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Simulating Headlamp Illumination Using Photometric Light Clusters

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ABSTRACT

Assessing the ability of a driver to see objects, pedestrians, or other vehicles at night is a necessary precursor to determining if that driver could have avoided a nighttime crash. The visibility of an object at night is largely due to the luminance contrast between the object and its background. This difference depends on many factors, one of which is the amount of illumination produced by a vehicle's headlamps. This paper focuses on a method for digitally modeling a vehicle headlamp, such that the illumination produced by the headlamps can be evaluated. The paper introduces the underlying concepts and a methodology for simulating, in a computer environment, a high-beam headlamp using a computer generated light cluster. In addition, the results of using this methodology are evaluated by comparing light values measured for a real headlamp to a simulated headlamp.

INTRODUCTION

Nighttime crashes often involve complex lighting conditions. The visibility of animals, pedestrians, cars, or other objects both on and off the road are affected by conditions such as the illumination by headlamps, street lamps, ambient lighting, oncoming traffic, and weather. Primarily, it is the luminance contrast between an object and its background that makes an object visible to an observer at night (Olson, 2003, p. 158). Luminance is the amount of light that is reflected off of a surface, and the luminance contrast, or difference in luminance between two objects, is dependent on surface properties such as color and reflectivity, as well as the amount of illumination arriving at that surface by light sources. In reconstructing a nighttime crash, evaluating the limits of visibility is important for determining both the distance at which and the degree to which something is visible. Current methods exist fore evaluating the limits of visibility which rely on replicating as closely as possible the conditions present at the time of the accident and performing an in situ evaluation, through observation and light measurement (Adrian, 1998, pp. 181-88; Klein, 1992; Owens, 1989).

However, replicating the lighting conditions under which an accident occurred can be difficult and expensive and may be impossible if the accident site no longer exists or has changed significantly. If one were able to digitally simulate the accident environment these constraints could, in many cases, be eliminated. However, creating a simulated environment would have its own obstacles, including the need to accurately model the various light sources in that environment. This paper does not attempt a comprehensive methodology for modeling the lighting conditions for an entire accident environment. Instead, it focuses on one of the building blocks that will ultimately form the basis for such a methodology, namely simulation of the illumination from a headlamp. This particular light source is often a critical one in determining a driver's visibility for an accident scenario.

With the recent development of sophisticated computer lighting modules and ability to create and control both light and material behavior in a three dimensional computer environment, a headlamp can be modeled and assembled in a virtual environment to reasonably mimic the behavior of that headlamp in the real world. The methodology for simulating headlights as discussed in this paper involves modeling the illuminance levels produced by a physical headlight source. While low and high beams are both of interest in modeling the light simulation, only high beams are analyzed in this paper.

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Headlight illumination depends on design factors such as the beam pattern of the projected lamp, its orientation relative to the object it is illuminating, and the intensity of the light. Environmental factors such as the atmosphere between the headlight and the object, or even dirt or debris that covers the headlamp lens can also affect the illumination. This study examines a new and clean, high-beam headlamp, but because the methodology in this paper utilizes the performance of a real world headlamp, environmental effects that are relevant, such as dirt or debris, can be added to the actual headlamp and incorporated in the results.

To measure the accuracy of the computer model, photometry values are calculated in the simulated lighting environment and compared to the actual photometric values measured in a real life environment. The results demonstrate that despite the complexity of the light patterns and distributions of a headlamp, an accurate headlamp simulation can be produced. As this process develops and is validated for larger more complex lighting environments, it is the intention that computer simulated light values could be used in conjunction with visibility models developed by Blackwell (1981) and Adrian (1987, pp. 3-12) to assess the limits of a driver's visibility within a specific accident scenario.

BACKGROUND ON LIGHT SIMULATION

One's ability to visually perceive an object is due to the difference in contrast between an object and its background (Alexander, 2002, p. 158; Olson, 2003, p. 183). This contrast results from differences in each object's color, texture, spatial frequency, and illuminance contrast. However, in nighttime driving conditions, the effect of illuminance contrast tends to be the greatest influence on the ability to perceive an object (Olson, 2003, p. 121). For this reason, the ability to visually perceive an object at night on the roadway is primarily determined by the relative illumination of these objects from the headlamps of the vehicles, the ambient lighting from the atmosphere or moon, or man-made lights on or off the street.

Techniques for digitally simulating light have existed for decades, though applications of light simulation have often focused on interior lighting or lighting design. In the context of accident reconstruction, Phillips (1990) has discussed the use of programs like Lumenpoint to determine light values given a particular scene environment. These programs work from basic light parameters and deal with the general behavior of light. What makes nighttime accidents a special problem for lighting simulation is the complexity of the light sources and the accuracy needed to evaluate the behavior of each of the light sources. Light simulation programs do not necessarily deal with the unique attributes that surround light being emitted from a complex light source such as a headlamp.

Headlamps range from light types such as incandescent, HID, or LED and include sophisticated reflectors and lenses that shape and distribute light in distinctive ways. Each headlamp model will have its own unique beam pattern, and hence, each headlamp model will have its own unique characteristics in terms of its changes in intensity, hot spot location and shape along the area it is illuminating. In accident reconstruction, because there are conditions unique to each accident, it is important to look at the specific headlamp model and analyze its unique patterns and distribution when evaluating visibility. Equally, it is important to be able to simulate the light distribution properties of a specific headlamp.

SIMULATED LIGHT PHOTOMETRICS

Vehicle headlamps have sophisticated light distribution patterns because of the performance standards they are required to meet and because of the use of parabolic reflectors and lenses to achieve the necessary efficacy. The image in Figure 1 is taken from SAE J2595 "Standard Performance Requirements for Sealed Beam Motor Vehicle Headlamps". The grid of points denotes a pattern of angles the light projects from the headlamp and associated candela values. The primary goal of these standards is to provide sufficient light power to the headlamps to illuminate objects ahead of the vehicle, while reducing the amount of glare that may be discomforting or distracting to oncoming traffic.[10] The standard has many data points, specifying both the angle and candela power. This standard represents the minimum performance criteria and many manufacturers have chosen additional criteria to augment their designs. The various points along the grid represent both minimum luminance values and maximum luminance values and as indicated in the top of Figure 1, the standard shown here applies to high beams only.

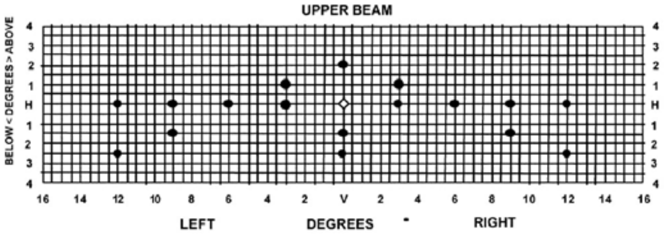


Figure 1

To visually understand the application of this standard, Figure 2 shows (top portion) a canvas mounted on a wall in a lit room, upon which a headlamp beam can be projected and then photographed. The bottom portion shows the photograph taken of the projected headlamp on that canvas, when the ambient lighting has been turned off.

