doors and various types of debris. Further, the robot is capable of subduing a perpetrator with a stun baton, which was determined safer than a standard stun gun that could easily waiver and hit an
unintended target, such as a hostage. A stun baton also has a much smaller range, requiring the baton to make contact with the person to be effective.

Since Boo B. Trap is geared for K-12 schools, the robot’s appearance was designed to be non-threatening to children. Figure 3.1 shows examples of assorted surface reference materials used to shade and texture the robot.

![Figure 3.1 Surface Design Sheet](image)

After initial textures and coloring were determined, extra detail was added to the robot’s surfacing. Since *Project Hero* focuses on Boo B. Trap’s use in an elementary school, the robot was given a backstory. The robot would be tested with different drills on location. Also the children would have a chance to interact with Boo B. Trap and become familiar with the robot. Dirt, dust, crayon markings, and stickers were therefore
added to the surface. Figures 3.2 shows these different elements added to the robot’s final surface texture.

![Figure 3.2 Surface Texture](image)

3.2 Light Probe Images

The reflective surfaces of the robot necessitated an actual environment to create believable lighting and reflections. Using a light probe image during lighting allowed the robot to reflect the surrounding environment. Light probe images were taken while on location filming the background plates. Capturing the light probe image required a chrome sphere to be placed in the middle of the environment. A camera, at the same height of the sphere, was placed perpendicular to the sphere but at a suitable distance to minimize the photographer’s reflection. After the chrome sphere and camera were set up,
photographs with high dynamic range were captured. The camera’s settings were then tailored to produce high-quality HDR images. For these images the ISO was set to 100. A camera’s ISO is described as measuring the sensitivity of the image sensor: the lower the number, “the less sensitive the camera is to light and the finer the grain” [Rows14]. Figure 3.3 shows the difference between low and high ISO. The image on the left exhibits less grain with a smoother transition between lights and darks. The grain in the image on the right affects the color and appears splotchy. For high-quality HDR images, a lower ISO is necessary.

![Image](image.png)

**Figure 3.3 An Example of 100 ISO (left) and 3200 ISO (right) [Rows14]**

Next the aperture was set to 5.6 to maximize the depth of field within the photograph. Figure 3.4 shows the difference between apertures 1.8 and 5.6. Focusing on the strings of the guitar, the image on the left has only two strings in focus whereas the
image on the right keeps all six strings in focus. For the light probe, an aperture of 5.6 allowed all objects in the environment to be in focus in the reflection on the ball. Additionally, the camera was set to aperture priority mode, allowing the camera to adjust the shutter speed based on the aperture and ISO.

Figure 3.4 An Example of Aperture 1.8 (left) and Aperture 5.6 (right) [Yamm14]

Figure 3.5 shows five photographs taken with different exposure increments. Exposure starts with -2 and increases by 1 in each photo. Once the photographs were uploaded to the computer, they were edited in Adobe Photoshop to remove any dust or imperfections on the chrome sphere. Photoshop’s Merge to HDR Pro tool was then used to blend all five of the exposure levels to create the HDR image shown in Figure 3.6.
Figure 3.5 Exposure Images: -2 (top left), -1, 0, +1 (bottom left), +2

Figure 3.6 Final HDR image
3.3 Recreating the School

An elementary school hallway and cafeteria were the backdrops for this project, which was meant to highlight the robot’s capabilities. A hallway was chosen because it connects rooms in the school and could show the robot’s navigation capabilities. The cafeteria provided a large space to show Boo B. Trap running without colliding with objects. Once the background plates were captured, a 3D scene was created as a proxy environment for animating the robot. Basic measurements of length, width and height were taken to model a hallway and cafeteria in Maya (Figure 3.7). Other markers were identified to help place the robot model within the scene during layout and compositing.

Figure 3.7 Hallway Model with Measurements
3.4 Layout and Animation

Measurements described in the previous section also assisted in matchmoving the camera in Maya to the background plates. In the layout file, the hallway and robot models were included through referencing. Using the markers at the filming site, the robot was initially positioned in the area of the door at which it was to appear. To match the 3D render camera to the original, an image plane was placed behind the wireframe for the hallway. From there only the camera was moved to match the model to the imported image plane, as shown in Figure 3.8. The green wireframe and light area outlines the hallway model, and reveals another hallway that runs perpendicular to the first. Matching the floor in the proxy model to the floor in the image was essential since it serves as a guide for the animation process.