Canvas on which the headlamp will be projeted (lights on)

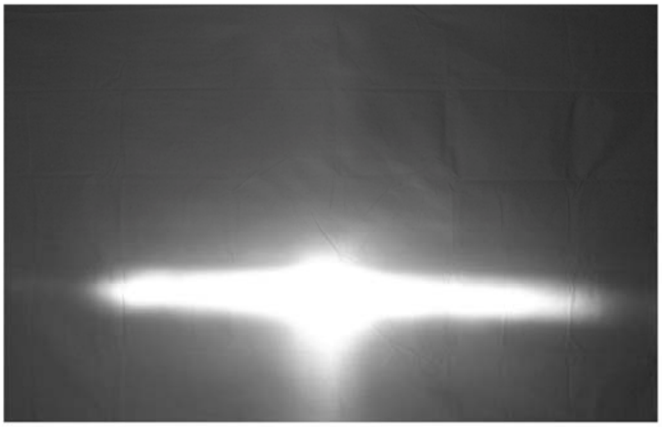


Photo of projected headlamp on canvas (lights off)

Figure 2

It can be observed that the light pattern contains a hotspot, where the intensity of the light energy is most concentrated. Also, the light spreads out from the hotspot in a horizontal and oblong pattern. The light intensity decreases toward the edges. As the headlamp moves forward or back from the surface on which it's projecting, the oblong shape changes, as does the location of the hotspot. In digitally modeling a headlamp, it is essential to capture this dynamic nature of the headlamp spread over distance.

The concept behind a simulated photometric light cluster is that the unique light distribution pattern can be created by shining light through a digital projection map, which properly displays the values from light to dark across the spectrum of the headlamp beam spread. A projection map is a digital image that acts much like a filter for a computer generated light source, controlling the light rays that the computer light source emits. As a digital image, the projection map contains pixel values from light to dark and as the computer generated light source passes through the map, the pixels of darker value allow less light than those pixels of lighter. It is in this general manner that the projection map combined with a computer generated light source can approximate actual light source since the resulting light from an actual lamp manifests its own filters as it projects onto a surface. In other words, if the photo in Figure 2 were a projection map, the areas in dark would prevent light from shining through, while the areas in white would allow it. The values that fall between white or black would allow a percentage of light through, equal to the percent of whiteness or blackness of that area of the projection map.

This concept is illustrated in Figure 3. In this illustration, a light source sits behind a projection map through which the light passes to project an image further away. The projection through this map results in the light being filtered to match the actual light spread and intensity of the photographed headlamp. In the actual computer environment, this map is not separate from a light source (as shown in the concept image Figure 3), but rather an algorithm assigned to a light source, defining the distribution of light emitted from the light source according to the specific pattern of light and dark.

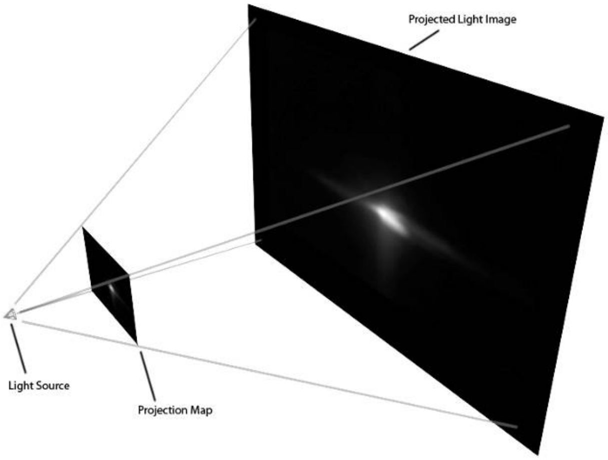


Figure 3

The illustration in Figure 3 shows a single light source and projection map. However, a single light source and a single projection map are not able to accommodate a headlamp's parabolic shape and sophisticated lenses that direct and focus the light in rather complex ways. The hotspot, for instance, is created from a combination of light coming from both the left and right sides of the headlamp. Figure 4 below shows the lens on a truck headlamp. There are several patterns that emerge on the surface of the headlamp that control the spread and distribution of the light. On the surface can be seen a series of rectangles of varying sizes. The size and location of these rectangles direct light in different ways to achieve a final light distribution. For the rectangle areas that control the hot spot, a pattern can be seen that is similar on both the right and left sides of the headlamp, represented in rectangles larger than the surrounding areas. These similar lens configurations on both sides of the lamp contribute to creating a focused hotspot in the center of the photograph in Figure 2. To simulate an effect such as this, it would then require two light sources, projecting through two maps to create an accurate hotspot, since in essence two lights are projecting from the actual headlamp surface.

Figure 4

This may seem counterintuitive since there is only one light source inside the headlamp assembly (the halogen bulb in this case). However, the parabolic reflectors and lens on the surface of the headlamp focus, redirect and reflect the single light in ways the make it exit the headlamp assembly from different locations, giving the impression of more than one light source.

Ultimately, the methodology described in this paper required a total of three light sources and three maps to properly generate an accurate simulation of this headlamp. The conceptual illustration in Figure 5 demonstrates how the three light sources project through image maps to create a single headlamp simulation.

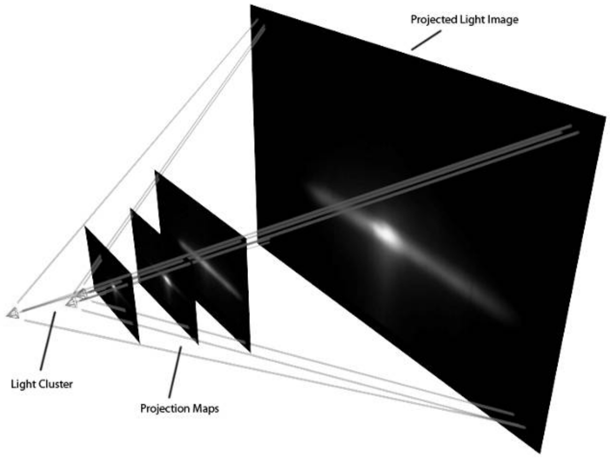


Figure 5

It should be noted that each projection map is only part of the overall light. In other words, each projection map only accounts for the amount of light coming from one area of the headlamp. When light passing through all three image maps, the projected light is collectively the same as the light coming from the actual headlamp. This enables a more accurate light simulation since it accounts for the complex light distribution that is caused by the parabolic reflector and lenses of the headlamp.