3.8 Layout for Shot 06
Two shots required animation for this production. In the first shot, the robot steps out of its resting place. A door opens in the live-action footage and Boo B. Trap walks from behind it and around the corner. This scene required a walk cycle for animation since the moving cameras are behind tinted glass and cannot be seen by the viewer. In Shot 08 Boo B. Trap races after an intruder to stun him. The robot therefore needed to run and stop abruptly, as well as extend the stun baton to engage the intruder.

3.5 Lighting

Following layout and animation, lighting the robot in Maya began. To match the lighting in the background plates, Maya’s mental ray renderer, in conjunction with image-based lighting, was used. The light probe image (as shown in Figure 3.6) provided the input to image-based lighting to approximate the incoming light from all directions in the environment.

When rendering with mental ray, the indirect lighting tab under the render settings allows the use of environmental lighting. An environment sphere was therefore created with the appropriate HDR image applied as its texture. The sphere was then rotated so that the texture matched the hallway plates. This process allowed lights in the scene to mimic those in the live-action footage. Maya’s default lights were disabled to show the full effect of the environment sphere (Figure 3.9). Initially the environment sphere was emitting light based on the texture; however, these results did not adequately match the scene as the rendered image was too bright.
As a result, a different technique using final gathering was implemented instead. In this approach, light was no longer emitted from the sphere to allow final gathering to determine light contribution. Not only were the render times much shorter, but the results matched the original light more closely.
Unfortunately, the environment sphere with final gathering did not produce enough light to illuminate the robot (Figure 3.10). Three area lights were therefore added to the scene to further enhance illumination. Area lights were chosen to simulate the fluorescent lights commonly found in school buildings. These three lights were placed in the scene matching markers placed within the physical environment, as previously mentioned (Figure 3.11). The intensity of the lights was adjusted until it matched the brightness of the original scene. A light yellow color was assigned to the area lights to match the reference. Figure 3.12 shows the finalized lights rendered with final gathering.
Figure 3.11 Layout of Lights in Maya

Figure 3.12 Robot Rendered with Final Gathering and Area Lights
3.6 Render Layers and Passes

Render layers and passes were utilized in this project to allow small adjustments to be made without requiring complete re-renders. Four layers were rendered: a character layer, a floor shadow layer, a floor reflection layer and an ambient occlusion layer. The character layer included the robot, environment sphere and area lights. The reflections on the robot’s glass-like texture were produced from the information provided by the environment sphere. Diffuse, reflection, refraction and specular passes were rendered for this layer (Figure 3.13).

Since rendering the floor was not necessary, a method was developed to render only the shadow and reflection for the robot. A ground plane was created and a Use Background Shader was applied to produce a shadow only. Further, the Use Background Shader was manipulated to separate the shadow and reflection. On the floor shadow layer, reflectivity was set to zero and the shadow mask was set to 1. On the floor reflection layer, the opposite was applied to the floor plane. The ambient occlusion layer included a floor plane and the robot model. All objects in the ambient occlusion layer were textured with a Surface Shader.
3.7 Compositing

All four render layers were read into Nuke along with an image sequence of the background plate. The character render layer was stored as a multiple-pass EXR file and consisted of the diffuse, reflection, refraction and specular render passes. In order to alter a single pass in compositing, each pass must be separated. Nuke enables the user to separate passes through a Shuffle node, which allows for rearranging and swapping channels within a single image [Lani10]. The entire original EXR file is read in by the
*Shuffle* node, but only information about a single layer is returned. The checked boxes under the color channels in Figure 3.14 demonstrate the way the diffuse layer is separated. Separating the other passes was handled similarly.