CREATING A PHOTOMETRIC LIGHT CLUSTER

Creating a light cluster (three lights total) for a light source such as a headlamp will be the focus of this methodology. This methodology was tested on a International 65 watt halogen sealed high beam, model 20-5363H3, for use with a tractor semi-trailer. The headlamp was new and clean, and the results represented in this paper do not include the effects of dirt or other external elements that might affect the beam pattern of the light. However, because the methodology uses an actual headlamp, dirt or debris can be added to the headlamp and its affect on the illumination would be manifested in the resulting computer generated light. The dirt or debris would simply need to be added to the surface of the lens when the light apparatus is first constructed. While this methodology focuses on headlamps, other light sources, such as street lamps can also be complex and have a wide range of distribution patterns depending on their style and application (Olson, 2003, pp. 255-260). This methodology is not light source dependent and in theory would work for all complex light systems, provided a sample lamp and lens could be obtained for analysis.

The following lists the basic steps in the methodology for creating a computer generated light cluster that mirrors the light behavior of a headlamp.

1. Obtain headlamp and analyze light patterns and distribution and construct apparatus
2. Project separate quadrants at distance intervals, record with photos
3. Convert photo plates to three dimensional mesh objects showing light intensity
4. Determine computer-generated light source locations
5. Create projection maps for each computer generated light source
6. Combine computer generated lights into one light cluster

These steps are described in detail in the sections that follow.

ANALYZE LIGHT DISTRIBUTION

The beam pattern for a headlamp is complicated by two predominate geometrical features of the headlamp assembly. Parabolic reflectors collect light from the bulb and focus the light out toward the front of the headlamp. In addition, lenses or shape differences on the surface where light is being focused redirect this focused light to maximize visibility for the driver while minimizing glare to other drivers (Olson, 2003, p. 158). Standard headlamp assemblies divide the affect of the parabolic focusing shape and the directed lens shape into two parts. However, newer headlights sometimes combine the parabolic shape and lens pattern into one form. This methodology only deals with the former condition where the lens that redirects focused light is on the exterior surface of the headlamp assembly, such as lens shown in Figure 4.

The lens on the surface of the headlamp plays a critical role in the behavior of the light, and the pattern and distribution of the light as it exits the headlamp assembly. As Figure 6 shows, the lens itself is made up of many smaller rectilinear shapes, each shape having an effect on how the light exits the assembly. In order to create a computer generated light cluster that simulates the light exiting the assembly, the surface of the lens must be analyzed and the complex geometry reduced to a few main areas that represent the general effect the lens has on the light in creating hotspots and other beam patterns. This is done through reducing the lens into four quadrants, or different sections. In this headlamp, the four quadrants are clearly seen as distinct sections of the lens surface and the difference in the geometry of the lens surface in each quadrant can be observed in Figure 6.

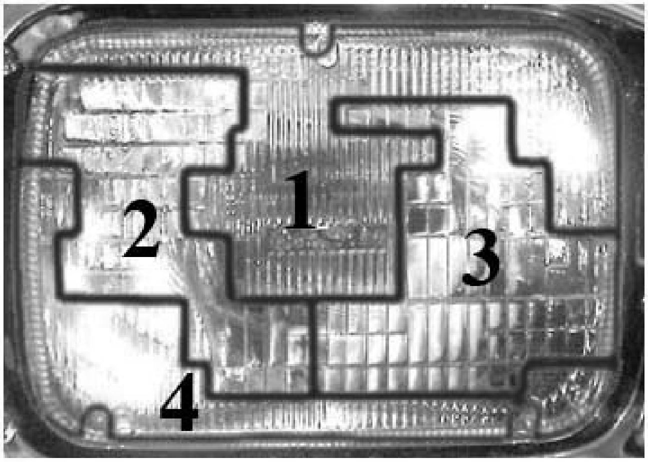


Figure 6

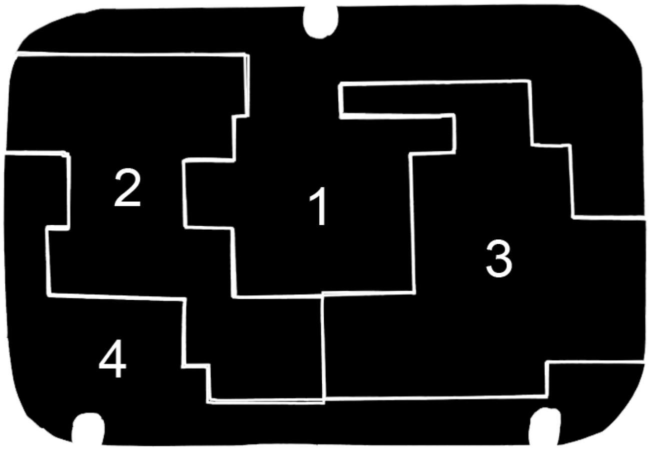


Figure 7

The quadrants, labeled with the Numbers 1 through 4, are identified in outline form on the headlamp itself and are also shown as separate masks in Figure 7. In terms of the overall light spread produced by this headlight, Quadrants 1 and 4 contribute to the horizontal spread of the beam pattern and Quadrants 2 and 3 are primarily responsible for producing the hotspot of the headlamp. Each of these independent quadrants have their own characteristics, shape and angle coming from the headlamp assembly and a separate computer generated light source may be required to simulate each quadrant individually.

By masking each quadrant separately, a complete picture of how the lens affects the light exiting the headlamp assembly can be analyzed and photographed. This documentation will allow each individual computer generated light source to properly contribute its share of the overall light emitted by the entire light cluster.

PROJECT QUANDRANTS AT DISTANCES

Once masks are created for each quadrant, (Figure 6 and 7) the headlamp and a camera are mounted on a rigid jig that can photograph the headlamp's light pattern as it is projected on to a wall in a dark room devoid of ambient lighting. Through the use of this jig, shown in Figure 8, the camera is placed directly above and parallel to the light bulb inside the headlamp housing with the camera and headlamp aligned perpendicular to the projection wall.

Figure 8

The distance from the center of the light bulb to the center of the camera lens is then physically measured along with the distance the camera is from the projection wall. The focal length of the camera is determined from the metadata associated with the digital photograph. These measurements can then be used to calculate the three dimensional location of any pixel in the photograph, relative to the headlamp. The three dimensional location of each pixel is needed to determine the contours that are used in constructing the 3D mesh described in the section Converting Photo Plates to Mesh Objects. The distance a pixel is from the camera is obtained from measurements, and the following equations yield the x and y location of the pixel relative to the headlamp.

$$x = P_x \cdot D \cdot \tan(\frac{fov_h}{2}) \quad (1)$$

$$y = P_x \cdot D \cdot \tan(\frac{fov_v}{2}) + L_{off} \quad (2)$$

Where P_x is the percent a pixel is, side to side, from the center to the edge of the photograph, and P_y is the percent a pixel is, up and down, from the center to the edge of the photograph. D is the measured distance of the headlamp to the wall, and fov_h and fov_v represent the field of view of the camera in the horizontal and vertical directions. L is the distance the camera is from the bulb of the headlamp.

For this methodology, distances of 6’, 9’, 12’ and 15’ are used, and the jig is set up at each distance with the headlamp assembly projecting a beam pattern on the wall. For each distance, quadrants are masked and a photograph is taken to record the contribution of each quadrant to the total beam pattern. For these 4 distances, the closest distance was far enough away from the wall to capture the headlight pattern in the photograph while the furthest distance was chosen to allow significant changes in the headlight pattern and intensity to develop and appear on the wall. The two intermediate distances where distributed evenly between near and far distances. The intermediate distances where used for checking any differences in the position and orientation of the light, any small difference found in the intermediate distances would be included, through averaging, in the final position and orientation for the computer generated light.

Figure 9 shows the results of the quadrants masked at a distance of 6’ from the wall. It is relevant at this step to record one light value at a known point of the projected headlamp using a light meter for calibrating the calculations performed in the computer generated scene. Since the computer measures luminance values in different units (pixel luminance values rather than cd/m^2), the unit value in the computer must be calibrated to a unit in the same location and distance recorded on the projected image. Since the measurement of light by the light meter and the computer are both linear, only one value is needed for calibration.

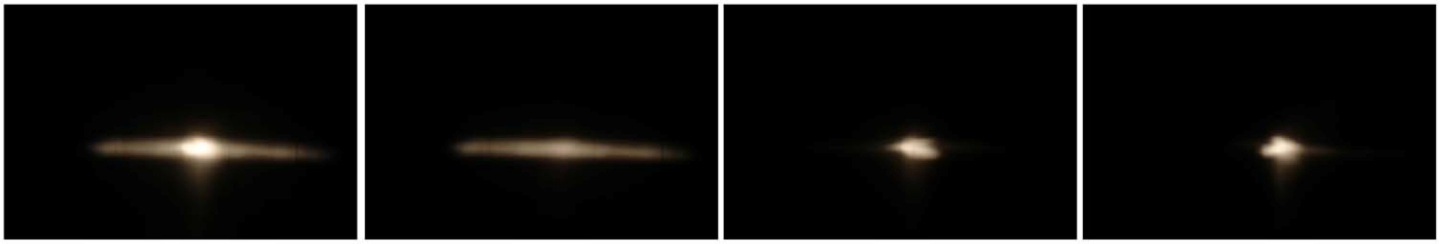
A photo of an unmasked headlamp is also included for reference on the left side of Figure 9. This process is repeated at each distance interval. The photos are also taken in raw format, so the values from light to dark in the image can maximize the available range in a 16 bit image. In addition, in raw format the pixel intensity is linearly proportional to the actual light intensity. Raw files essentially record the illumination levels at the scene and can be used to measure light intensity as long as the pixel intensity can be correlated to a light intensity reading taken at the scene. It is beyond the scope of this paper to discuss parameters and application of digital photography. Articles by Allin (2007) and Krauss (2006) discuss this topic. For this study, a Sony SR-1 10.3 mega pixel camera was used, and images recorded in RAW format.

CONVERTING PHOTO PLATES TO MESH OBJECTS

Four separate distances were recorded, each distance contains three projected beam patterns, one showing Quadrants 2 and 3 masked, one showing Quadrants 1, 3 and 4 masked and one showing Quadrants 1, 2, and 4 masked. Each of these three masked beam patterns will result in a separate computer generated light source. For simplicity, the remaining steps in the methodology will deal with the creation of only one of these light sources in the light cluster. This methodology would be the same for creating the remaining two light sources.

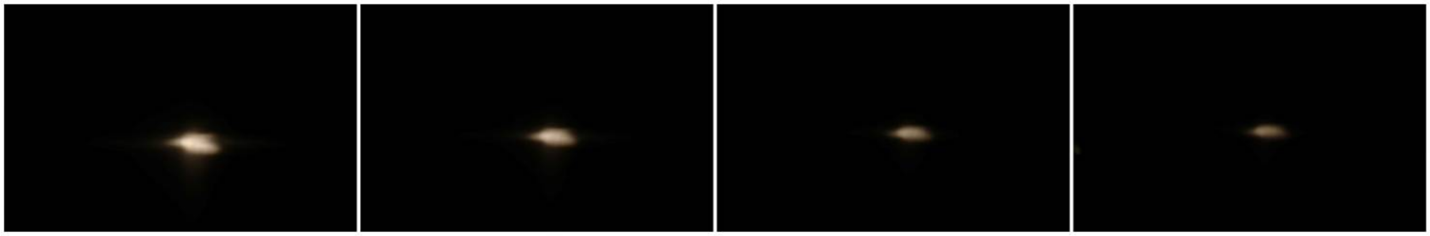
The masked set that is discussed below represents the headlamp with Quadrants 1, 3 and 4 masked. An image of this projected beam pattern can be seen in Figure 9. As seen in the photograph, the beam pattern for this quadrant is primarily a hotspot. The photographs shown in Figure 10 represent the masked headlamp at 6’, 9’, 12’ and 15’. As expected, as the distance from the wall increases, the amount of light intensity visible in the image decreases. The relevance of this step in the methodology is to use the change in intensity levels between the photographic images to determine the location of a light source that would generate the same light pattern and intensity. To determine the location of the light source that will simulate the beam pattern shown in Figure 9, three dimensional models of the photographs are generated and analyzed according to their maximum intensity level. Figure 11 demonstrates the process of taking a photograph and generating a three dimensional intensity mesh from it.

In short, the photograph is analyzed digitally and separated into contours that describe changes in intensity from dark to light. These contours notated in varying colors, provide the framework for a three dimensional model of the photograph. Like a terrain contour map, the contour map of the beam pattern related high intensity values to higher elevation, and darker intensity values to flatter elevations. The values in the photograph that are white are represented in the mesh model with a value of one, and are flat on the mesh plane. Values on the photograph that increase with light intensity rise from the plane of the mesh according to the contours.



Full headlamp, no masks **Quadrants 1 and 4 unmasked** **Quadrant 2 unmasked** **Quadrant 3 unmasked**

Figure 9



6’ photo of masked headlamp **9’ photo of masked headlamp** **12’ photo of masked headlamp** **15’ photo of masked headlamp**

Figure 10

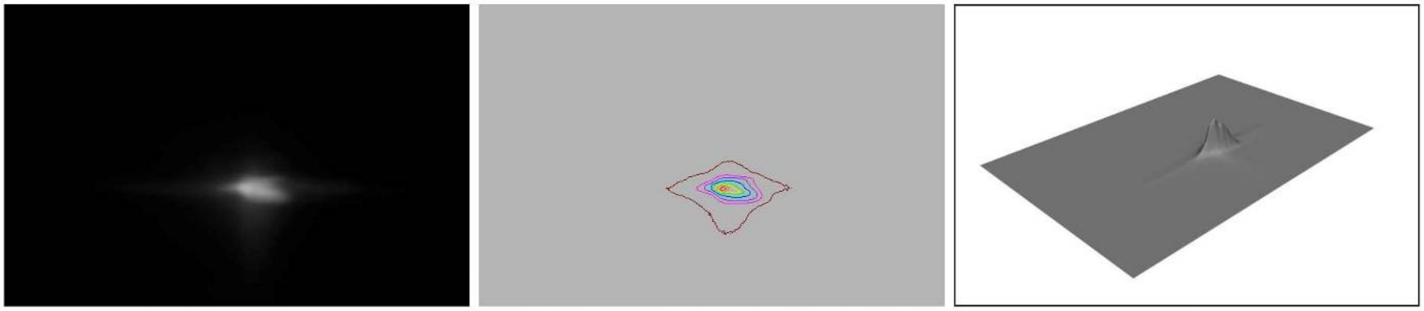


Photo at 6’ **Contours of light intensity levels** **Mesh model of light intensity**