![Shuffle Node for Diffuse Layer](image)

Figure 3.14 Shuffle Node for Diffuse Layer

Once the *Shuffle* nodes have been applied, each pass can be handled separately. *ColorCorrect* nodes were added to apply adjustments to each pass. Saturation, contrast, gamma, gain, and offset can be affected with a *ColorCorrect* node. In addition to changing pixels across the entire image, the *ColorCorrect* node can alter a single tonal range such as shadows, midtones and highlights. Next each shuffled pass was reassembled using *Merge* nodes. A *Merge* node takes two inputs and combines them using input A as the top layer and input B underneath. The *Merge* node has different blending options for the combination of the two layers. Diffuse, reflection, refraction and specular passes were added using the ‘plus’ mode.
The shadow and reflection layers for the floor were changed using Grade nodes. Grade nodes allow the user to control the black point and white point of the image. The reflection is merged over the shadow using the ‘over’ blending mode. In turn these merged layers were combined with the character layer using the ‘over’ blending mode. Using a ‘multiply’ operation, the ambient occlusion pass was merged with the other layers. Again another Merge node was used to add the character to the background plate.

Other nodes were retroactively added to integrate the character with the background plate. For instance a Defocus node was applied to add blurriness similar to that achieved by a camera’s depth of field. Grain was added via the Grain node. Sliders for red, green and blue grains are provided to adjust the size and irregularity of each. Lastly roto-painting allowed elements from the background plate to appear as though they were in the foreground. Roto-painting is the manual task of hand drawing compositing masks. A mask was drawn around the door and Background 1 was applied as the color. Figure 3.15 illustrates the image before the roto-paint, while Figure 3.16 shows the results of using roto-paint to bring part of the background to the foreground.
Figure 3.15 Original Image

Figure 3.16 Image After Applying Roto-paint
Another Roto-Paint node was added to the reflection layer to fade the reflection further as it receded. The final Nuke tree appears Figure 3.17. To reduce clutter from the Shuffle nodes, a layer parser was created and altered in a separate tab (Figure 3.18).

Figure 3.17 Final Nuke Tree

Once the desired results were achieved in Nuke, final image sequences were rendered. Each image sequence representing a shot was ordered to create a final film. The resulting production contained nine shots, two of which featured the robot and are shown in Chapter 4.
Figure 3.18 LayerParser
CHAPTER FOUR

FINAL RESULTS

The processes used for this film proved successful in creating a film that cohesively combined both live and digital aspects. The combination of image-based lighting, mental ray rendering and render passes led to a believable output. Compositing helped to enhance the rendered frames and fully integrate them with the background plates.

Figures 4.1 and 4.2 are images from shot 06 of the final film. These shots introduce the audience to Boo B. Trap. Figure 4.1 shows a glimpse of the robot behind the open door. Figure 4.2 shows more of the robot as it emerges from behind the door. Figures 4.3, 4.4, and 4.5 are rendered frames from shot 08. Figure 4.3 is an image of the robot running and an example of the motion blur added to match the original footage. Figure 4.4 is a frame that shows the stun baton effect. Figure 4.5 shows the robot at rest in the scene.
Figure 4.1 Shot 06 Rendered Frame

4.2 Shot 06 Rendered Frame
CHAPTER FIVE
CONCLUSION

Photorealism played a central part of this project, which involved creating a film that relayed the idea of the robot’s purpose. Convincing the viewer that Boo B. Trap was actually built and working was the end goal. The robot began as a polygonal model in Maya and was then surfaced, animated, lit and finally composited into the final product.

The image-based lighting process helped to produce the photorealism seen in the final images. Using the environment sphere proved to be the most efficient process with the shortest rendering times. It helped to establish a base lighting for the robot. The simple addition of area lights aided in finishing the process. Rendering images from Maya and storing them as EXR files also helped with efficiency. The amount of control accessible during compositing allowed for changes during post-production with reduced time costs.

This short film is the basis for future applications of this project. It is a foundation to encourage action on the topics of safety and gun violence. Project Hero will debut April 22\textsuperscript{nd}, 2014, at a local Anderson elementary school. Government officials, leading robotics experts and other technology companies, such as Verizon, are expected to make an appearance at the event. To implement such a project, many experts are needed, from crisis responders to teachers. As people collaborate further on this project, details will change and the technology depicted in this film may become a reality.
REFERENCES