Figure 11

This three dimensional intensity mesh is created for each distance for a total of four intensity meshes. This intensity mesh is a 3D object of the light pattern at a specific distance. The position of the vertices in x and y correspond to the locations of the pixel samples in 3D space while the z position represents the intensity of the pixel sample. Because this analysis is done in a Cartesian modeling system, the meshes are created to scale and positioned according to their relative distance from each other. Figure 12 shows all four meshes in line with each other at the same distances where photographs were taken of the headlamp beam pattern. While only four mesh objects are shown in this study, multiple additional intervals could be used. As the intervals of mesh objects increases, a more continuous contrast map would emerge.

The mesh objects are oriented perpendicular to the direction of the headlamp beam, and positioned 3 feet apart as shown. As expected, mesh models closer to the light source exhibit intensity levels proportionally greater than those of the mesh models from a farther distance from the headlamp source. Thus, Figure 12 shows mesh models that are a three dimensional representations of photographs taken at 3’ intervals. Because the meshes are positioned in scale, a light location and light parameters can be determined and used to create a simulated light that projects the same light intensity as the headlamp recorded in the photographs.

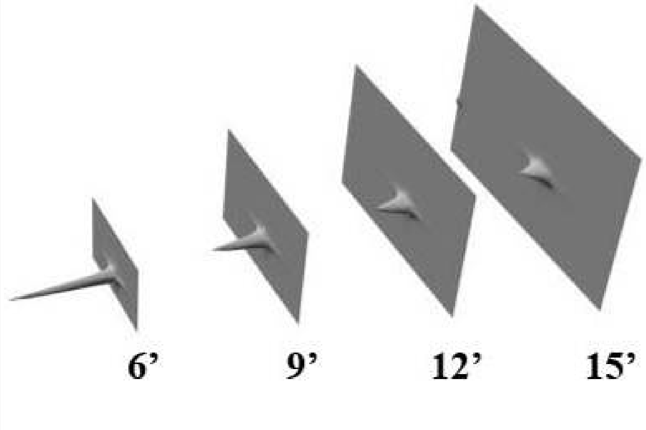


Figure 12

DETERMINE COMPUTER GENERATED LIGHT SOURCE LOCATIONS

There are two factors that determine the position of the computer generated light source: (1) the angle or line along which that light is pointed and (2) the position back that the computer generated light must be placed to create the correct shape and distribution. The first factor that must be determined is the line along which the light source is placed and angled. The principle for determining this is the following: The position of the computer generated light source will lie along the path that is defined by the highest intensity light level of each of the mesh models. This is the central concept for locating the position of the computer generated light source. Figure 13 shows a diagram of this concept.

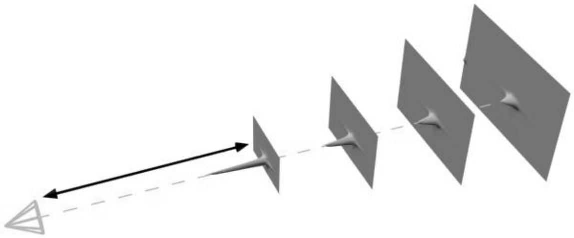


Figure 13

In short, a single line can be drawn that intersects the highest intensity point of each mesh object. In Figure 13, a line is shown intersection each three foot interval mesh model, at the peak intensity. Since the peak intensity at each mesh plane would correspond to being illuminated directly by the light, then the intersection of these peaks would create the line normal to the angle the light is directed. In other words, the light source would shine directly back at the peak intensities. The light that then arrives at the surface decreases in intensity from the center of where the light source is pointing because light arriving at the edges must travel a farther distance. This phenomenon supports the principle of how to determine where the light source is pointed.

This is consistent with a typical light in the real world as well. Consider a flashlight, for instance, that also has a hot spot. The center of the hotspot contains the highest intensities and the light falls off in intensity from the center. With the line along which the computer generated light is positioned, the only other variable is the distance back from the plane of the headlamp, or plane of the mesh models that the computer generated light source must be placed to create accurate light levels. Recall that the intensity of the light diminishes as distance from the projected wall increases. Because intensity is directly related to the distance, this second factor must be considered. As mentioned before, the complex light reflections and focusing that occur at the plane of lens in real life cannot be replicated in the computer by placing a single light source at that plane. Rather at some point back from that plane is the location where a computer generated light source can project light that is the same intensity as the resulting light from the plane of the lens.

Determining the distance from the lens plane that the computer generated light is located requires increasing and decreasing the intensity values from a computer generated light source at varying distances back from the plane of the headlamp until the intensity of the computer generated light sources matches those measured in the three dimensional mesh models. Figure 13 is an illustration of this concept.

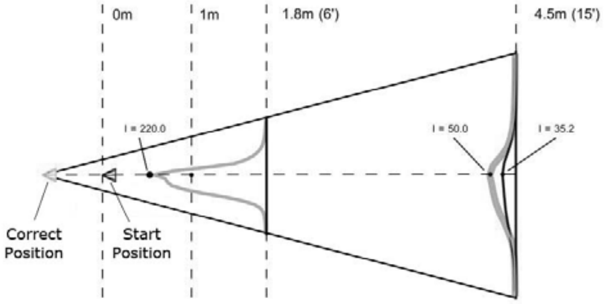


Figure 14

In this illustration, there are interval distances or 0 meters, 1 m, 1.8 m (6') and 4.5 m (15'). At 6' and 15' are located the three dimension mesh models generated from the photographs. Their light intensity is also shown from this side view, though their value, not their actual scale in the image, is the relevant variable. The intensity value is represented in Figure 14 for explanation purposes only. There are also two light sources. One is labeled "start position" and has a corresponding thin line of intensity level located at 4.5m. The other is labeled correct position, and also has a corresponding line of intensity level located at 4.5m, but this line is slightly thicker. In order to determine the location of the light source back from the lens plane, the inverse square function for light falloff over distance is used and is represented in the equation:

$$I = \frac{1}{x^2} \tag{3}$$

Where I is the intensity level and x is the distance the light travels from the source. The light intensity at 6' is first measured and normalized to 1m accounting for the effects of the percent reflectivity of the material and the angle at which the light struck the surface. Figure 15 demonstrates this concept. In this figure, D is the distance from the wall, α is the angle from a perpendicular vector, and A is the sample point.

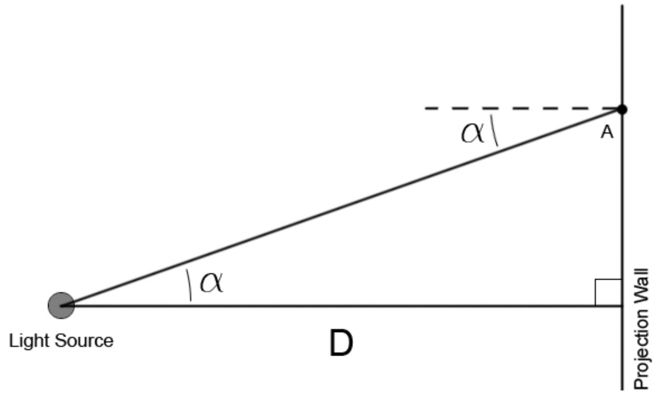


Figure 15

The normalization equation then becomes:

$$I_s = \frac{I_r \cdot D^2}{K_d \cdot (\cos\alpha)^3} \tag{4}$$

Where I_s is the intensity of the light source, I_r is the intensity reflected, and K_d is the percent reflectivity of the surface. The equation accounts for the distance the light traveled from the source to A and for reflectance of the wall. Since the photograph captured the intensity of the light reflected off of the wall rather than the amount of light arriving at the wall this difference must be accounted for in the normalization equation. The normalization equation incorporates a commonly used computer graphics shading model to account for the reflected light.

$$I_r = I_d \cdot K_d \cdot \cos\alpha \tag{5}$$

Where I_d is the intensity at A and α is angle between the incoming light ray and the surface normal, denoted by the dashed line in Figure 15. The light intensity is calculated for 4.5m to obtain the light measure at that distance. A light source is initially placed at 0 meters and the resulting intensity compared to what the real intensity value should be as calculated. This is demonstrated, in Figure 14 by the light labeled “start position”. In this illustration, the light level 4.5m from a light source at 0m would only be 35.2 cd/m^2, whereas the value calculated from the actual headlamp would need to be 50 cd/m^2. The light labeled “start position” is then modified by moving backward, but projecting through the same image, till it matches an intensity level of 50 cd/m^2 at 4.5m while maintaining an intensity of 220 cd/m^2 at a distance of 1.8m . It should be noted that as the distance changes, it does so along the direct line determined by the first part of this step in the methodology: the angle or line along which that light is pointed. This new position and direction correspond to a computer generated light source that would create a light distribution that is the same as the component of the headlamp analyzed (i.e. the quadrant being solved for). This step would be calculated for each quadrant analyzed, so that multiple lights would eventually be solved for, and group into a light cluster. Collectively this light cluster projects a light distribution that is the same as the actual headlamp.

CREATE PROJECTION MAPS FOR COMPUTER GENERATED LIGHT SOURCES

With the location and direction of the light resolved, the last step before assembling the lights into a cluster is to produce the digital projection maps that will control the light intensity emitted from the computer generated light source. Without a projection map, each light would act as a point source light, emitting light in all directions evenly. In reality, each light source must have a separate map to contribute is proper part of the total projected light. Projected maps are digital filters assigned only to one light source, and are ignored by all other light sources. These projection maps are two-dimensional digital images where the white value of the pixels corresponds to the intensity of the light at that pixel (Krauss, 2006).

The maps are generated directly from the previous step. Since a mesh model has been created by the light source (the mesh used to match the mesh created form the photograph of the headlamp) the projection map can be extracted from the mesh model, and therefore contain correct light values. However, since the light projection map is a curved surface in a computer generated environment, and the map that was created in the previous step was generated on a flat surface, a correction factor must be used defined by the equation:

$$C = \frac{1}{\cos\alpha} \tag{6}$$

This factor accounts for the difference in light intensity from a light source arriving at a surface at an angle. This is an aspect of materials properties in computer environments and a common correction that is used (Kalwick, 2004). Because the photographic image from which the projection map is ultimately made is the end product of light that has already reflected off of the surface at an angle, the projection map must reinsert this correction factor so the resulting light that is projected will not under illuminate the areas that spread out from the center of the light.

The projection maps are high resolution images that are mapped to the computer generated lights, and combined into one light cluster that acts as one light source, projecting light through three unique light maps accounting for unique patterns and distributions of an actual headlamp. Refer again to Figure 5 for a representation of this final step.

VALIDATION

Two different comparisons were performed to evaluate how closely the computer generated light cluster behaved compared to the actual headlamp that was tested. One comparison involved measuring the luminance values of the actual headlamp and comparing these measurements to luminance values as calculated in the computer using an object of the same reflectance and distance from the light cluster. The second method involved visually comparing the photographs of the actual light to rendered images of the computer generated light cluster.

Comparison 1: The first method for validation compares measured light values from the actual headlamp with light values at the same distance and location in the computer generated environment. Light values were obtained from points that lay inside the area that is directly illuminated by the headlamp. Figure 16 shows a photograph of the 5 points that were compared between the actual and computer generated lights.

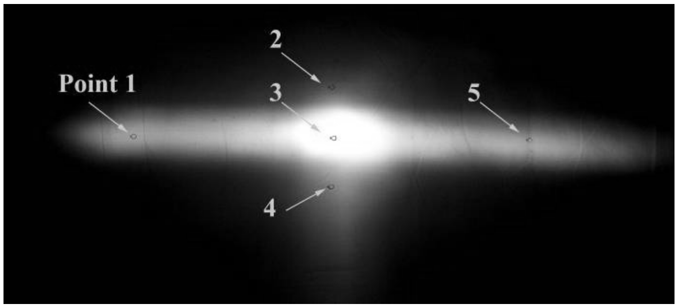


Figure 16

Points 1 through 5 were measured using a Konica Minolta LS-100 1° luminance meter, and the same points were measured in the computer environment and reported in Appendix B. The target size was approximately 1" in diameter, marked as a thin black circle on the canvas. The wall that the headlamp projected onto had a reflectance of 83%. This same reflectance valued was used in the computer environment in order to reflect the same amount of light in the computer environment as the wall in real life. The same points on the wall were duplicated in the computer environment and the intensity levels at those points measured. The points were chosen to represent a broad spectrum of light to dark in the headlamp beam pattern. This step was repeated at each distance interval for a total of 20 points of comparison. Graphs mapping the relative differences at each distance are shown in Appendix B. The results of this numerical comparison show that the greatest percent differences be under 15 percent, and that 15 of 20 points analyzed had a percentage difference less than 5 percent. Some of this difference can be attributed to the fluctuation in real world measurements by the luminance meter used to measure the real world values. Particularly in the brighter areas, the luminance meter fluctuated 10%-15%. The error resulting from physical measurements will need to be greatly reduced or accounted for in future tests to determine what part the physical measurement error plays in the overall differences between real world measurements and computer calculated measurements.

Comparison 2: In addition to a numerical comparison, a visual comparison of the results was also performed. Appendix C shows the results of the visual comparison. Two columns differentiate those images made from the original photographs of the headlamp, and the renderings created by the light cluster of that headlamp. The renderings and photograph were kept as digital images, and the visual comparisons of the images were conducted on an LCD screen. Not only do the images show visually similarity at each distance, but the light intensity distribution at each distance is also the same. This is visually demonstrated in the contour analysis shown beside each image. This visual comparison avoids some of the real world measurement errors that exist in Comparison 2; however, it is more difficult to find the differences between the contour maps of the actual headlamp to those of the computer generated headlamp. This is due to the fact that none of the contours are exactly alike, though visually they appear to be nearly identical. It is difficult to measure the small differences in this visual comparison, or to estimate what real affect these differences have on the accuracy of the computer generated headlamp to replicate the real headlamp. While the rendered image is not intended to show what the naked eye can see, it does provide a visually similar image to what is captured in the photograph. Such a comparison demonstrates the simulated light clusters usefulness in both predicting the light values of a headlamp, as well as visually representing what would be captured in a photograph.

DISCUSSION AND CONCLUSIONS

The methodology discussed in this paper demonstrates the criteria and analysis needed to build a computer model that can simulate the light beam pattern and light intensity of an actual headlamp. This process uses multiple computer light sources whose light intensities are filtered through digital maps generated directly from an analysis of the actual headlamp. The results show that the measured intensity values between the simulated light and the actual headlamp vary less than 15% and for most of the points compared the measurements vary less than 5%. This was true at all four distances measured, up to the maximum distance of 15'. Since the model is able to produce the proper light pattern and intensity the computer generated headlight should continue to produce accurate results at distances greater than those discussed earlier. Light intensity falloff follows the inverse square law therefore the most dramatic changes in the light pattern and intensity occur over relatively short distances. It is likely that the model will continue produce accurate results at greater distances where the changes in the light pattern and intensity are less extreme.

In addition to greater distances that are more consistent with the distances typically associated with visibility conditions, it is necessary to validate this methodology in real-world conditions, with multiple light types. It is also relevant to consider newer headlamp designs including LED and HID lamps that may be fundamentally different in light distribution. New headlamp designs sometimes combine the reflector that collects the light source and lens that directs the light projection into one part such that the exterior of the lamp is actually clear glass. This changes the light stylistically, but may also affect the ability to determine how many computer generated light sources are needed to simulate the headlamp. This limitation may exist because a newer headlamp that combines the lens and reflector cannot be analyzed in the same fashion described in this methodology. As shown in Figure 6, the lens in this study is an exterior surface and can therefore be analyzed independent of the reflector shape. A newer headlamp that combines the lens in the reflector itself may require a different setup to determine the effect the lens has on the projected beam pattern.

The main focus of this paper has been laying out the theory and methods for creating a computer light cluster that mirrors the characteristics, light values and distribution patterns of an actual headlamp. This method avoids some of the limitations present in other methodologies as mentioned in the introduction section, and shows potential for use in predicting light values for objects in more complex scenes. One particular aspect of this methodology is that access to the physical incident site is not necessary to develop the computer generated light cluster for a specific headlamp. Further, since the modeling can be done in a simulated environment, the change of light values over time can also be calculated. This flexibility can help determine when objects become visible as a driver travels along a roadway. In addition, Luminance values can be calculated and used to determine visibility based on models developed by Blackwell (1981) and Adrian (1987, pp. 3-12). For this process, calculated luminance values of objects that are illuminated by the headlamps can be compared to the luminance values of the object's background. The values then can be correlated directly to the models developed by Adrian and Blackwell to determine visibility. However, real word field testing, as mentioned above, is needed to verify the application of this technology for this purpose.

REFERENCES

1. Adrian, Ing W. "Visibility Levels under Night-time Driving Conditions." *Journal of the Illumination Engineering Society*, 1987.

2. Adrian, Ing W., "Visibility of Targets: Model for Calculation." *Lighting Research and Technology 21*, 1989.

3. Alexander, Gerson J., Robert E. Dewar, and Paul L. Olson, Human Factors in Traffic Safety, Boston, MA: Lawyers & Judges Company, Incorporated, 2002.

4. Apodaca, Anthony A., and Larry Gritz, Advanced RenderMan: Creating CGI for Motion Pictures. San Francisco, CA: Morgan Kaufmann, 1999.

5. Blackwell, H. R., "An analytic model for describing. the influence of lighting parameters upon visual performance," CIE Report 1, 1981.

6. Klein, Ernest and Stephens, Gregory, "Visibility Study – Methodologies and Reconstruction," Society of Automotive Engineers Technical Paper Number 921575.

7. Olson, Paul L., and Eugene Farber. Forensic Aspects of Driver Perception and Response. 2nd ed. Boston, MA: Lawyers & Judges Company, Incorporated, 2003.

8. Owens, D. A., and Ellie L. Francis., "Visibility Distance with Headlights: A Functional Approach," Society of Automotive Engineers Technical Paper Number 890684.

9. Phillips, Erich. "Vision and Visibility in Vehicular Accident Reconstruction," Society of Automotive Engineers Technical Paper Number 900369.

10. Allin, Boyd D. "Digital Camera Calibration for Luminance Estimatio in Nighttime Visibility Studies," Society of Automotive Engineers Technical Paper Number 2007-01-0718.

11. Krauss, David A. "Validation of Digtial Image Representations of Low-Illumination Scenes," Society of Automotive Engineers Technical Paper Number 2006-01-1288.

12. Kalwick, David, 3D Max Essentials: A Real World Approach, New York, NY: Charles River Media, 2004.

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APPENDIX A

Distance 6'

Target	Actual Lum (cd/m^2)	Sim Lum (cd/m2)	Difference (cd/m2)	% Difference	
1	67.1	67.1	--	--	Calibration
2	23.7	25.6	-1.9	-8.0%	
3	964.6	968.1	-3.5	-0.4%	
4	50.4	49.2	1.2	2.4%	
5	60	58.5	1.5	2.5%	

Distance 9'

Target	Actual Lum (cd/m^2)	Sim Lum (cd/m2)	Difference (cd/m2)	Average
1	26.8	29.6	-2.8	-10.4%
2	14	15.9	-1.9	-13.6%
3	418	424.8	-6.8	-1.6%
4	76.5	69.6	6.9	9.0%
5	24.1	25.3	-1.2	-5.0%

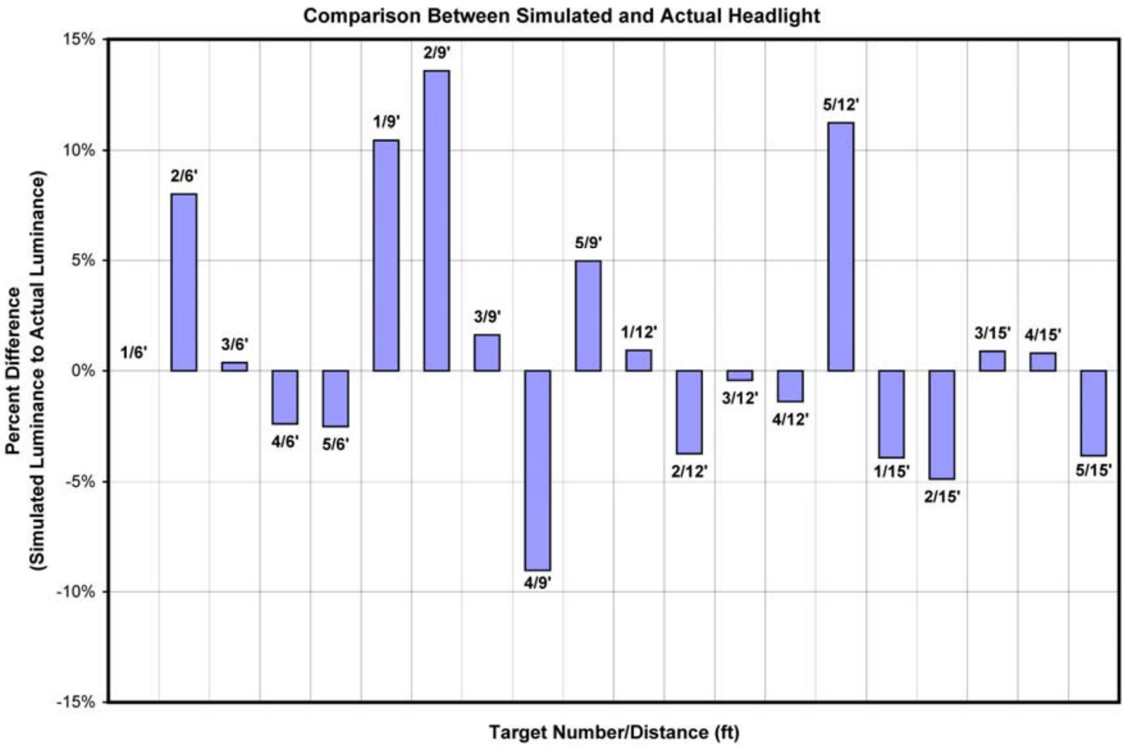
Distance 12'

Target	Actual Lum (cd/m^2)	Sim Lum (cd/m2)	Difference (cd/m2)	Average
1	21.6	21.8	-0.2	-0.9%
2	13.4	12.9	0.5	3.7%
3	245.2	244.2	1	0.4%
4	80.5	79.4	1.1	1.4%
5	21.4	23.8	-2.4	-11.2%

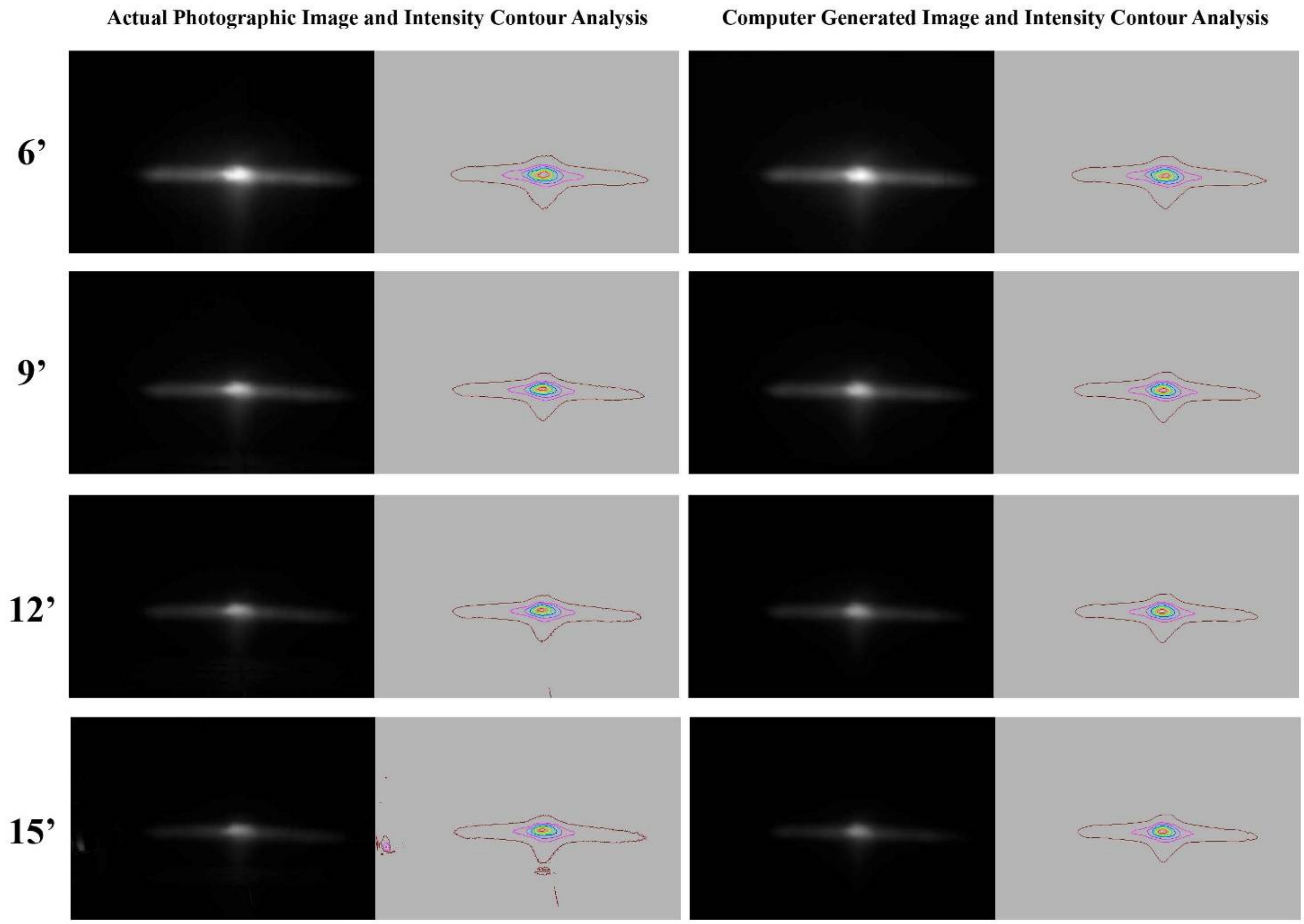
Distance 15'

Target	Actual Lum (cd/m^2)	Sim Lum (cd/m2)	Difference (cd/m2)	Average
1	12.8	12.3	0.5	3.9%
2	8.2	7.8	0.4	4.9%
3	102	102.9	-0.9	-0.9%
4	113	113.9	-0.9	-0.8%
5	15.7	15.1	0.6	3.8%

APPENDIX B


Comparison Between Simulated and Actual Headlight

APPENDIX C



Actual Photographic Image and Intensity Contour Analysis

Computer Generated Image and Intensity Contour Analysis